

EVALUATION AND CONCEPTUAL FRAMEWORK OF INSTITUTIONAL BEST PRACTICES FOR TRANSFORMING ENGINEERING EDUCATION TOWARDS EDUCATION 4.0 AND INDUSTRY 4.0

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Abstract

Engineering education is changing because of the rapid growth of Industry 4.0 technologies. Modern industries require engineers who have digital skills, innovation ability and practical knowledge. Therefore, engineering institutions must improve their education systems. This paper examines the best practices adopted by engineering institutes and compiled by AICTE (27 institutes and 120 distinct best practices) in order to support the transition toward Education 4.0 and Industry 4.0. The study identifies several institutional practices such as innovation and start-up support, sustainability initiatives, outcome-based education with ICT tools, industry collaboration, mentorship programs, employability training and digital governance systems. The paper also presents a conceptual framework that explains how these practices help to develop Industry 4.0-ready engineers. The analysis shows that many institutions have started adopting digital learning tools, industry partnerships and skill development programs. However, the level of adoption varies across institutions. The study highlights the importance of integrating technology, innovation and industry collaboration in engineering education. Such practices help to create a modern learning environment and prepare students for technology-driven industrial workplaces.

Keywords: Best Practices, Industry 4.0, Higher Education 4.0, Strategy, Skill Development.

1. Introduction

India has strong potential to become a global leader in technology. The Indian economy has grown steadily in recent years, and several industrial sectors have become globally competitive. These industries can further expand their presence in the international market. However, the success of this growth largely depends on the strength of the technical education system in India. High-quality education is necessary to develop skilled professionals who can meet global standards. The quality of higher education depends on several factors such as accreditation, student intake, qualified faculty and adequate infrastructure. Quality assurance and accreditation systems help institutions monitor their performance and continuously improve educational standards.

At the same time, industries are experiencing rapid transformation due to the Fourth Industrial Revolution, commonly known as Industry 4.0. Industry 4.0 is changing the way products are designed, manufactured and delivered. Modern industries are adopting technologies such as the Internet of Things (IoT), cloud computing, data analytics, artificial intelligence and machine learning. Smart factories now use sensors, embedded software and robotics to collect and

analyze data. This helps organizations improve efficiency and make better decisions. When production data is combined with information from enterprise systems such as supply chains, enterprise resource planning and customer services, industries can achieve greater operational efficiency and insights (Kagermann et al., 2013; Xu. et al., 2018).

Technological developments have also influenced the education sector. In the early 21st century, technology began to play a major role in teaching and learning. This stage was referred to as Education 2.0. Later, the growth of interactive and user-generated internet platforms led to the development of Education 3.0, which encouraged collaboration and active participation in learning (Sharma and Sharma, 2020). Currently, Education 4.0 is emerging alongside Industry 4.0. Education 4.0 focuses on using advanced digital technologies to transform teaching and learning processes. It includes technologies such as cloud computing, cyber-physical systems, the Internet of Things, big data, simulation tools, digital twins, robotics, additive manufacturing and artificial intelligence.

Many countries are now moving toward Industry 4.0. This transformation is changing the nature of work and the structure of organizations. However, there is a growing shortage of skilled professionals

who can work in Industry 4.0 environments. Many engineering institutions still follow traditional teaching methods that do not fully match current industry needs. Industry 4.0 has created demand for new types of jobs that require knowledge of both information technology and production systems. Therefore, it is important to understand the skills required for future engineering roles and adapt education systems accordingly (Björklund, 2019).

In this situation, higher education, especially engineering education, has become more important than ever. Educational institutions must prepare students for a rapidly changing and technology-driven economy. Important questions arise about what skills students need to learn and how institutions can prepare them for modern careers.

Higher education institutions have a major responsibility to prepare the future workforce. Engineering institutes must ensure that graduates are capable of meeting industry expectations. It is also important to strengthen the engineering profession so that it remains competitive, respected and attractive. Several initiatives have been introduced in recent years to improve the quality of technical education and to meet the demand for engineers in emerging technologies.

Although the basic structure of engineering education has remained similar for many years, some improvements have been introduced. These include mandatory internships, industry-sponsored projects, mentorship programs, undergraduate research opportunities, online learning platforms, and flipped classroom methods. These initiatives provide students with practical exposure and real-world experience. However, there is still a need to examine how widely these practices are implemented. A major challenge is to develop an engineering education model that can deliver quality learning outcomes at a large scale.

