Embracing Open Science in Industrial Engineering Education: A Roadmap for Pedagogical Innovation

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Abstract

Integrating open science into industrial engineering education forms the cornerstone for pedagogical innovation in the era of rapidly advancing technology. This article crafts a roadmap for adopting open science within industrial engineering education, anchored on the United Nations' recommendations for open science and accreditation requirements for engineering education. Using a systematic review of relevant literature, we extrapolate vital concepts, potential implementation strategies, and potential challenges. The study aims to illuminate the pathway to enhancing inclusivity, relevance, and global reach of industrial engineering education through the lens of open science.

Keywords: open science, industrial engineering education, pedagogical innovation, strategic roadmap

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1. Introduction

Open science emphasizes transparency and accessibility, fostering a collaborative research culture. This approach reshapes the academic landscape, especially in university industrial engineering departments. As technology influences industrial engineering, educational approaches need to adapt, making open science crucial.

Incorporating open science into industrial engineering education catalyzes pedagogical change by fostering a research-centric mindset. This empowers students to transition from passive learners to active knowledge contributors. Open science broadens research avenues, allowing international collaborations, infusing diverse expertise, and addressing complex engineering issues.

Industry 4.0 marks a pivotal era where technology intersects with various sectors, ushering innovations like artificial intelligence and the Internet of Things (Schwab, 2016). This revolution challenges higher education to evolve, leading to the emergence of the Education 4.0 model. This new pedagogical approach emphasizes essential skills like critical thinking and digital literacy, readying students for a tech-driven world.

For industrial engineering education, the implications are profound. Traditional teaching methods may no longer be adequate in this evolving industrial landscape. Universities need to pivot, favoring collaborative and interdisciplinary methods. Open science principles, championing transparency and collaboration, align with Industry 4.0's interconnected ethos. They also promote digital tools, dovetailing with Education 4.0. Thus, by adopting open science, industrial engineering education can synchronize with modern industrial demands.

UNESCO promotes open science as a global public good, emphasizing universal access to scientific knowledge (UNESCO, 2021). They believe that by ensuring widespread access to research, an interconnected global learning ecosystem is fostered in higher education. Their guidelines also stress international cooperation, suggesting that sharing research across borders can unify global knowledge communities, enhance research quality, and drive innovation in fields like industrial engineering. Furthermore, UNESCO underscores research transparency, advocating for open data sharing. This boosts the reliability of research results and strengthens public trust in academic endeavors.

Despite technological advances, industrial engineering education struggles to keep pace with Industry 4.0 developments. Many universities don't adequately prepare students for the evolving tech-driven industrial landscape, and comprehensive strategies incorporating Industry 4.0, Education 4.0, and the UN's open science guidelines remain sparse. This study crafts a strategic plan to embed open science into industrial engineering curricula, targeting challenges and solutions, aiming to align with modern industrial and educational paradigms, emphasizing collaboration and research quality. However, the article has constraints: its insights may not apply universally across disciplines due to varied challenges. Assumptions are made about universities' alignment with Industry 4.0 and Education 4.0, which might not hold true everywhere, especially in regions with limited digital growth. Intellectual property rights and ethical issues around open access aren't deeply explored, meriting future research. Yet, despite these limitations, this research offers a valuable framework for educators seeking to modernize their approach in industrial engineering.

2. Method

The method of this study comprises a comprehensive literature review, followed by analysis to develop a strategic roadmap for integrating open science into industrial engineering education at universities.

2.1. Literature Review Phase

The initial research phase conducts an in-depth literature review on open science, Industry 4.0, Education 4.0, current industrial engineering education, and the UN's open science guidelines. This exploration serves dual purposes. First, it provides a comprehensive understanding of current advancements, methodologies, and insights in these areas, especially their impact on engineering education (Lee et al., 2019; Schwab, 2016). Second, it identifies existing methods and gaps in integrating open science into industrial engineering education, examining university endeavors, challenges, and focal areas (Kramer & Bosman, 2018; Nielsen, 2012).

