Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45815

Chemical Process Design to meet Industry 5.0 competencies

Dr. Daniela Galatro, University of Toronto
Dr. Sourojeet Chakraborty, Johns Hopkins University

Dr. Sourojeet Chakraborty is a Lecturer at the Department of Chemical and Biomolecular Engineering at Johns Hopkins University, USA, having earned his Ph.D. (University of Toronto) and MSc. and DIC (Imperial College London) in chemical engineering. He was a Postdoctoral Fellow at the Department of Earth Sciences, and a Junior Fellow of the Massey College, University of Toronto. His research interests lie in transport phenomena, fluid mechanics, and the design of complex fluids. Within engineering education, his research interests lie in mapping Industry 5.0 to Education 5.0, curriculum design, pedagogical strategies for innovation, enriching and empowering the student learning experience at Higher Education Institutes (HEIs).

Chemical Process Design to meet Industry 5.0 competencies.

Daniela Galatro[1] and Sourojeet Chakraborty[2]

[1]Department of Chemical Engineering & Applied Chemistry, University of Toronto ON M5S 3E5 Canada
[2]Department of Chemical & Biomolecular Engineering, Johns Hopkins University, Baltimore MD 21218 USA

Correspondence email: daniela.galatro@utoronto.ca

Abstract

Industry 5.0 (I.D. 5.0) envisions an efficient, productive industry with a strong societal role. Education 5.0 (E.D. 5.0) fosters human-centric, personalized, and collaborative learning, integrating advanced technologies such as Artificial Intelligence (AI) and Machine Learning (ML). Chemical Engineering (Chem Eng) courses like Process Design and Plant Design require students to integrate knowledge across disciplines to solve complex engineering problems. This work identifies gaps in aligning I.D. 5.0 with E.D. 5.0 and present strategies for revamping CHE 334 (Team Strategies for Engineering Design), a bridge course between Process Design and the Plant Design capstone, emphasizing teamwork, leadership, conflict resolution, decision-making, and process engineering problem-solving. In its revamped version, CHE 334 includes deliverables based on sustainability and circular economy pillars, while maintaining its process design essence via the development of process diagrams and process equipment calculations within a regulated safety and environmental framework. Course effectiveness is assessed based on E.D. 5.0 principles: (i) personalized learning through student performance metrics, (ii) collaboration through teamwork activities, (iii) flexibility by accommodating different learning styles, and (iv) data-driven decision-making via student outcome analysis. A unique set of novel insights and lessons learned were generated from our implementation, including reflections on the usage of Generative AI, the overall well-being of students, as well as the future roadmap for student-centric, educator-focused, and institution-based implementation of E.D. 5.0. This course revamp is part of a broader effort to align Chem Eng education with E.D. 5.0 goals. By preparing students for I.D. 5.0 competencies, this approach cultivates a skilled workforce valued across interdisciplinary sectors. Ongoing research further maps I.D. 5.0 to E.D. 5.0, with findings from this study serving as a benchmark for optimizing university pedagogical strategies. Industry 5.0 (I.D. 5.0) envisions an efficient, productive industry with a strong societal role. Education 5.0 (E.D. 5.0) fosters human-centric, personalized, and collaborative learning, integrating advanced technologies such as Artificial Intelligence (AI) and Machine Learning (ML). Chemical Engineering courses like Process Design and Plant Design require students to integrate knowledge across disciplines to solve complex engineering problems. This work identifies gaps in aligning I.D. 5.0 with E.D. 5.0 and present strategies for revamping CHE 334 (Team Strategies for Engineering Design), a bridge course between Process Design and the Plant Design capstone, emphasizing teamwork, leadership, conflict resolution, decision-making, and process engineering problem-solving. In its revamped version, CHE 334 includes deliverables based on sustainability and circular economy pillars, while maintaining its process design essence via the development of process diagrams and process equipment calculations within a regulated safety and environmental framework. Course effectiveness is assessed based on E.D. 5.0 principles: (i) personalized learning through student performance metrics, (ii) collaboration through teamwork activities, (iii) flexibility by accommodating different learning styles, and (iv) data-driven decision-making via student

outcome analysis. A unique set of novel insights and lessons learned were generated from our implementation, including reflections on the usage of Generative AI, the overall well-being of students, as well as the future roadmap for student-centric, educator-focused, and institution-based implementation of E.D. 5.0. This course revamp is part of a broader effort to align Chem Eng education with E.D. 5.0 goals. By preparing students for I.D. 5.0 competencies, this approach cultivates a skilled workforce valued across interdisciplinary sectors. Ongoing research further maps I.D. 5.0 to E.D. 5.0, with findings from this study serving as a benchmark for optimizing university pedagogical strategies.

