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Research Problems: A Pathway to Introduce Industry 4.0 in Undergraduate Education

Dr. Mahesh Kumar Pallikonda, Austin Peay State University

Dr Pallikonda is an Assistant Professor in the department of Engineering Technology at Austin Peay State University, TN, USA. He has a cumulative Industry, Research and Teaching experiences of over 10 years. His research interests lie at the interface of Manufacturing and Material Science, Pedagogy and Industry 4.0.

Prof. Ravi C. Manimaran, Department Chair, Engineering Technology, Austin Peay State University

Ravi C Manimaran is Professor and Chair of the Department of Engineering Technology, Austin Peay State University, Clarksville, Tennessee. His education includes two Master of Science degrees in Electrical and Computer Engineering, and Electronics and Control Engineering. He has been actively involved in higher education leadership in various capacities as a Dean, Department Chair, PI, Project Director, and a faculty member since 1997. He has served as the PI / Project Director for multiple agencies including NSF, DOL, DOD and Perkin's Grant. His research interests include Industrial Automation Systems, VLSI, ASIC, and FPGA. Other areas of interest are Higher Education Leadership and Accreditation including ABET.

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Abstract:

Industry 4.0 is a new paradigm in the technology world. Through this project a set of research problems in the realm of Industry 4.0 are presented to the students. Research problems are selected broadly from the domain of Industry 4.0 which includes current and emerging technologies. Students are also given the opportunity to select the topics, however, they need to receive the instructor's approval. During the project, students conduct literature reviews on the selected topics. The cohort size of the pilot class is 23 students; ten teams with two students each, and one team with three students. The objectives and deliverables of the project are clearly stated in advance to keep students informed. The objective of this project is to incorporate Industry 4.0 skills and knowledge to the students in addition to learn the methods to stay current in industry. The project deliverables are (1) students will present their work to the rest of the class, and (2) submit a reflective paper on their experience. This paper will discuss the setup of research problems, survey results of the student experience before and after working on the project, and summary of findings on the student experience from the reflective papers. Reflective papers serve as a tool both to summarize the student experience and for continuous improvement in the context of this project and future studies.

Introduction:

Over centuries human civilization has gone through various periods of technological advancements. These technological advancements can be traced back to pre-historic periods where humans first started using stone tools for hunting and invented methods to control the use of fire [1][2]. The curiosity of humans has led to multiple eras of technological advancements thus far. However, modern technology-centric societies are shaped by inventions over a series of industrial revolutions. As accepted by several industrialists, researchers and educators, modern society has been through three periods of industrial revolutions and is now entering the fourth industrial revolution [3][4]. The first Industrial revolution begun in the late 18th century in Britain and gradually spread to various parts of the world. The steam engine was considered the greatest invention at that time, which fueled innovation and machinery-based production [5]. This enabled us to establish industries and mass produce goods. This was followed by a second industrial revolution in the late 19th century. During the second industrial revolution the widespread use of electricity [6] fueled the rapid growth of industries and newer technologies such as telecommunications, oil production and others improved economic growth, created new jobs, and increased productivity.

Furthermore, in the late 20th century, the advent of computers and a widespread awareness of control systems fueled the third-industrial revolution [7], also often referred to as the digital revolution. Arguably the adoption of digital technologies, integration of robotics and automation are some of the key drivers of the third-industrial revolution. Although the third-industrial revolution is still evolving, the invention of the internet and widespread use of digital technologies and satellite communication systems fueled an entirely new period in the industrial revolution. This new period which closely overlaps with the digital revolution is the fourth industrial revolution, commonly came to be known as Industry 4.0 (I4.0). Figure 1 shows a timeline of evolution of industrial revolution.

The term Industry 4.0 (I4.0) was first coined by the German government in 2011 as a part of their High-Tech Strategy for Germany [8][9]. Germany being one of the forefront countries during the second and third industrial revolutions, launched the fourth cycle to be competitive in the rapidly evolving industrial world. As a part of the I4.0 initiative, it supported the integration of Cyber Physical Systems (CPS) and Internet of Things and Services (IoTS) to further improve resource management, quality control, efficiency, and productivity [10]. The CPS in the manufacturing environment include intelligent equipment, storage systems, and production facilities capable of independently sharing information, networking, and controlling one another [11]. The goal behind launching this new strategy is to combat the challenges due to shortage of skilled work force, demographic changes, promoting work-life balance and global competition in the manufacturing sector [12]. Nevertheless, looking into the areas where I4.0 is focused, one cannot miss noticing that these challenges are addressed to attract and retain the next generation of work force, both Millennials and Generation Z.