2.2. Analysis of the Literature

After the literature review, we'll conduct a thematic analysis to identify patterns in data related to open science in industrial engineering education (Braun & Clarke, 2006). This in-depth method will spotlight key themes, challenges, and strategies, emphasizing the integration of Industry 4.0 and Education 4.0 concepts. The iterative analysis involves repeated literature reviews and is flexible, ensuring comprehensive and robust insights.

2.3. Development of a Strategic Roadmap

Using our literature review and analysis, we've devised a strategic roadmap for weaving open science into industrial engineering education. This guide offers universities a systematic approach to update their engineering courses, addressing identified challenges. It aligns with Industry 4.0, Education 4.0, and the UN's open science guidelines, ensuring curricula stay current and forward-looking.

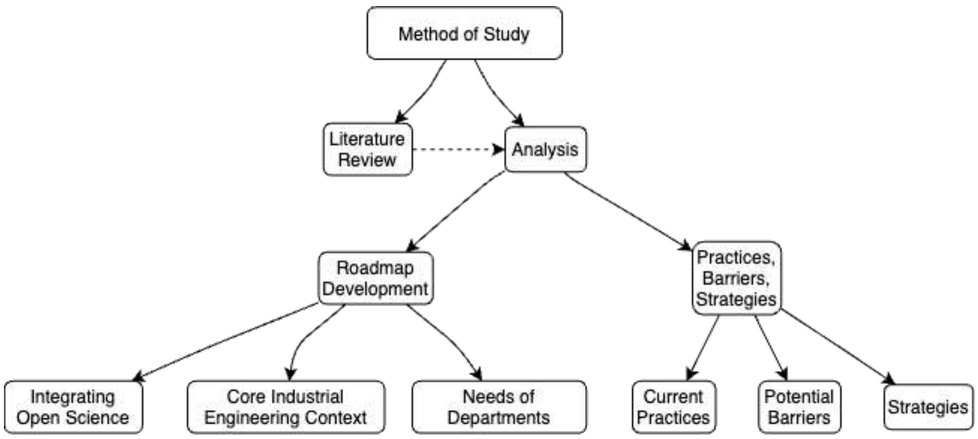

Figure 1. Workflow of the Study

3. Results and Discussions

3.1. Findings from the Literature Review

Using the Scopus database, we reviewed 2018-2023 articles on "Open Science and Industrial Engineering Education" and "Industry 4.0 in Engineering Education." With 46 documents returned for the former, the literature mainly discusses innovative teaching methods and integration challenges.

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"Open Science and Industrial Engineering Education"

TITLE-ABS-KEY ( open  AND science  AND  industrial  AND engineering  AND education )
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Initial results: 180 documents. The filtered results: 46 documents

The search "Industry 4.0 in Engineering Education" yielded 766 documents, showcasing extensive research on equipping engineering students with Industry 4.0 skills like data handling, artificial intelligence, and cyber-physical systems proficiency.

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"Industry 4.0 in Engineering Education"
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Initial result: 1,120 documents. Filtered results: 766 documents

The search "Education 4.0 and Engineering" yielded 1019 documents, underscoring the push to align engineering education with the Fourth Industrial Revolution's demands. This literature delves into flipped classrooms, project-based learning, and integrating digital literacy in contemporary engineering courses.

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"Education 4.0 and Engineering"

TITLE-ABS-KEY ( education  4.0  AND  engineering )
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Initial result: 1,419 documents. The filtered results: 1,019 documents

Lastly, the phrase "UNESCO Open Science Recommendations in Higher Education" yielded only three documents, reflecting the relatively unexplored nature of this specific field. Despite the scant research, the existing studies underline the necessity of adhering to UNESCO's recommendations when incorporating open science into university curricula.

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"UNESCO Open Science Recommendations in Higher Education"
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The filtered results: 3 documents

The literature review unearthed invaluable insights regarding current practices, challenges, and the need for a strategic roadmap to guide the integration of open science into industrial engineering education, keeping in line with Industry 4.0 and Education 4.0 trends.

3.2. Analysis Insights

"Collaboration" was a key theme in open science, highlighting cooperative learning and joint research (Kramer & Bosman, 2018). "Digital Skills Development" emphasized tools, AI, and cyber-physical systems proficiency. "Critical Thinking and Problem-Solving" were vital for engineers, with open science enhancing these skills. Notable challenges were "Infrastructure Constraints," "Digital Literacy Deficits," and "Resistance to Change" (Fecher & Friesike, 2014), suggesting a need for better infrastructure, training, and an innovation-driven culture.