Keywords

Industry 5.0, Education 5.0, Curriculum Design, Chemical Engineering (Chem Eng), Process Design, Artificial Intelligence (AI), Machine Learning (ML).

Introduction

Chemical engineering has evolved from producing chemicals through batch processing during the Industrial Revolution to a diverse engineering field integrating mathematics, physics, biology, and chemistry principles to produce a vast range of products using advanced technologies and sustainability practices [1]. Within an undergraduate (UG) chemical engineering (Chem Eng) curriculum, chemical process design plays a fundamental role in the development and optimization of chemical processes by (i) creating efficient processes involving different unit operations and reaction systems, (ii) reducing production costs, (iii) ensuring safe operations, and (iv) meeting product quality standards. Modern chemical process design adds sustainability practices and circular economy indicators to minimize environmental impact [2].

Chemical process design in UG Chem Eng programs in North America can be seen as standalone unit operations-based courses, vertically integrated in different core and optional courses by designing standalone solutions (e.g., sizing shell and tube heat exchangers in Heat Transfer), and knowledge-integrative courses (e.g., capstone courses). In a typical capstone project-based course, teams are formed to solve open-ended engineering design problems following the traditional workflow of developing process simulations, heat and material balances, process flow diagrams, piping and instrumentation diagrams, safety assessments, and economic analysis [3]. Ideally, projects are linked to industry needs, for which real-world clients interact with students, boosting non-technical skills required for chemical process design, such as communication and collaboration. Combining technical and non-technical skills leads to successful chemical process design and, down the road, to successful professionals in the workplace.

When reviewing the desired/required non-technical skills for chemical engineers, we look, in addition to communication and adaptability, to collaboration, problem-solving skills, leadership, project management, and critical thinking [4]. While these skills might be already taught and reinforced in the current design spines of our curricula, there are evolving aspects within the framework of Industry 5.0 (I.D. 5.0) and Society 5.0 that we look to integrate into Education 5.0 [5], [6]. I.D. 5.0 requires a human-centric approach integrated with advanced technologies, such as Artificial Intelligence, while efficiently using resources and applying sustainable practices [5]. Moreover, our future society must solve societal challenges and enhance the quality of life for which Society 5.0 was envisioned [7]. The following question then arises: What are our higher education institutions doing to map E.D. 5.0 with I.D. 5.0 and Society 5.0 within the context of chemical process design? This is, indeed, a quite challenging question to address, as E.D. 5.0 is a fast-paced and non-uniform framework, for which different efforts have been researched and tested among colleges and universities in many different contexts and programs. Moreover, how can educators assess the effectiveness of implementing such efforts into our curricula? Another challenging question that might require intensive and integrated research and industry-based solutions to address.

This work introduces some strategies to map E.D. 5.0 with I.D. 5.0 and Society 5.0 in the context of chemical process design. Some specific examples of implemented strategies are presented and discussed to finally offer, from our lessons-learned process, a path for mapping them. Throughout this work, we will be using several abbreviations and acronyms, as summarized in the **Appendix**.

Methods

We began our mapping journey by looking at the current design spine of our UG Chem Eng program at our university and comparing it with the approaches adopted by other universities in North America and Europe. This exercise aims to present the current chemical process design picture in our UG curricula universe and is performed by checking the program websites of different universities.