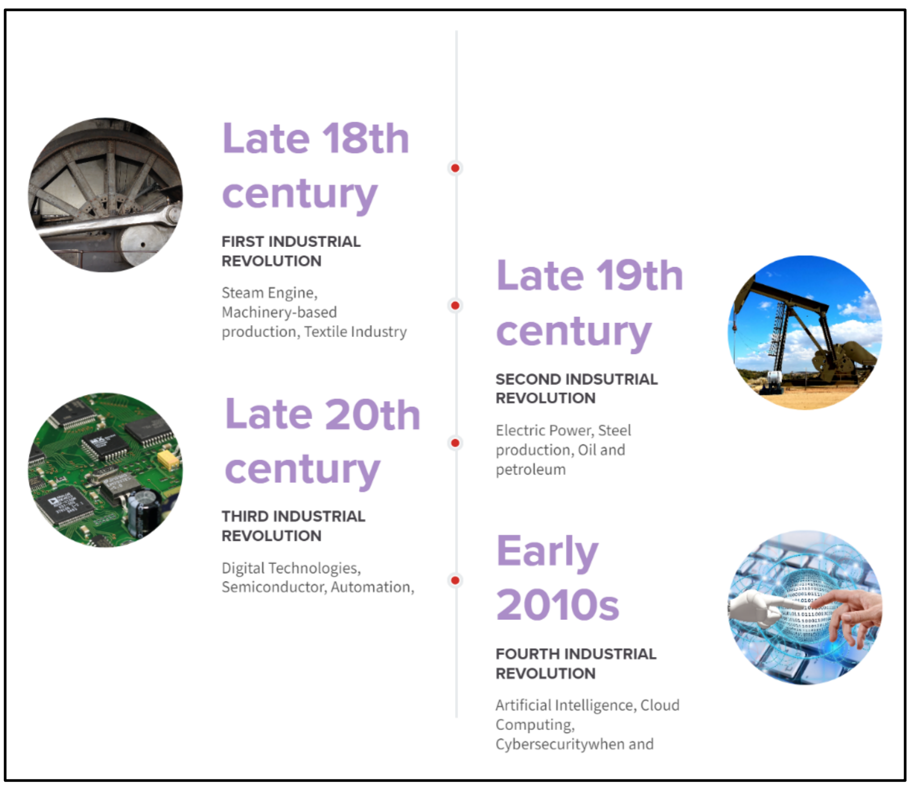

Figure 1: Timeline of the four stages of industrial revolution

According to Pew research [13], the new generations, Millennials and Generation Z are racially and ethnically more diverse than the preceding generations. The rapid globalization also demanded the need for diversity and inclusion. Besides these factors, the new generations are expected to be more educated than their predecessors. Converging all these factors, one can argue the new generation of the workforce will be much more able to accept and integrate newer technologies into their work and everyday life. This not only reduces the workload but also improves the work-life balance, although further research is needed in this area. Looking at both I4.0 goals and adaptability skills of next generation workforce, we can deduce that integrating I4.0 skillset into the Engineering and Engineering technology curriculum is quintessential.

Given not all higher education institutes are evenly funded, several small and medium sized universities struggle to upgrade their infrastructure and adapt to the current and emerging technologies. This impedes the primary goal of the higher education institutions, particularly in the engineering and engineering technology related majors, in their ability to prepare the students with the right skillsets for the current and emerging technologies. This inability is amplified by multiple direct and indirect factors such as shortage of skilled instructors, aging of tenure-track faculty, availability of grants and endorsement, and others. According to CUPA-HR [14], the median age of tenure-track faculty is 49 years which is significantly higher than the median age of US labor force. Additionally, the faculty of age 65 and older represent 13% of the total tenured faculty pool which is again significantly higher when compared with all the US workers, which is only 6%. This data shows at least one-tenth of the faculty are at the age of retirement and will soon present a dire reality of knowledge loss; however, these positions will be replaced by the more technologically advanced and adaptable millennials who are graduating with advanced degrees and skillsets that match the I4.0 strategy. Additionally, the reality of integrating I4.0 in the curriculum is challenging and demands a significant effort to build the infrastructure for hands on learning. Meanwhile, the faculty in both engineering and engineering technology fields are continuing to integrate project-based learning, self-directed learning, and investigative problem-solving strategies.