Higher Education 4.0 represents a shift from traditional teaching approaches to flexible and technology-enabled learning methods. It focuses on integrating digital technologies, encouraging innovative teaching practices and aligning education with the needs of Industry 4.0. This approach helps prepare students for a rapidly changing technological environment.

Engineering education in India plays a key role in developing professionals who contribute to technological innovation and industrial growth. With the emergence of Industry 4.0, engineering institutes must produce graduates who possess both theoretical knowledge and practical skills. Students must also develop creativity, innovation and adaptability. In this context, the adoption of best

practices in engineering institutes becomes essential.

Best practices refer to effective and innovative academic and institutional strategies that improve teaching, research, industry interaction and student development (Utane, 2021). These practices include outcome-based education, project-based learning, industry internships, skill-based training, student research opportunities, digital learning tools, industry collaborations, incubation centers and entrepreneurship programs. Such initiatives create a learning environment that encourages creativity, critical thinking and problem-solving.

In India, quality assurance in higher education is supported by accreditation systems. The National Assessment and Accreditation Council (NAAC) play an important role in evaluating the quality of higher education institutions. NAAC encourages institutions to identify and implement best practices as part of their quality improvement process. During accreditation, institutions are required to document innovative practices that contribute to academic excellence and institutional development. This motivates engineering institutes to adopt modern teaching approaches, strengthen industry partnerships and continuously improve their performance.

The adoption of best practices is closely linked to the requirements of Industry 4.0. Modern industries require professionals with interdisciplinary knowledge, digital skills and practical experience. Therefore, engineering education must move beyond traditional classroom teaching. It must focus on hands-on learning, research, innovation and strong collaboration with industry.

Thus, best practices play an important role in transforming engineering education in India. They help create a flexible and dynamic education system that prepares students for the challenges of Industry 4.0. Engineering institutes can improve their teaching methods and encourage innovation. They should also make sure that education matches the needs of industry. This will help students become skilled professionals who can contribute to the global knowledge economy.

The All India Council for Technical Education (AICTE) has emphasized innovation and quality in engineering education. To promote continuous improvement, AICTE compiles best practices from its approved institutions, highlighting reforms in pedagogy, research, employability, and governance (AICTE, 2022). With the advent of Industry 4.0, engineering education must evolve into Education 4.0, which focuses on personalized, flexible, and technology-enabled learning. This paper studies the best practices adopted by engineering institutions

and explains how they align with the requirements of Education 4.0 and Industry 4.0. It presents a framework to show how these institutional practices support the transformation of traditional engineering education into modern Education 4.0 learning environments. These practices help students develop important skills such as innovation, digital literacy, awareness of sustainability, and learning through practical experience. Such competencies are necessary to prepare graduates for the fast-changing technological world of Industry 4.0.

Related Literature

The rapid digital transformation of industries has greatly influenced engineering education around the world. The emergence of Industry 4.0 has created new expectations for engineering graduates. Industry 4.0 is characterized by technologies such as cyber-physical systems, artificial intelligence, the Internet of Things (IoT), big data analytics, and digitally connected manufacturing systems. Because of these developments, higher education institutions are gradually aligning their teaching and learning systems with the concept of Education 4.0. Education 4.0 focuses on student-centered learning, digital learning environments, interdisciplinary collaboration, and strong connections with industry (Grasso & Burkins, 2009; Khan & Mourad, 2025). Therefore, engineering institutions must adopt innovative academic practices that prepare students to work effectively in technology-driven industrial environments.

Early studies on engineering education highlighted the limitations of traditional curricula. Conventional engineering programs mainly focused on delivering technical knowledge. However, they often ignored broader skills such as systems thinking, interdisciplinary collaboration, and innovation capability. Grasso and Burkins (2009) emphasized that engineering education should move beyond traditional classroom learning. They suggested that programs should include experiential learning, research exposure, and interdisciplinary education. Modern engineers must be able to address complex global challenges that involve technological, economic, and social issues. Therefore, engineering education must follow a more holistic approach (Grasso & Burkins, 2009). Several studies have also examined institutional practices that improve engineering education. Rao, Viswanadhan, and Raghunandana (2015) studied leading privately funded engineering institutions in India to identify their best practices. Their research showed that institutions with decentralized governance and greater academic autonomy are

better able to introduce curriculum reforms and adopt new technologies. These institutions can respond more quickly to industry requirements and technological changes. As a result, their programs remain closely aligned with industry needs (Rao et al., 2015).