The previous exercise was followed by performing a bibliometric analysis using the Scopus database and the software VOS viewer, to cluster co-occurrence relations that could lead us to find the required knowledge and skills for chemical process design. Scopus is an abstract/citation database by Elsevier that provides resources for tracking research from different institutions. VOS viewer is a free tool/software designed to build and visualize bibliometric networks. The knowledge and skill combined approach integrates the theoretical understanding of unit operations and chemical processes to skills required to enhance personal and professional development by recognizing information and principles while applying knowledge. The search process includes searching journal and conference articles in the database, leading us to the combination of words such as Industry 5.0 AND Society 5.0 AND engineering; and Industry 5.0 AND Society 5.0 AND Education 5.0. Bibliometric analyses might offer mostly research-based solutions to answer our questions. Given that we are mapping E.D. with I.D. 5.0, we also manually searched for the required knowledge and skills in the professional database Indeed, a well-known job search engine.

Our research findings from Scopus and Indeed led us to gather the required skills and consequently select core components that can be feasibly implemented in courses such as CHE334 Team Strategies for Engineering Design. The corresponding implementation example is presented and discussed, as well as our reflections on missing components, challenges, and a feasible roadmap for mapping E.D. 5.0 with I.D. 5.0 and Society 5.0.

Results

The current design spine of our UG Chem Eng mostly includes core courses leading to acquiring knowledge and skills to be finally implemented in a 4^{th}-year capstone course. Our vertically integrated curriculum, through a biodiesel production initiative, links unit operations/process design to laboratory efforts, aiming at reinforcing Chemical Engineering Design [8]. Moreover, standalone projects in courses such as Heat and Mass Transfer and Fluid Mechanics also provide students with knowledge-based projects to size equipment such as pumps and heat exchangers. A closer look into our design spine shows a critical path defined by the courses Process Design, Team Strategies for Engineering Design (CHE334), and Plant Design, supported by other course courses such as Reactor Engineering, Separation Processes, and Professional Engineering Consultancy, which is a communication-based course designed to enhance teamwork, communication skills, and professionalism. Process Design is a 3rd-year course that integrates material and energy balances, along with the design of single unit operations, while providing the basis for developing piping and instrumentation diagrams and process safety studies. This course is chronologically followed by CHE334, which provides team strategies (teamwork, leading and managing teams, and decision-making methodologies) while designing a guided process plant. Finally, Plant Design, a 4th-year course, is our capstone course, in which students work in teams mainly designing chemical processes and examining their economic viability. **Figure 1** shows our main current design spine, for years 3 and 4.

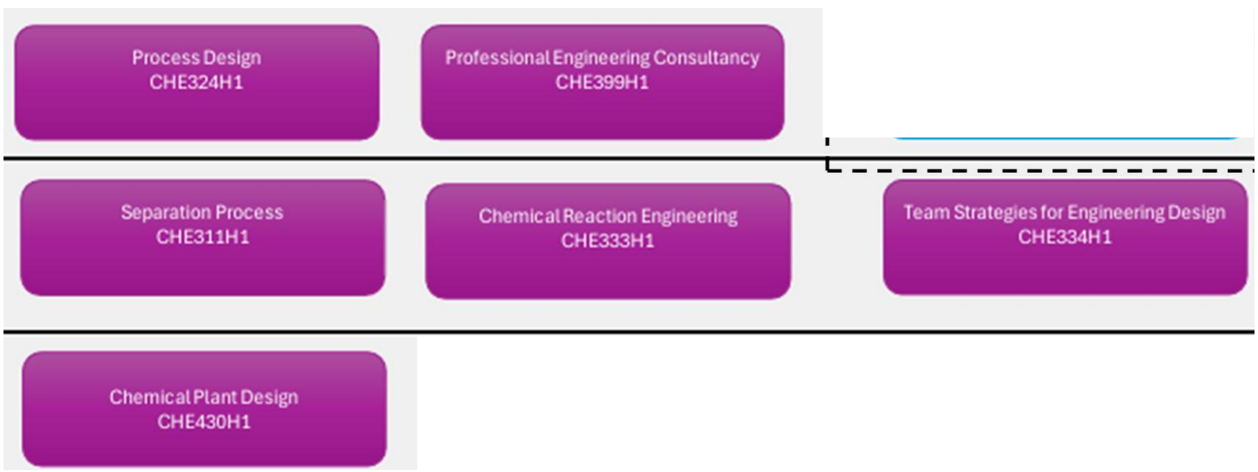

Figure 1. Main current design spine currently at the University of Toronto's Department of Chemical Engineering & Applied Chemistry.