This paper is aimed at summarizing the results of using the above-mentioned strategies to impart the I4.0 skillset to students. The cohort of students that participated in this study are sophomores majoring in Engineering technology with concentrations in Manufacturing, Mechanical, Electrical, and Mechatronics. As a part of this study, students were oriented to conduct self-directed learning and investigate the challenges and opportunities of I4.0. This study is part of a project aimed at developing project-based learning and continuous improvement strategies to align with ABET student outcomes. Finally, this paper will summarize the student responses to the surveys, their responses for self-directed learning and future recommendations for similar studies.

Data set:

This is a pilot study conducted in Robotics Fundamentals, a required course for the B.S. in Engineering Technology degree at Austin Peay State University. Students enrolled in the course are taken as a data set. The cohort size is 23 active students, and the coursework was spread over a 15-week regular semester model. Majority of the students in this sample set are male (82.6%; 19 out of 23 students). Furthermore, the sample set consists of Engineering Technology majors (78.3%; 18 out of 23 students), 13% are of no reported major (3 out of 23 students), and 8.7% are computer science and information technology majors (2 out of 23 students).

Additionally, the surveys are left optional and not considered as a part of the project. The reason behind this decision is to keep the survey results anonymous and encourage voluntary student participation. Pre-completion survey was conducted early into the semester and a second post completion survey was released during the final examination week. The pre-completion survey was completed by 95.6% students (22 out of 23 students); however, the post-completion survey was completed by only 47.8% students (11 out of 23 students). The low completion rate for the post-completion survey is due to its timing. Releasing the post-completion survey during the final examination week did not encourage most of the students to participate. In contrast, reminding students to complete the pre-completion survey early in the semester and repeated remainders enabled them to complete it. This is a key takeaway for future work. The timing of the survey needs to be reevaluated.

Research problems setup:

This project consists of two parts. Part-1: students will present their findings and perspectives on a particular topic to the rest of the class, and Part-2: submit a reflective paper, see Figure 2. Students are given the freedom to choose any topic within the scope of Industry 4.0, subject to the instructor's approval. Additionally, they are advised to take an informal approach for their reflective paper so they can write their own perspectives rather than a literature review. Students are informed to treat the reflective paper as an essay rather than an actual paper. This decision is made upon the request from the students, given most of the students in the participating pool are non-traditional and to keep the burden of formatting and styling to a minimum so they can focus on the content.

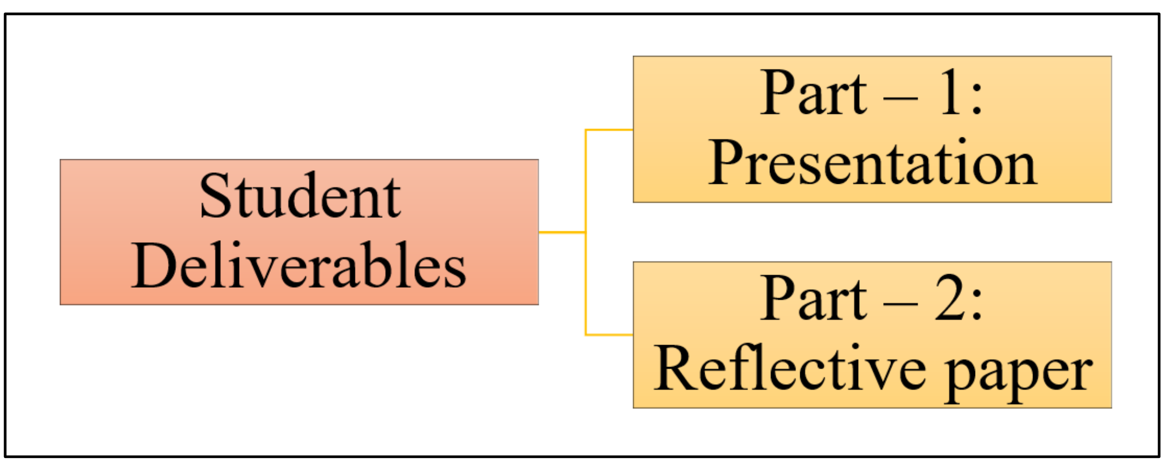

Figure 2: Student project deliverables.