The study also highlights the importance of faculty development and research activities. Institutions that encourage faculty members to participate in research, consultancy, sponsored projects, and patent development create stronger innovation environments. Incentive systems that support research publications, higher education for faculty members, and collaboration with industry further strengthen institutional innovation capacity (Rao et al., 2015). These activities are particularly important in the context of Industry 4.0, where continuous knowledge creation and interdisciplinary research are essential.

In addition to faculty development, student-centered learning environments are also important for improving engineering education. Outcome-based education has encouraged institutions to adopt new teaching methods. These include project-based learning, laboratory-based experiential learning, and research-oriented assignments. Such approaches help students apply theoretical knowledge to practical problems. They also develop analytical thinking, creativity, and teamwork skills. These competencies are essential for engineers working in Industry 4.0 environments (Khan & Mourad, 2025).

Institutional quality assurance systems also support academic excellence. Internal Quality Assurance Cells (IQAC) help institutions continuously improve their academic processes. They promote participative leadership, regular feedback from stakeholders, and systematic evaluation of academic activities. These processes help maintain quality standards while encouraging innovative teaching methods. The use of Information and Communication Technology (ICT), digital learning platforms, and interactive learning tools also improves student engagement and supports flexible learning environments that match Education 4.0 principles (Rao et al., 2015).

Another important aspect of modern engineering education is global research collaboration. Chang, Atkinson, and Hirlleman (2013) studied the impact of international research experiences through the National Science Foundation's International Research and Education in Engineering (IREE) program. Their findings show that international research opportunities improve students' research skills, technical knowledge, and global awareness. Students who work in international laboratories

gain exposure to advanced technologies and multidisciplinary research teams. They also contribute to solving global challenges such as sustainable energy, environmental protection, and healthcare technologies (Chang et al., 2013).

International research experiences also help students develop professional skills such as communication, leadership, teamwork, and cross-cultural collaboration. These skills are important in Industry 4.0 environments where engineering projects often involve global teams and interdisciplinary work (Chang et al., 2013). Therefore, institutions that promote international partnerships and student mobility programs are better prepared to develop globally competent engineers.

Despite improvements in governance, teaching methods, and international collaboration, engineering institutions still face challenges. One major challenge is aligning engineering curricula with rapidly changing industrial skill requirements. Several studies have identified gaps between the skills taught in engineering programs and those required by Industry 4.0. One initiative addressing this issue is the Erasmus+ MSIE 4.0 project. This project aimed to modernize industrial engineering curricula by identifying skill gaps and developing updated curriculum models.

The results of the project showed that many engineering programs provide limited exposure to emerging technological areas. These include data analytics, digital manufacturing systems, smart supply chains, and real-time industrial monitoring systems. To address these gaps, the project recommends competency-based curriculum design. It also encourages active learning approaches such as project-based learning, problem-based learning, and work-based training. These methods help students develop higher-level skills such as critical thinking, problem solving, and innovation (MSIE 4.0 Project Consortium).

Recent studies have also examined how Industry 4.0 technologies are integrated into engineering education. Khan and Mourad (2025) reviewed research publications from 2015 to 2024 on this topic. Their study shows that industries have quickly adopted technologies such as IoT, artificial intelligence, cloud computing, digital twins, and cyber-physical systems. However, many engineering programs are still in the early stages of integrating these technologies into their curricula (Khan & Mourad, 2025).

The study identifies several teaching approaches that support Industry 4.0 skill development. These include project-based learning, flipped classrooms, simulation-based laboratories, and interdisciplinary

learning environments. Among these methods, project-based learning and simulation-based learning are particularly effective. They allow students to work on real-world engineering problems and understand complex industrial systems (Khan & Mourad, 2025).

The literature also highlights the importance of strong collaboration between industry and academia. Engineering institutions that work closely with industry partners are better able to keep their curricula relevant. These collaborations include internships, joint research projects, industry-sponsored laboratories, and industry advisory boards. Such partnerships give students practical exposure to industrial systems. They also help institutions update their programs based on industry feedback (Khan & Mourad, 2025).

However, integrating Industry 4.0 concepts into engineering education is not without challenges. Institutions often face high infrastructure costs for advanced laboratories. Faculty members may have limited expertise in emerging technologies. Traditional curriculum structures may also restrict flexibility. In addition, students may have different levels of digital literacy. Addressing these challenges requires strategic institutional initiatives. These may include faculty training programs, flexible curriculum design, interdisciplinary research centers, and strong collaboration with industry (Khan & Mourad, 2025).