When compared to UG Chem Eng of other universities, such as the Massachusetts Institute of Technology (MIT), Standford University, Technical University of Munich (TUM), California Institute of Technology (Caltech) and University of Waterloo (UW), for instance, we summarize the following key and common features: (i) a design spine supported by a core process design course followed by a capstone project[9], [10], [11], [12], [13], and (ii) emphasis on process simulation, process optimization, economic feasibility, sustainability, collaboration with industry partners, and in some cases, involving multidisciplinary collaboration [12], and data-driven approaches to process design [10], [12]. MIT, Stanford, TUM, and our university introduce process simulation within other design or core courses. At the same time, Caltech offers a dedicated course focused on process simulation within its UG Chem Eng curriculum, called "Introduction to Chemical Engineering Computation" [10], as well as UW [13]. Likewise, all these universities include communication-based courses integrated into various engineering courses or dedicated courses, such as Project Management and Communication, for example [12]. Similarly, economic analysis has been included as part of the design process in dedicated or within core courses associated with the design spine of their curricula [9], [10], [11], [12]. An interesting approach to the capstone design project is offered by UW, which includes two parts, the first part focused on project definition and preliminary design, and the second part focused on detailed design and implementation [13]. Following our design spine comparison among different universities, we visualize the findings of our bibliometric analysis as follows.

Figure 2 shows the results of performing a bibliometric analysis around the words Industry 5.0 (I.D. 5.0) and Society 5.0 within the engineering context.

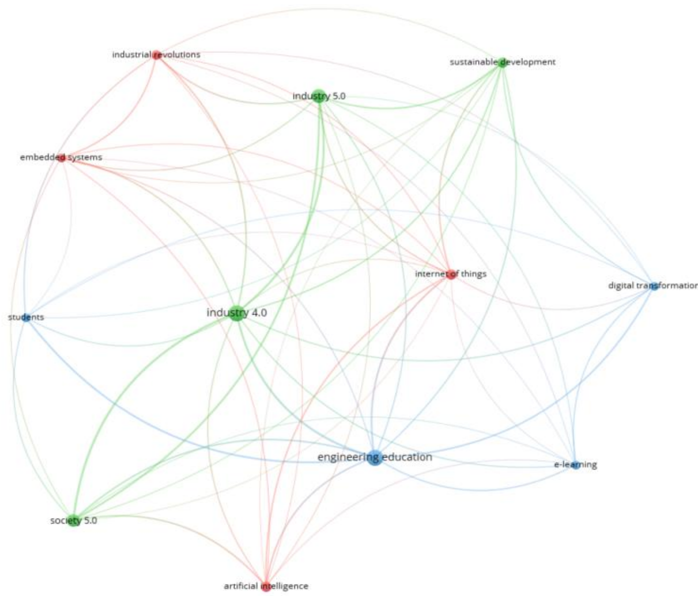

Figure 2. Results of the bibliometric analysis around Industry 5.0 (I.D. 5.0) and Society 5.0 within the engineering context.

Clusters from **Figure 2** suggest the current transition from I.D. 4.0 to I.D. 5.0, with a "weaker" green cluster/circle around Society 5.0. Digitalization and sustainability appear as key players around them and are linked to engineering education. Of the 71 documents found, 9.2% are associated with Chemical Engineering. China demographically leads all these documents (19.7%), followed by Japan and the United Kingdom (with 8.5% each) and Germany (7.0%).

Figure 3 shows the results of performing a bibliometric analysis around the words Industry 5.0, Society 5.0, and Education 5.0.

Clusters from **Figure 3** capture aspects such as digital transformation/digitalization, artificial intelligence, and sustainable development. Of the 89 documents found, 3.3% are associated with Chemical Engineering. India and Ukraine demographically lead all these documents (with 11.2% each), followed by Indonesia (10.1%) and the Russian Federation (7.8%).