Students are required to form a team of two students and one team with three students. Although students work in teams on studying and preparing for the presentation, the reflective papers are meant to be individual artifacts. Reflective papers are not tied to teamwork and are aimed at gathering each student's personal thoughts and reflections on the topic chosen by the team. Figure 3 shows the anonymized list of topics student teams picked for their self-directed learning (Project).

Team #	Project Title
TEAM 1	Exo-boots research and analysis
TEAM 2	Rainbow Dash
TEAM 3	Soft Robots that Grip with the Right Amount of Force
TEAM 4	3D Printing Drones
TEAM 5	Machine Learning
TEAM 6	Why robots should not make life and death decisions
TEAM 7	The future of learning is in Virtual Reality
TEAM 8	How Robotics Is Shaping Industry
TEAM 9	The Opportunities and Threats of Lights Out Factories
TEAM 10	Emerging Technologies for GEN-Z
TEAM 11	Why AI Shouldn't be Making Life-and-Death Decisions

Figure 3: List of topics student teams selected to conduct self-directed learning project

Survey setup:

In addition to the project, a pre- and post-project completion survey was conducted to understand the students' progress into learning I4.0 concepts and their preparedness for entering the workforce. The latter part is critical given major part of the cohort was non-traditional and works part-time, if not full-time. Additionally, this survey is used to find a relation of student learning in a self-directed study and acquiring knowledge on I4.0. This is because I4.0 is still emerging and to prepare the next generation workforce, we must consider the potential of emergence of disruptive innovations. Next generation workforce should be open to adapt these newer technologies. Of the several methods to keep current with the innovations, one method is to regularly follow technical periodicals, newsletters for industrial consortiums and technical journals. Therefore, through these surveys, we sought to establish a relationship between studying technical papers and journals, and knowledge on I4.0 skills. The questionnaire used for the pre-project completion survey is as follows:

1. What is your knowledge on Smart manufacturing? Have you heard of this term before?
2. What do you know about Digital twin? Have you heard of this term before?
3. Have you heard of Lights out factories before this semester? If so, where?
4. Have you heard of the term Industry 4.0? If so, what is your take on it?

5. Are you ready to enter the modern technology centric workforce at mid-level? (Yes/No) any comments are welcome.
6. Rate the following on a scale of 1 to 10. 1 shows you have no prior knowledge on the topic, 10 shows you are proficient on them.
    a. Digital Twin
    b. Industry 4.0
    c. Smart Manufacturing
    d. Lights-out factories

Similarly, the questionnaire used for post-project completion survey is as below:

1. What do you expect your roles at a mid-level position in Industry?
2. What comes to your mind when you hear Smart manufacturing?
3. Can you briefly explain Digital Twin? If yes, please explain in 2 sentences.
4. What are lights out factories?
5. Can you briefly explain Industry 4.0?
6. Are you ready to enter the modern technology centric workforce at mid-level? (Yes/No) any comments are welcome.
7. Rate the following on a scale of 1 to 10. 1 shows you have no prior knowledge on the topic, 10 shows you are proficient on them.
    a. Digital Twin
    b. Industry 4.0
    c. Smart Manufacturing
    d. Lights-out factories

Analysis of Pre-project completion survey:

Through this survey we intend to gauge the student's skillset before the start of the project work. The survey is kept short to be as concise as possible. This encourages students to finish it. Out of 23 students in the data set, 22 students participated in this survey. When asked about readiness to work in industry at mid-level, the results indicate a negative response as expected (64% of students indicated not ready; 14 out of 22 responses). This is expected given the students did not complete their coursework and have lots to learn. Knowing they are not ready will keep them focused on their career paths. Students that indicated positive response (27% of students indicated readiness; 6 out of 22 responses) are already working at some level in industry and two others indicated “may be” depending upon the role.