Overall, the literature shows that best practices in engineering education are evolving toward integrated educational systems. These systems combine effective governance, innovative teaching methods, global research collaboration, and industry-aligned curriculum design (Grasso & Burkins, 2009; Rao et al., 2015; Chang et al., 2013; Khan & Mourad, 2025). Institutions that adopt such practices are better able to implement Education 4.0 principles. They are also better prepared to produce graduates who can work successfully in Industry 4.0 environments. The integration of digital technologies, competency-based education, practical learning, and global collaboration provides a strong pathway for developing future-ready engineers.

Several institutional initiatives further support this transformation. These include creating a culture of innovation through incubation centers and start-up support, promoting environmental sustainability through green campus initiatives, implementing outcome-based education with ICT support, and adopting digital governance for academic and administrative efficiency. Institutions are also bridging the industry-academia gap through Centers of Excellence and collaborative projects.

Mentorship models are introduced to support holistic student development. In addition, company-specific training programs are implemented to improve student employability and meet industry requirements.

2. Analysis of Best Practices Adopted by AICTE Approved Engineering Institutes

Table 1 presents the major institutional best practices adopted by engineering institutes to support modern engineering education. These practices focus on innovation, sustainability, digital

learning, industry collaboration, student mentorship, skill development, and digital governance. Together, these initiatives help create a learning environment that supports the principles of Education 4.0. They also help prepare engineering students with the knowledge, skills, and competencies required for Industry 4.0 environments.

Table 1. Institutional best practices and expected outcome / impact.

Category of Best Practice	Key Practices / Institutional Initiatives	Expected Outcomes / Impact
Creating a Culture of Innovation through Incubation and Start-up Support	Establishment of incubation centers, entrepreneurship cells, start-up mentoring programs, innovation labs, hackathons, and funding support for student start-ups. Collaboration with industry mentors and access to prototyping facilities.	Promotes entrepreneurial mindset, supports commercialization of innovative ideas, encourages research-based start-ups, and creates job creators rather than job seekers. Incubation ecosystems help students transform innovative ideas into viable business ventures.
Greening the Campus: Steps Toward Environmental Sustainability	Implementation of green campus initiatives such as energy conservation, waste management, water harvesting, solar power installations, green buildings, environmental awareness programs, and sustainability projects.	Develops environmental responsibility among students, reduces institutional carbon footprint, promotes sustainable engineering practices, and integrates sustainability principles into engineering education.
Institutionalizing Outcome-Based Education (OBE) with ICT Support	Adoption of outcome-based curriculum design, mapping course outcomes with program outcomes, continuous internal evaluation, and use of ICT tools such as Learning Management Systems, virtual laboratories, digital libraries, and flipped classroom models.	Enhances competency-based learning, supports personalized and flexible learning environments, improves academic quality, and ensures alignment between learning outcomes and industry skill requirements.
Digital Governance for Academic and Administrative Efficiency	Implementation of digital management systems such as ERP platforms, online admission systems, digital attendance, e-examination systems, student information systems, grievance redressal portals, and digital communication platforms.	Improves institutional transparency, reduces administrative workload, enhances efficiency of academic processes, and enables data-driven decision-making in educational institutions.
Bridging the Industry–Academia Gap through Centers of Excellence (CoE) and Collaborative Projects	Establishment of industry-sponsored laboratories and Centers of Excellence in emerging areas such as AI, robotics, IoT, and advanced manufacturing. Conducting collaborative research projects, internships, and industry training programs.	Enhances industry exposure, improves practical skills, aligns academic curriculum with industry requirements, and strengthens innovation and research capabilities.
Mentorship Model for Holistic Student Development	Faculty mentoring systems where each faculty member guides a group of students in academic planning, career development, emotional well-being, and professional growth. Regular mentor-mentee meetings and academic counseling sessions.	Supports holistic student development, improves academic performance, addresses personal and professional challenges, and fosters stronger student–faculty relationships.
Bridging the Employability Gap through Company-Specific Training Modules	Industry-oriented training programs, aptitude training, soft skill development, communication training, certification programs, internships, and placement preparation workshops. Conducting training modules designed by specific companies.	Improves employability, enhances workplace readiness, increases placement opportunities, and equips students with both technical and soft skills required by industry.