Some potential geographical implications of these results can be explained by (i) strong backing for digitalization in countries like China, (ii) a special interest in Society 5.0 by Japan, as they pioneer it and integrate it as a national strategy, and (ii) the UK and Germany position themselves as leaders in industrial innovation. Moreover, emerging economies such as India, Ukraine, and Indonesia have shown a recent focus on digital education, potentially leading to a workforce shift towards AI and automation practices. In contrast, established economies such as China, Japan, and Germany, as manufacturing leaders, set the direction for chemical process design frameworks. On the other hand, the limited presence of Chemical Engineering suggests that sustainability and digitalization are still not fully integrated into Chemical Engineering curricula.

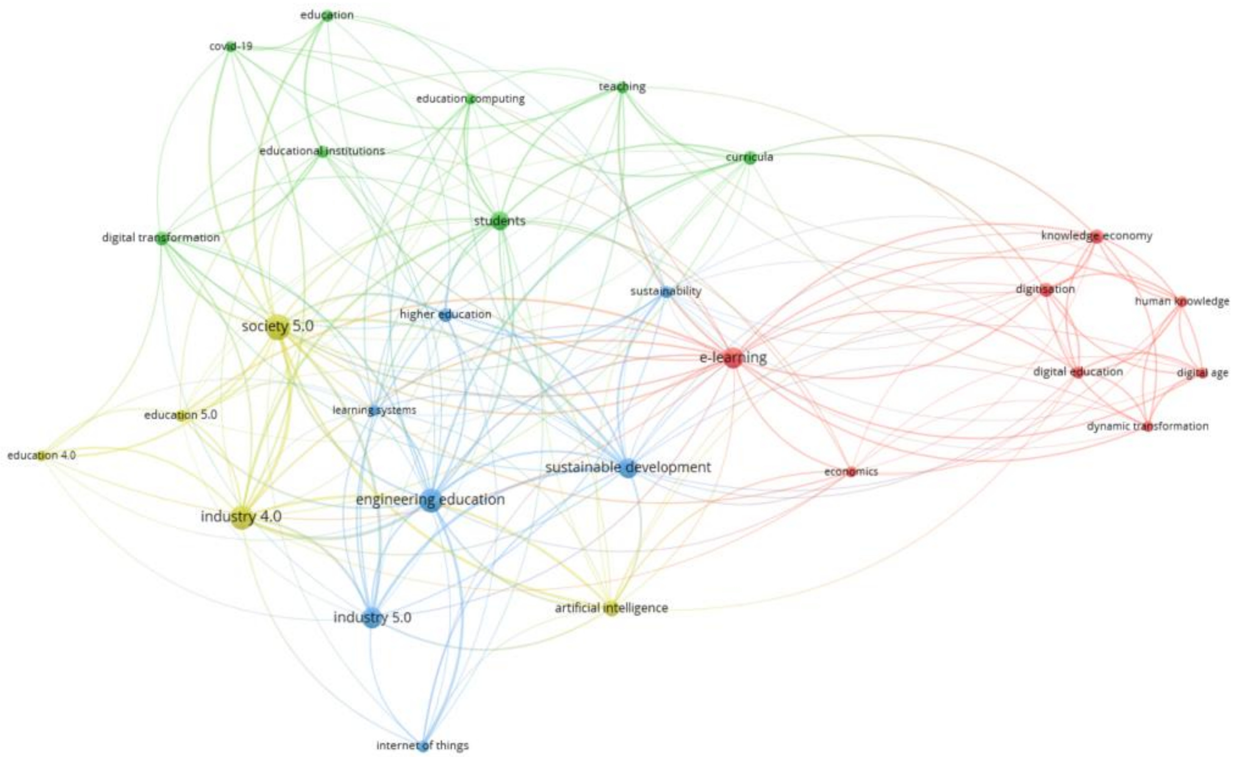

Figure 3. Bibliometric analysis results around Industry 5.0, Society 5.0, and Education 5.0.

Note: Clusters are identified by color with no importance level assigned to them. The circle sizes within a cluster reflect the effort concentration associated with the specific item, for instance, “artificial intelligence” is “weaker” compared to Society 5.0.