3.3. The Strategic Roadmap

3.3.1. Building Awareness and Cultivating a Culture of Open Science

Open science enhances knowledge through transparency, accessibility, and collaboration. To integrate it into curricula, it's vital to raise awareness of its principles and benefits among faculty and students. Activities like seminars and expert-led workshops can emphasize open science's ethical foundation and its role in fostering innovation (Nosek et al., 2015). Incorporating modules on facets like open access, data integrity, and legal concerns informs students comprehensively (Creswell et al., 2021). Universities like Gottingen and California, with their open science policies and training sessions, exemplify successful integration. Long-term success necessitates rewarding faculty and students for open science engagement, offering incentives like funding and performance recognition (McKiernan et al., 2016).

3.3.2. Developing Digital Literacy Skills

In the age of Industry 4.0 and Education 4.0, digital literacy is essential. It's more than just using digital tools; it involves efficiently and ethically managing and communicating digital information (Bawden, 2008). Curriculum updates should include data management, programming, and understanding digital ethics (Van Laar et al., 2017). Skills like dataset management and programming automation are invaluable for industrial engineering students (Resnick et al., 2019).

Many universities are ahead in this domain. The University of Southampton introduced the "Web Science Institute" to teach students digital network analysis (Halford et al., 2013). Similarly, MIT offers a program on digital literacy and computational thinking, helping students understand digital technology's societal impact (Brennan & Resnick, 2012). Such digital literacy advancements can enhance collaborative open science projects, spurring innovation (Leonelli, 2016).

3.3.3. Establishing Open Access Initiatives

To embrace open science, universities should prioritize open-access initiatives, offering unrestricted access to academic research (Suber, 2012). This not only boosts scientific discovery and collaboration but also ensures reproducibility (Willinsky, 2006). A foundational step is the creation of an institutional repository, using platforms like DSpace, Eprints, or Zenodo, for archiving and freely accessing articles, data, and theses (Lovett et al., 2017). Such repositories consolidate research data, publications, metadata, datasets, and even software. They also encompass educational materials, enriching academia. These platforms promote research transparency and collaboration. Figure 5 displays global repositories based on 2022's PLOS Open Science Indicators, while Figure 6 illustrates the growth of repositories from 2019-2022.