3. Linking Best Practices with Education 4.0 Competencies, Industry 4.0 Skills and Student Outcomes

The best practices adopted by engineering institutes play an important role in improving the quality of engineering education. These practices help institutions align their teaching and learning

processes with the needs of modern industries. They also support the development of Education 4.0 competencies and Industry 4.0 skills among students. Table 2 presents the relationship between institutional best practices, Education 4.0 competencies, Industry 4.0 skills, and expected student outcomes.

Table 2. Relationship between institutional best practices, Education 4.0 competencies, Industry 4.0 skills, and expected student outcomes

Best Practice Category	Education 4.0 Competencies Developed	Industry 4.0 Skills Supported	Expected Student Outcomes
Creating a Culture of Innovation through Incubation and Start-up Support	Creative thinking, problem-solving, entrepreneurial mindset, interdisciplinary collaboration, experiential learning	Innovation management, technology development, prototyping, AI/IoT application awareness, start-up ecosystem engagement	Students develop start-up ideas, patents, prototypes, and entrepreneurial ventures.
Greening the Campus: Steps Toward Environmental Sustainability	Sustainability awareness, ethical responsibility, systems thinking, community engagement	Green technology development, sustainable engineering practices, energy management, environmental compliance skills	Students become environmentally responsible engineers capable of designing sustainable technologies.
Institutionalizing Outcome-Based Education with ICT Support	Self-directed learning, competency-based learning, digital literacy, critical thinking	Data analysis, digital engineering tools, simulation platforms, smart system design	Students demonstrate measurable learning outcomes and adaptability to technology-driven workplaces.
Digital Governance for Academic and Administrative Efficiency	Digital collaboration, data-driven decision making, technological adaptability	Enterprise software utilization, digital workflow management, cyber-security awareness, digital communication	Students gain exposure to digital organizational environments similar to modern technology companies.
Bridging Industry–Academia Gap through Centers of Excellence and Collaborative Projects	Experiential learning, industry-oriented problem solving, applied research skills	Robotics, automation, smart manufacturing systems, industrial IoT, advanced production technologies	Students gain real-world engineering experience and industry-relevant technical competencies.
Mentorship Model for Holistic Student Development	Personalized learning, emotional intelligence, leadership development, teamwork	Communication skills, leadership capabilities, adaptability, professional ethics	Students develop balanced professional and personal competencies necessary for modern workplaces.
Bridging the Employability Gap through Company-Specific Training Modules	Skill-based education, career readiness, lifelong learning orientation	Coding proficiency, analytical reasoning, technical aptitude, industry-specific technical skills	Students improve placement readiness and demonstrate higher employability in technology companies.

Table 3. % of institutes reporting the adoption of best practice

Category of Best Practice	% of Institutes Reporting the Practice
Creating a Culture of Innovation through Incubation and Start-up Support	32%
Greening the Campus: Steps Toward Environmental Sustainability	18%
Institutionalizing Outcome-Based Education with ICT Support	41%
Digital Governance for Academic and Administrative Efficiency	27%
Bridging Industry–Academia Gap through COE and Collaborative Projects	36%
Mentorship Model for Holistic Student Development	29%
Bridging the Employability Gap through Company-Specific Training Modules	38%

4. Analysis of Institutional Practices

The analysis shows that many engineering institutions have adopted Outcome-Based Education (OBE) supported by ICT tools (41%). Industry-academia collaboration initiatives are also widely implemented (36%). These practices reflect the growing focus on competency-based education that matches Industry 4.0 requirements.

Many institutions also provide company-specific employability training (38%). This shows that institutions are trying to reduce the gap between academic learning and industry expectations. However, fewer institutions have implemented sustainability-related campus initiatives (18%). This suggests that environmental responsibility is still developing as a strategic priority in engineering education.

Readiness of Engineering Institutes for Industry 4.0

The rapid growth of Industry 4.0 technologies has changed the skill requirements of engineers. Technologies such as cyber-physical systems, artificial intelligence, automation, data analytics, cloud computing, and the Internet of Things (IoT) are widely used in modern industries. Engineering institutions must therefore redesign their education systems to prepare students for technology-driven workplaces. The analysis of institutional practices helps to understand how prepared these institutions are for Industry 4.0.

Innovation Ecosystems and Entrepreneurial Readiness

Many engineering institutions have established incubation centers, innovation laboratories, and start-up support programs. These initiatives encourage students to develop new ideas, build prototypes, and work on technology-based products. Such activities support innovation, which is an important part of Industry 4.0.