Not surprisingly, **Figures 2** and **3** might guide us to focus our knowledge-based efforts to include, within the context of chemical process design, digitalization (probably in the shape of artificial intelligence/machine learning), and sustainability.

When looking at job engines such as Indeed, in addition to the expected knowledge required by chemical engineers, soft skills like communication and problem-solving are the most highlighted, followed by time management, leadership, and adaptability, and less frequently, we also captured ethical judgment and conflict resolution. “New” or non-traditional technical skills clustered by our Indeed search include (i) experience with predictive modeling (e.g., R, Python, MATLAB) for roles in process optimization and quality control, (ii) machine learning in manufacturing for roles in process automation, data analysis, and modeling complex systems, (iii) big data and industrial internet of things (IoT) in chemical and/or energy industries, and (iv) predictive maintenance and fault detection. Moreover, sustainability is embedded in roles for industries such as chemical manufacturing, energy, pharmaceutical, and environmental services, as Indeed reports knowledge of circular economy, lower environmental footprint solutions, regulatory knowledge, life cycle assessment, energy efficiency, and green chemistry/renewable resources.

Discussion

Based on our previous findings, the roadmap to map E.D. 5.0 with I.D. 5.0 and Society 5.0 within the context of chemical process design can be drawn by (i) adding technical skills in the shape of artificial intelligence/machine learning tools for modeling and optimizing chemical processes around circular economy/sustainability and (ii) reinforcing soft skills clustered into communication, teamwork and collaboration, problem-solving and critical thinking, time management, leadership, ethical principles, and interpersonal skills. In alignment with accreditation requirements, we can visualize this mapping by adding components in core courses throughout the curriculum (e.g., assignments) and planning for or reinforcing dedicated courses (e.g., communication skills and machine learning within chemical process simulation). A design spine within our UG Chem Eng curriculum would require, therefore, a critical path of courses preparing students for the capstone project, fed by technical and soft skills acquired in core and optional courses, while adding assignments/projects in core and optional courses, for dedicated unit operations and reaction systems. An example of implementing non-traditional technical skills and soft skills is shown as follows.

CHE334 (Team Strategies for Engineering Design) is a design-based course informally considered a "bridge" course linking Process Design and the Plant Design capstone courses. Students are provided with strategies on how to work in teams, lead, mitigate, and negotiate conflicts, manage teams, make decisions based on engineering judgment, and solve problems within the context of process engineering design. Our revamped version includes deliverables based on sustainability and circular economy pillars while maintaining the traditionally required technical skills of developing process flow diagrams, piping and instrumentation diagrams, and developing safety and economic analyses [11]. A comprehensive tool was designed to help us map the newly identified I.D. 5.0 requirements and reinforce the existing technical/soft skills clusters, and it is shown in **Table 1**.

In **Table 1** we simply describe our deliverables as we link them with the technical and soft skills required to prepare them. These skills must be fully aligned with the course learning outcomes.

Our focus for the assigned CHE334 project was to work on solutions leading to maximizing circularity in the chemical process design exercise, such as minimizing waste/emissions, maximizing energy efficiency, and minimizing costs. This focus allows us to map chemical process design with sustainability formally. In addition to clustering the number of deliverables into four main ones, considerably reducing the original approach to CHE334, there are two aspects within the technical skills that are fully linked with our mapping findings (highlighted in grey): (i) a data-based modeling approach for equipment sizing, which includes optimizing the sizing of main equipment by using basic machine learning tools such as neural network and other surrogate models to select the "optimal" process conditions leading to an "optimal" equipment sizing; and (ii), discussing existing life cycle assessments to comparatively analyze the current process design with existing/similar ones. Circularity-based elements were included in our deliverables to encourage discussion on ethical judgment when designing chemical processes. Finally, our newly implemented strategies report differs from the previous approach of presenting a technically based report, as we avoided the iterative process that would lead students to present a better version of their processes in the final report.