Moreover, a similar percentage of positive and negative responses are identified in the rest of the questions. However, when asked about “Digital Twin” 95% of students (21 out of 22 responses) indicated they had never heard of this term and/or have no knowledge of it. One student that indicated he heard the term also commented “don’t know much about it.” Figure 4 shows the students self-rating on their knowledge on Digital twin, Industry 4.0, Smart Manufacturing and Lights out factories on a scale of 1 to 10, where 1 indicates no prior knowledge and 10 indicates heard about it and know briefly about it. We are not expecting students to know the totality of each concept; however, we want students to understand these concepts and learn more about them as they progress.

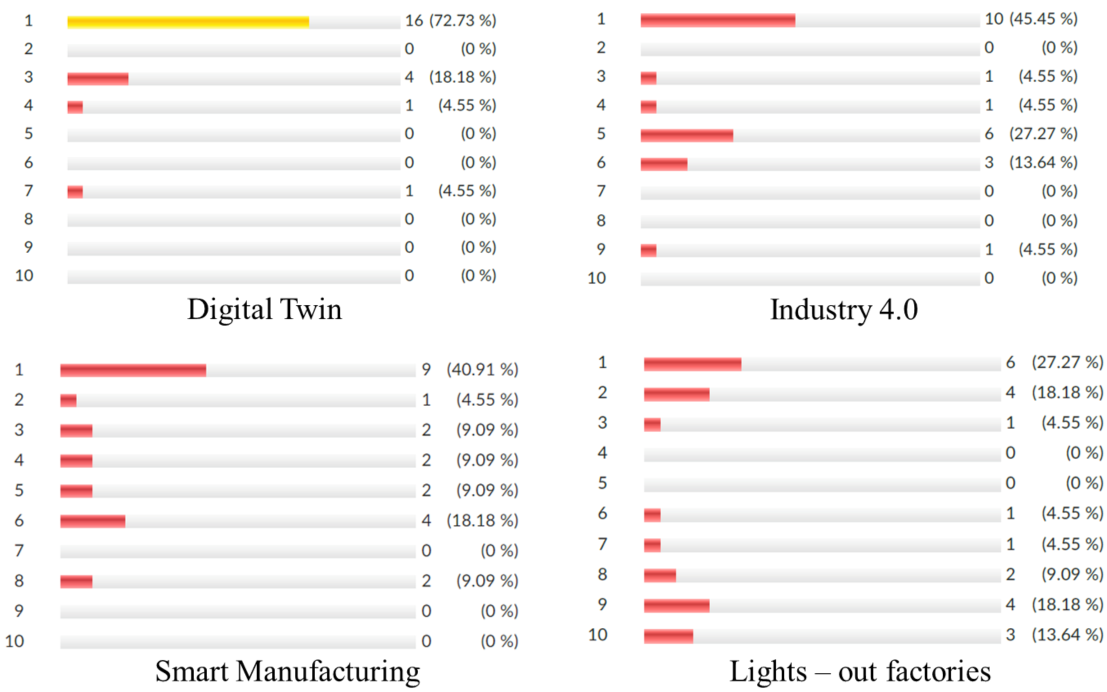

Figure 4: Students self-rating on their knowledge on various concepts in I4.0 before the start of the project.

Analysis of Post-project completion survey:

Out of the 23 students surveyed, only 11 students participated in the post-project completion survey. The probable reasons for low participation and mitigation strategies for future studies are explained above in the Data set section. Through this survey, we intend to evaluate students' understanding of the I4.0 concepts. It was noticed that the student responses to the questions are satisfactory, and they demonstrated a higher level of understanding in I4.0. Student responses include the usage keywords related to I4.0. Some of the keywords found in student responses are AI, data analytics, virtual spaces, digital replica, autonomous, and closed-loop systems. Figure 5 shows students self-rating on their knowledge on Digital twin, Industry 4.0, Smart Manufacturing and Lights out factories on a scale of 1 to 10 after completing the project.