However, in many institutions, incubation activities mainly focus on idea development and early mentoring. Only a few institutions provide long-term financial and technological support to convert student ideas into real products or start-ups.

Industry 4.0 innovation also requires collaboration between different disciplines such as data science, automation, electronics, and advanced manufacturing. In many institutions, innovation activities are still limited to individual departments. This restricts the development of integrated technological solutions. Therefore, innovation ecosystems need stronger interdisciplinary collaboration.

Sustainability Initiatives and Smart Infrastructure

Some engineering institutions have introduced green campus initiatives. These include solar energy systems, rainwater harvesting, and waste management practices. These activities show increasing awareness of environmental sustainability.

However, many of these initiatives are mainly infrastructure-based. They are not fully connected with digital technologies such as sensors, monitoring systems, and data analytics.

Industry 4.0 promotes smart and sustainable systems that use real-time monitoring and data-driven management. Many campuses have not yet integrated sustainability initiatives with smart technologies. As a result, students may not gain practical exposure to smart environmental systems. Institutions therefore need to develop smart campus models that combine digital technologies with sustainability practices.

ICT Integration and Digital Learning

Many institutions have adopted ICT-enabled teaching tools and Outcome-Based Education frameworks. Learning Management Systems, virtual laboratories, and digital learning platforms are widely used. These tools support flexible learning and provide access to digital resources.

ICT tools also help students become familiar with digital platforms and online collaboration environments. These skills are important for Industry 4.0 workplaces.

However, in many cases ICT tools are mainly used for delivering course content. They are not always used to teach advanced technologies such as artificial intelligence, machine learning, industrial automation, or digital twins.

Another challenge is the variation in faculty skills and digital infrastructure across institutions. Because of this, the full potential of digital learning systems is not always achieved.

Digital Governance and Institutional Transformation

Many engineering institutions have implemented Enterprise Resource Planning (ERP) systems and digital governance platforms. These systems improve administrative efficiency and simplify processes such as admissions, examinations, attendance, and academic record management.

Digital governance also helps students understand data-driven organizational systems. However, many of these digital systems focus mainly on administration.

Industry 4.0 organizations use advanced data analytics and predictive decision-making systems. Engineering institutions therefore need to go

beyond basic digital administration. They should use data analytics for academic planning, student performance analysis, and institutional decision making.

Industry–Academia Collaboration

Collaboration with industry is one of the most important practices observed in engineering institutions. Many institutions have established Centers of Excellence (COEs) and collaborative projects with industry partners.

These initiatives provide students with access to industrial technologies, practical training environments, and research opportunities. Students gain hands-on experience with technologies such as robotics, automation systems, smart manufacturing tools, and industrial software.

However, in many cases industry collaboration is limited to guest lectures, internships, or short training programs. Long-term partnerships for research and technology development are less common.

To prepare students for Industry 4.0, institutions need stronger collaboration with industry. This may include joint research laboratories, industry-driven curriculum design, and real-world technology projects.

Mentorship and Human Skills Development

Mentorship programs are important for supporting student development. Faculty mentors guide students in academic planning, career decisions, and personal growth.

These programs help students develop communication skills, teamwork, leadership ability, and emotional intelligence. These human skills are important in Industry 4.0 environments where engineers work with intelligent systems and multidisciplinary teams.

However, mentorship programs in many institutions are informal. They depend heavily on individual faculty members and often lack structured evaluation systems.

Institutions can improve these programs by introducing formal mentoring frameworks and involving industry professionals as mentors.

Employability Training and Skill Development

Many institutions provide company-specific training, coding workshops, and aptitude training programs. These programs help students prepare for recruitment processes and improve their chances of employment.

However, these programs often focus mainly on short-term placement preparation. They may not always focus on long-term technological competence.

Industry 4.0 requires engineers with advanced skills in areas such as data analytics, artificial intelligence, automation systems, cybersecurity, and digital engineering tools. Therefore, employability training programs should focus more on advanced technical skills and continuous learning.

Overall Readiness for Industry 4.0

The analysis shows that engineering institutions have taken several steps to improve their education systems. Digital learning tools, innovation programs, industry collaboration, and employability training show that institutions are trying to align with Education 4.0 and Industry 4.0. However, the readiness of institutions is still uneven. Many institutions have introduced useful practices, but the level of technological integration and interdisciplinary learning is still limited. Greater focus on emerging technologies, smart infrastructure, research collaboration, and digital skill development is necessary. These improvements will help institutions better prepare graduates for the modern technological environment.