Table 1. CHE334 Implementation tool for mapping E.D. 5.0 and I.D. 5.0[14]

<table>
<tr><th rowspan="2">Deliverable</th><th colspan="2">Skills</th></tr>
<tr><th>Technical</th><th>Soft</th></tr>
<tr><td>Process drawings</td><td>Process description

Process simulation/heat and material balance

Process flow diagram

Piping and instrumentation diagram</td><td rowspan="4">Teamwork and collaboration

Problem-solving and critical thinking

Technical writing

Time management

Decision-making/leadership

Ethical judgment

Presentations – NONE

Communication with clients - NONE</td></tr>
<tr><td>Sizing and safety</td><td>Equipment sizing

Data-based modeling (Machine Learning)

Hazard Identification (HAZID) study</td></tr>
<tr><td>Circular economy</td><td>Capital Expenditures (CAPEX) and Operational Expenditures (OPEX)

Life Cycle Assessment or LCA (Sustainability)</td></tr>
<tr><td>Strategies report</td><td>-</td></tr>
</table>

Instead, our strategies report conveys reflections on designing a chemical process plant. Students are required to discuss in the report, individually and as a team, their technical and non-technical challenges faced to provide a technical solution for a process design, the strategies used to overcome challenges, and recommendations for future chemical process design endeavors, looking at preparing themselves for Plant Design or their professional experience year co-op program.

To longitudinally assess the effectiveness of our new approach to CHE334, we are currently looking at a set of E.D. 5.0 requirements such as (i) personalized learning, including metrics such as student data, (ii) collaboration and connectedness, which includes aspects such as student engagement in collaborative learning activities and environments, (iii) flexibility, as different learning styles are adapted, and (iv) data-driven decision making, by assessing student outcomes. Our preliminary results lead us to reflect that early efforts in terms of machine learning are required in our curriculum for different purposes, such as learning core concepts and modeling processes, as our students visibly encounter difficulties when modeling. We understand this paradigm shift should be embraced throughout our UG program. The use of Generative AI in other courses, such as Data-based Modelling for Prediction and Control and Petroleum Processing, has proven to be a powerful ally in the roadmap for student-centric, educator-focused, and institution-based implementation of E.D. 5.0, for which it will be considered for next versions of CHE334. Other missing components in CHE334 that are complemented by courses such as Professional Engineering Consultancy (before Plant Design, where they are indeed implemented in the current deliverables) are reinforcing soft skills around communication such as communication with clients and making presentations, as well as evaluating ethics in design. Future efforts might require including these components in preparation for Plant Design. Throughout our UG Chem Eng curriculum, some findings lead us to think about integrating data analysis/machine learning in process control and process design. Other aspects such as big data and IoT might be challenging as intensive computational resources are required, faculty expertise and training must be built, practical and hands-on learning opportunities with industry collaboration must be designed and funded, and more importantly, data privacy, security, and ethical considerations must be taught to provide students with a solid foundation in ethical decision-making when handling datasets.

Another missing component for chemical process designers is a lack of troubleshooting strategies (beyond safety assessments), predictive maintenance, and fault detection. Including them in our UG Chem Eng curriculum faces uphill challenges due to their complexity, faculty skill gap, integration requirements with process control, and data/technology availability.

The previous analysis led us to prioritize implementing strategies around circularity-based chemical process design, using machine learning for data-based modeling (for equipment sizing purposes), and mapping/reinforcing soft skills when conceptualizing our deliverables.

An interesting aspect of the design spine of our curricula might be related to the student workload. As mentioned before, the University of Waterloo, for instance, has a one-year capstone design project, potentially providing more opportunities for including alternative approaches to process design without considerably affecting the workload. A drawback of this initiative would be to maintain the industry's commitment to serving as clients for one year instead of one term or semester.

Finally, implementing interdisciplinary and multidisciplinary approaches in our UG Chem Eng curriculum is crucial to preparing our students to tackle and solve complex tasks and chemical process designs. We envision that further faculty coordination is required, for which a cross-departmental collaboration shall be encouraged. A flexible curriculum is important to allow students to explore other disciplines while specializing in their engineering fields.