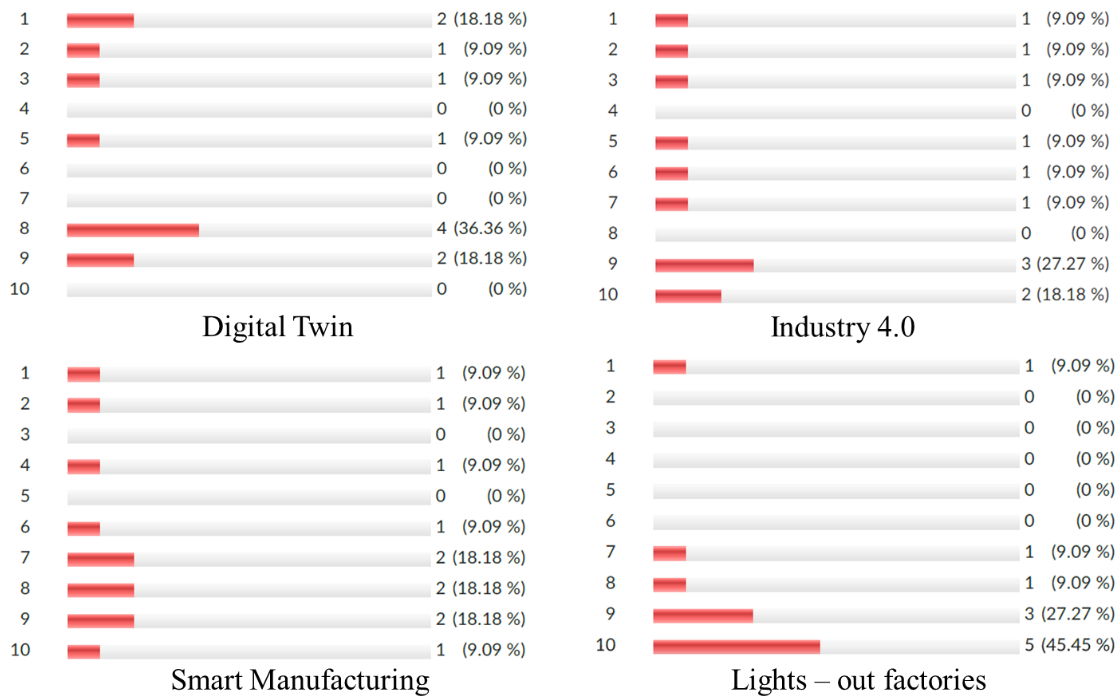

Figure 5: Students self-rating on their knowledge on various concepts in I4.0 at the end of the project.

Furthermore, we can notice that there is a significant shift in the student's self-evaluation between pre- and post-project completion surveys. This shift is expected and indicates the gaining of I4.0 skills. This will encourage students to engage in workplace conversations and implement I4.0 at the workplace. Student responses to the questions listed in the survey setup, both pre- and post-project completion, are differentiable and demonstrate the student's ability to comprehend I4.0. Although only 11students completed the post-project completion survey, the answers are satisfactory and demonstrate the students' improved understanding into I4.0.

Moreover, students expressed the desire to learn more about the I4.0 through their reflective papers. Some of the comments from students' reflective papers are as follows:

- At the end, I truly enjoyed this project. (…...), but I had fun and learned. Truthfully speaking I find any project that you can come up with saying was fun and you learned a lot more is worth it.
- No matter how advanced we get there will always be a need for some form of human moral thinking needed for rash decisions.
- I believe in the future we will utilize (Soft robots that grip with the right amount of force) technology to make robots reach other industries other than manufacturing such as commercial or entertainment.
- Upon further study I find the use of (3D printing drones) technology to be very niche at best at least at its current evolution but has great potential for future applications. …... I

also still find it amazing we, as engineers, still find inspiration for new technologies in nature despite how technologically advanced humans have become.

- I believe that these specifics will always be a constant need for social evolution and will continue to improve for future generations. Because of these technologies continuing to be modified, the world will always need them.

Future recommendations:

At the end of the pilot project, we identified the low participation needs to be addressed in future studies. Below are some of the recommendations for future studies in this area.

1. Increase the number of questions in survey questionnaire.
2. The timing of the survey needs to be more considerate.
3. Increase student participation by including the surveys as a part of the project work.
4. More direct assessments such as a quiz (for bonus points).
5. Mandate formatting (IEEE or APA) for reflective papers.

Conclusion:

The pilot study shows positive results in self-directed student learning. There are a few positive takeaways, however, there is still need for the instructor's intervention to explain some topics in a clear and easy to understand method. For example, during the presentations, students showed an increased interest in virtual reality. However, as an instructor, it is my responsibility to let students know the status of such technologies and avoid misconceptions. Students did demonstrate a good understanding of the I4.0 concepts. Nevertheless, it is essential to remind students that I4.0 is an emerging area; therefore, students must be willing to learn and adapt the innovative technologies and concepts.

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