5. Roles and Strategies to Enhance Readiness of Engineering Graduates for Industry 4.0

The analysis of institutional practices shows that engineering education is gradually evolving in response to Industry 4.0. Many institutions have introduced initiatives related to innovation, digital learning, and industry collaboration. However, a more systematic transformation is still needed. The findings of this study provide several important implications and strategies for institutions, policymakers, and industry stakeholders.

Role of Engineering Institutions

Engineering institutions need to move from traditional teaching models to technology-enabled and competency-based education systems. Many institutions have adopted digital learning tools and outcome-based education. However, emerging technologies are not fully integrated into the curriculum in many cases. Institutions should introduce interdisciplinary courses and practical training in areas such as artificial intelligence, data analytics, robotics, cyber-physical systems, and Industrial Internet of Things. Institutions should also strengthen innovation ecosystems. Incubation centers should support not only idea generation but also prototype development, patent creation, and technology commercialization. Faculty development is another important area. Faculty members should receive training in digital teaching methods, project-based learning, and Industry 4.0 technologies.

Role of Industry–Academia Collaboration

The study highlights the need for stronger collaboration between industry and academic institutions. Although many institutions have internship programs and Centers of Excellence, collaboration often remains limited to short-term activities. Institutions and industry partners should develop long-term partnerships. These may include joint research laboratories, collaborative research projects, and industry participation in curriculum design. Industry professionals can also contribute by mentoring students, evaluating projects, and conducting skill development programs.

Role of Higher Education Regulators

Government agencies and regulatory bodies play an important role in transforming engineering education. Policy frameworks should encourage institutions to adopt advanced technological infrastructure and innovation ecosystems. Financial support and research grants can help institutions establish modern laboratories and digital innovation centers. Accreditation frameworks can also include indicators related to Industry 4.0 readiness. These indicators may focus on emerging technology integration, industry collaboration, and innovation outcomes.

Policymakers should also support the development of smart campuses and digital learning environments through investments in digital infrastructure.

6. A conceptual framework of “Best Practices for Industry 4.0 Ready Engineering Education”

The proposed conceptual framework is shown in figure. The conceptual framework explains how the best practices adopted by engineering institutes

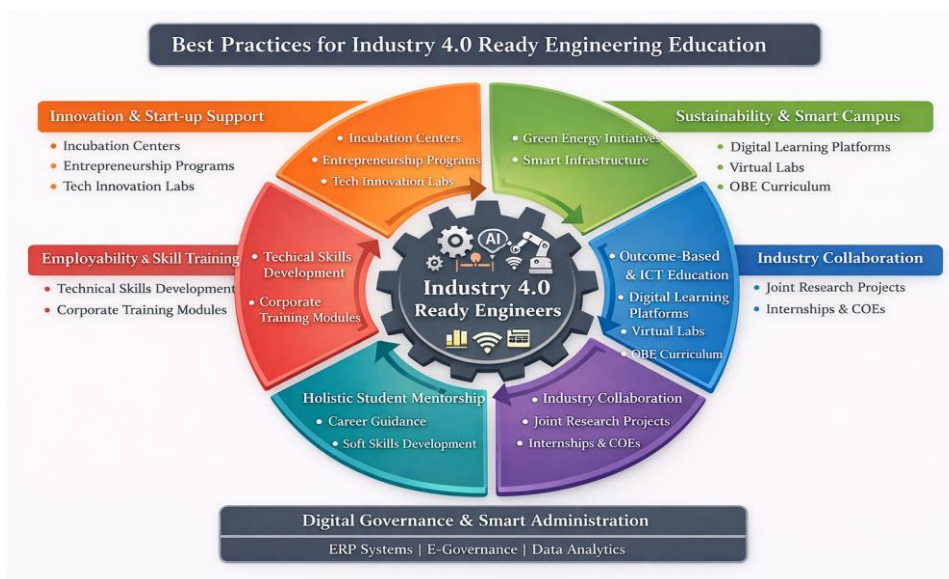
help in developing engineers who are ready for Industry 4.0. At the center of the framework are Industry 4.0–ready engineers. This shows that all institutional initiatives aim to prepare graduates who can work effectively in modern, technology-driven industries. The other components around the center represent the important institutional practices that support this goal.