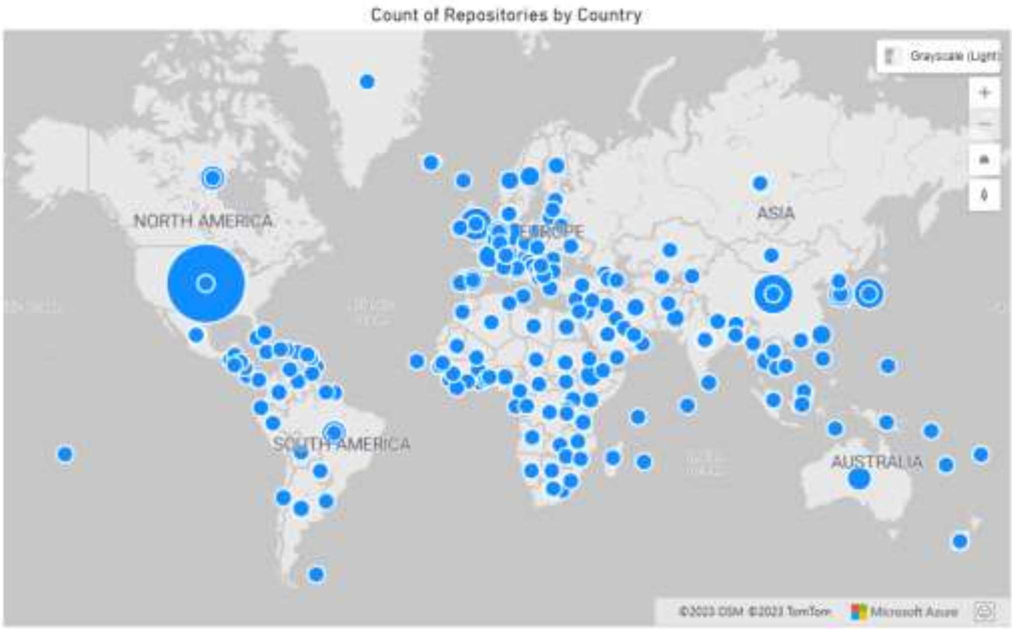

Figure 2. Count of Repositories by Country. Source: PLOS Open Science Indicators

Harvard University's DASH (https://dash.harvard.edu/) serves as a prime model of an open-access research repository, providing free access to scholarly articles from Harvard scholars. Similarly, universities should push faculty and students to publish in open-access journals, fostering transparent science communication (Tennant et al., 2016). The University of California's open-access policy, requiring faculty to deposit their research in an open repository, underscores this approach. To address the cost of publishing in open-access journals, universities can create funds to handle article processing charges. The Compact for Open Access Publishing Equity (COPE - http://www.oacompact.org/) exemplifies collective university efforts in this direction (Shieber & Suber, 2016).

3.3.4. Integrating Industry 4.0 and Education 4.0 Principles

Integrating open science in industrial engineering education requires merging Industry 4.0 and Education 4.0, both of which leverage digital technologies for enhanced learning (Heradio et al., 2016). Industry 4.0 uses tools like IoT and AI to modernize industrial processes (Lasi et al., 2014). Incorporating these into education prepares students for digitized industries. For instance, the University of Stuttgart's ARENA2036 (https://www.arena2036.de/en/) fosters collaboration between academia and industry, promoting open science (Brettel et al., 2014). Meanwhile, Education 4.0 aligns pedagogy with the digital age, emphasizing self-directed and online collaborative learning (Zawacki-Richter et al., 2019). The Singapore University of Technology and Design (SUTD - https://www.sutd.edu.sg/) exemplifies this by stressing interdisciplinary learning and using open science to tackle engineering challenges.

3.3.5. Continuous Improvement and Innovation

Integrating open science in industrial engineering education requires an ongoing commitment, perfectly embodied by the Deming Cycle or PDCA methodology (Shewhart, 1939). Universities should "plan" strategies, then "do" or execute them. It's vital to "check" results against set benchmarks, such as the rate of open science adoption or frequency of open-access publications (Nosek et al., 2015). Surveys and analytics can aid this evaluation. Then, in the "act" phase, universities refine based on findings, possibly offering more faculty training or enhancing digital platforms (Tague, 2004). The University of Delft exemplifies this iterative method, consistently updating its open science policy and infrastructure (van den Besselaar et al., 2017). Embracing open science in this field is about consistent adaptation, fueling pedagogical innovation and superior learning outcomes (De Jong et al., 2015).

3.4. Aligning with UN's Open Science Recommendations and Accreditation Requirements for Engineering Education

UNESCO is devising a global open science framework to bolster knowledge exchange and collaboration (UNESCO, 2020). This emphasizes embedding open science in university curricula, especially in pivotal fields like industrial engineering. Key UNESCO directives include democratizing scientific access and bolstering global open science aptitude. Universities can resonate with these directives through open access platforms, faculty publishing, and infusing open science and digital proficiency into their curriculum.

Regarding engineering accreditation, the Accreditation Board for Engineering and Technology (ABET) values outcomes-driven education and consistent advancement (ABET, 2021). The blueprint for infusing open science in industrial engineering dovetails with ABET's ideals, emphasizing educational innovation and embracing Industry 4.0 and Education 4.0

tenets. Open science inherently cultivates skills like critical thinking, collaboration, and digital fluency.

Thus, assimilating open science in industrial engineering addresses UNESCO's directives and meets engineering education's accreditation norms, promising an enriched educational quality and societal impact.

3.5. Potential Challenges and Strategies

As universities venture towards integrating open science within industrial engineering education, they will encounter many hurdles. Table 3 presents potential challenges and offers strategic solutions to navigate these obstacles effectively.