Conclusion

This work introduced some strategies to map E.D. 5.0 with I.D. 5.0 and Society 5.0 in the context of chemical process design. Our research was oriented to identify the technical and soft skills required by the industry through a bibliometric analysis and analyzing the Indeed job postings. The lessons learned and findings derived from this research allowed us to design and later present and discuss examples where we show the implementation of mapping strategies within existing courses, looking at feasible paths for mapping E.D. 5.0, I.D. 50 and Society 5.0. We conclude that the mapping roadmap can be drawn by adding technical skills in the shape of machine learning tools for modeling and optimizing chemical processes with process designs based on the circular economy and by reinforcing soft skills, including communication, teamwork and collaboration, problem-solving and critical thinking, time management, leadership, ethical principles, and interpersonal skills. We highlight the importance of defining a critical path of chemical process design courses fed by technical and soft skills acquired in core and optional courses while adding assignments/projects in core and optional courses for dedicated unit operations and reaction systems. E.D. 5.0 is mandated to create a future skilled workforce that meets the I.D. 5.0 competencies, and therefore, chemical engineers are perceived as valuable contributors to Society 5.0 when designing chemical process plants.

References

[1] M. Taylor, "The History of Chemical Engineering," NewEngineer.

[2] N. A. Halim, N. Z. Kasim, A. R. M. Radzi, and F. M. Turan, "A Proposed Methodological Considerations for Sustainable Chemical Process Design," in *Key Engineering Materials*, vol. 938, Trans Tech Publications Ltd, 2022, pp. 123–131. doi: 10.4028/p-5b44o6.

[3] R. Sinnott and G. Towler, *Chemical Engineering Design*. 2020.

[4] O. E. Adedeji, "10 Must-Have Skills For Chemical Engineers," The Engineer's Perspective.

[5] D. Gürdür Broo, O. Kaynak, and S. M. Sait, "Rethinking engineering education at the age of industry 5.0," *J Ind Inf Integr*, vol. 25, Jan. 2022, doi: 10.1016/j.jii.2021.100311.

[6] S. Chakraborty, Y. Gonzalez-Triana, J. Mendoza, and D. Galatro, "Insights on mapping Industry 4.0 and Education 4.0," *Front Educ (Lausanne)*, vol. 8, 2023, doi: 10.3389/feduc.2023.1150190.

[7] S. Huang, B. Wang, X. Li, P. Zheng, D. Mourtzis, and L. Wang, "Industry 5.0 and Society 5.0—Comparison, complementation and co-evolution," *J Manuf Syst*, vol. 64, pp. 424–428, Jul. 2022, doi: 10.1016/j.jmsy.2022.07.010.

[8] D. Galatro, Y.-H. Chin, and B. Saville, "STRATEGIES FOR CHEMICAL PROCESS DESIGN: A SUSTAINABILITY-BASED APPROACH," in *2024 ASEE St. Lawrence Section Annual Conference Proceedings*, ASEE Conferences. doi: 10.18260/1-2-660.1113-48560.

[9] Massachusetts Institute of Technology, "Department of Chemical Engineering," School of Engineering.

[10] Caltech, "Chemical Engineering Option and Minor (ChE)," California Institute of Technology.

[11] Stanford, "Stanford Chemical Engineering," Stanford University.

[12] TUM, "Chemical Engineering," Technical University of Munich.

[13] University of Waterloo, "Chemical Engineering Degree," University of Waterloo.

[14] D. Galatro, Y.-H. Chin, and B. Saville, "STRATEGIES FOR CHEMICAL PROCESS DESIGN: A SUSTAINABILITY-BASED APPROACH." doi: 10.18260/1-2-660.1113-48560.

Appendix: List of abbreviations and acronyms used in this work.

Abbreviation / Acronym	Description
AI	Artificial Intelligence
AR	Augmented Reality
CAPEX	Capital Expenditures
E.D. 4.0	Education 4.0 (4^{th} Education Revolution)
E.D. 5.0	Education 5.0 (5^{th} Education Revolution)
HEI	Higher Education Institutes
I.D. 4.0	Industry 4.0 (4^{th} Industrial Revolution)
I.D. 5.0	Industry 5.0 (5^{th} Industrial Revolution)
LCA	Life Cycle Assessment
ML	Machine Learning
OPEX	Operating Expenditures
UG	Undergraduate
VR	Virtual Reality