1. Innovation and Start-up Support

The framework includes innovation and start-up support systems such as incubation centres, entrepreneurship programs, and innovation laboratories. These initiatives create an environment that encourages students to develop new ideas and solve real-world problems. In the context of Industry 4.0, students get opportunities to work with new technologies such as artificial intelligence, automation, and the Internet of Things (IoT). Through start-up activities and innovation projects, students develop creative thinking, technical skills, and the ability to turn ideas into practical solutions.

2. Sustainability and Smart Campus Initiatives

The framework also includes sustainability and smart campus initiatives. Many institutions promote green practices such as renewable energy use and smart infrastructure. These initiatives support global goals of sustainable development and responsible engineering. In Industry 4.0 environments, sustainability is often supported by digital systems, sensors, and smart energy management technologies. Exposure to such practices helps students understand how engineering can support sustainable technological systems.



3. Outcome-Based Education and ICT-Enabled Learning

Another important part of the framework is Outcome-Based Education (OBE) supported by Information and Communication Technology (ICT). Digital platforms, virtual laboratories, and online assessment tools help create flexible and student-centered learning environments. This approach follows the principles of Education 4.0, where learning is technology-supported and focused on developing competencies. ICT-enabled learning also allows students to use simulation tools and digital platforms that are commonly used in modern industries.

4. Industry Collaboration and Centers of Excellence

The framework highlights the importance of collaboration between industry and academic institutions. Many institutes establish Centers of Excellence, industry projects, and internship programs. These collaborations help students gain exposure to real industrial technologies and practical engineering problems. Students can work with technologies such as robotics, automation systems, and smart manufacturing tools that are widely used in Industry 4.0 environments.

5. Holistic Student Mentorship

Mentorship is another key component of the framework. Faculty mentors guide students in their academic progress, career planning, and personal development. In Industry 4.0 workplaces, engineers must have not only technical knowledge but also strong communication and leadership skills. Mentorship programs help students develop teamwork, professional behavior, and interpersonal skills that are important in modern organizations.

6. Employability and Skill Development

The framework also includes employability and skill development initiatives. These include company-specific training, coding workshops, and technical skill development programs. Such programs help reduce the gap between academic learning and industry expectations. By aligning training with industry recruitment needs, institutions improve students' job readiness and prepare them for careers in technology-based industries.

7. Digital Governance and Smart Administration

Digital governance and smart administrative systems support the effective functioning of institutions. Many institutes use Enterprise Resource Planning (ERP) systems and e-governance platforms to manage academic and administrative processes. These systems improve efficiency, transparency, and data management.

They also expose students to digital environments similar to those used in modern Industry 4.0 organizations.

The framework shows that the readiness of engineering institutions for Industry 4.0 depends on the integration of several institutional practices. Innovation systems, digital learning platforms, industry partnerships, sustainability initiatives, mentorship programs, and skill development activities together create a modern educational environment based on Education 4.0 principles.

When these elements work together, they help develop engineers with strong technical knowledge, innovative thinking, digital skills, and professional competencies required for Industry 4.0 industries. Therefore, preparing Industry 4.0-ready engineers requires a complete transformation of engineering education. This transformation involves curriculum changes, improved infrastructure, strong industry collaboration, and a supportive institutional culture.

8. Conclusion

The study shows that engineering institutions are gradually adopting several best practices to improve the quality of education. These practices support the transition from traditional education to Education 4.0. Initiatives such as innovation centers, industry collaboration, ICT-enabled learning, and mentorship programs help students gain practical knowledge and modern skills. Many institutions also provide employability training to improve student placement opportunities.

However, the level of readiness for Industry 4.0 is still uneven. Some institutions have strong innovation ecosystems and industry partnerships, while others are still in the early stages of adopting modern technologies. The integration of emerging technologies such as artificial intelligence, data analytics, and smart manufacturing into the curriculum is still limited in many institutions.

To prepare Industry 4.0-ready engineers, institutions must strengthen digital learning systems, research activities, and interdisciplinary collaboration. Strong partnerships between academia and industry are also necessary. Continuous faculty development and investment in advanced laboratories are important for supporting this transformation.

Overall, best practices adopted by engineering institutions play an important role in creating a flexible, technology-enabled, and industry-aligned education system. These practices help develop engineers who are capable of working in modern digital and automated industrial environments.

This study mainly focuses on identifying institutional best practices and explaining their role in supporting Education 4.0 and Industry 4.0 readiness. However, several areas require further research. Future studies can examine the contextual factors like grade of NBA and NAAC accreditation & type of institute. The critical success factors (CSF) of Education 4.0 and industry 4.0 may be investigated to identify the causal relationship with preparedness.

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