Table 1. Challenges and Strategies in Implementing Open Science in Industrial Engineering Education

No.	Challenges	Proposed Strategies
1	Financial Constraints	• Seek external funding through grants, partnerships, or sponsorships for educational innovation (Kwiek, 2016). • Utilize open-source or low-cost alternatives for digital tools and resources.
2	Resistance to Change	• Implement change management strategies, focusing on clear communication and involvement of faculty and students in the decision-making process (Oreg, Vakola, & Armenakis, 2011). • Provide training and support to ease the transition.
3	Ethical and Legal Concerns	• Develop comprehensive policies that address these concerns and ensure compliance with legal requirements. • Provide training on ethical considerations and legal implications associated with open science (Pontika, Knoth, Cancellieri & Pearce, 2015).
4	Quality Control and Assessment	• Establish peer-review mechanisms for the content shared through open-access platforms. • Develop criteria and tools for quality assessment and control (Björk, 2015).
5	Technological Barriers	• Invest in upgrading technological infrastructure. • Implement comprehensive digital literacy training programs for faculty and students (Eshet-Alkalai, 2012).
6	Sustainability	• Develop a sustainability plan that includes diverse funding sources, continuous evaluation, and adaptive strategies. • Foster partnerships with industry and other stakeholders to ensure ongoing support and collaboration (Chan, Kirsop & Arunachalam, 2005).

Table 2 presents a structured strategy for implementing open science within an industrial engineering department. This table delineates the necessary technical solutions, identifies the responsible organizational units, ranks the importance of each component, and suggests the sequence for implementation. The numerical values in the first column denote the order of implementation, while the "Preceded by" column signals the completed components before initiating the following components. Table 3 proposes a timeline for successfully deploying these components.

Table 2. Implementation Plan for Open Science in Industrial Engineering Departments' Education

#	Component	Solution	Organizational Unit	Importance (1: Most Important)	Preceded by
1	Awareness and Culture Building	Webinars, online learning modules, educational software	Academic Unit	1	-
2	Digital Literacy	Coding boot camps, online courses on data management, digital content creation tools, virtual collaboration tools	Academic Unit	2	1
3	Open Access Initiatives	Deployment of the institutional repository, open-access publishing platforms, and fund management software	Library Services, Research Department	2	1
4	Integration of Industry 4.0 and Education 4.0	IoT devices for labs, AI-powered teaching software, VR/AR tools for practical learning, online collaboration platforms	Academic Unit, Research Department	3	2
5	Continuous Improvement and Innovation	Online survey tools, data analytics software, digital dashboards for tracking KPIs	All Departments	4	4
6	Alignment with UN Recommendations and Accreditation Requirements	Documentation software, compliance management software	Academic Unit, Administration	1	3
7	Addressing Challenges	Collaborative problem-solving platforms, online legal and ethical training modules	All Departments	5	5

The tables present a blueprint for integrating open science into industrial engineering, highlighting elements, approaches, and timelines. This roadmap facilitates seamless open science adoption in universities. In the Industry 4.0 era, embracing open science can revolutionize engineering education, enhancing transparency and collaboration.

4. Conclusions

This article presents a strategy to integrate open science into industrial engineering education, highlighting its transformative potential. Key steps involve boosting open science awareness, digital literacy, and initiating open-access projects. Synchronizing with Industry 4.0 and Education 4.0, this approach showcases a harmonious blend of contemporary paradigms and open science, adhering to UN guidelines and meeting engineering education criteria. Despite its advantages, hurdles like digital disparities and cultural reluctance could emerge. Still, with proactive planning, a shift to this model is plausible.

Incorporating open science in industrial engineering ushers in significant changes, paving the way for a modern, tech-forward educational environment. Adopting Industry 4.0

and Education 4.0 principles prepares students for evolving industrial challenges. Open-access methods expand knowledge reach, enhancing the quality of education. A commitment to ongoing innovation ensures adaptability and growth.

The framework offers vast research prospects. Areas to explore include crafting open science modules and digital literacy schemes. Evaluating strategies' success, using indicators like adoption rates and learning outcomes, is vital. Insights from universities successful in open science and the wider implications of this approach, encompassing ethical concerns to academia-industry collaborations, deserve attention.

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