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### Role of Universities in Promotion of Industry 4.0 in Pakistan

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	Abstract
<p><b>Dr. Lal Muhammad</b> Associate Professor, Department of Business Administration, Sarhad University of Science &amp; IT, Peshawar Email: <a href="mailto:lal.ba@suit.edu.pk">lal.ba@suit.edu.pk</a></p> <p><b>Ishtiaq Khan</b> Assistant Professor, Department of Sports Sciences &amp; Physical Education, Sarhad University of Science and Information Technology (SUIT), Peshawar. <a href="mailto:ishtiaq.ss@suit.edu.pk">ishtiaq.ss@suit.edu.pk</a></p>	<p>This paper examines the role of Universities in promoting Industry 4.0 in Pakistan. The fourth industrial revolution with the blend of physical, digital and biological technologies offers transformative possibilities for national economic development. In Pakistan, where industrial modernization appears to be a key priority, universities represent key institutions for the adoption of Industry 4.0 with their roles in research, education, and industry collaboration. This article focuses on the multiple dimension of Pakistani higher education institutions in promoting Industry 4.0 through focusing on their contribution towards workforce development, technological innovation, research commercialization, and policy formulation. Drawing on recent empirical studies and policy documents, this research finds that there are significant accomplishments such as the creation of special research centers, digital transformation efforts and university-industry partnership schemes. However, persistent challenges such as lack of adequate infrastructure, funding, poor industry linkages, and poor curriculum affect optimal performance. The study uses Triple Helix model as analytical framework to evaluate the relationship between university- industry-government in order to get strategic recommendations on how to improve the effectiveness of universities in the context of Industry 4.0 transition in Pakistan. The findings suggest that while, Pakistani universities have made significant achievements in terms of establishing some basic capacities for the promotion of Industry 4.0, they need to implement systemic reforms to convert the potential to real change. This research forges into the literature space on higher education and industrial transformation in the developing economies with specific context-based information for policymakers, academic leadership and industry players.</p>
Keywords	Industry 4.0, Higher Education, University- Industry Collaboration, Digital transformation, Triple Helix Model, Pakistan, Innovation Ecosystem, Workforce Developmen



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### Introduction

The global manufacturing landscape is experiencing a paradigmatic shift catalyzed by the fourth industrial revolution, or simply known as Industry 4.0. This transformation with its main features of cyber-physical systems, Internet of Things (IoT), artificial intelligence, big data analytics, and additive manufacturing holds a promise of unprecedented opportunities in productivity enhancement, innovation acceleration and sustainable development (Kagermann et al., 2013). For developing economies like Pakistan, adopting Industry 4.0 is an imperative both as an opportunity to attain global creative edge as well as a challenge due to currently achieved technological and institutional limitations.

Higher education institutions have a central role in national innovation systems, as knowledge-generators, talent-developers and bridge-builders between research and commercial use (Etzkowitz and Leydesdorff, 2000). In the process of Industry 4.0, universities have taken on more extensive tasks than does education and research: technology transfer, entrepreneurial incubation and collaborative innovations with industrial partners. The success of universities in achieving these roles determine to a great extent the national preparedness for the fourth industrial revolution.

Pakistan's higher education sector has witnessed phenomenal growth in the past two decades, where the Higher Education Commission (HEC) has established more than 200 universities and degree-awarding colleges and institutions all over the country (HEC Pakistan, 2024). This institutional infrastructure brings large potential within it for initiating industrial transformation. However, there are formidable challenges associated with translating the academic potential and promoting industry 4.0 such as inadequate research funding, weak university industry linkages, obsolete curriculum and energy infrastructure (Khalid et al., 2024).

This article examines the role of universities in promoting Industry 4.0 in Pakistan by investigating their contribution to the movement with respect to education, research and engagement domains and identifying the barriers towards optimal performance. The analysis has the following structure: In Section 2, theoretical frameworks and international literature are reviewed on universities in innovation systems. Section 3 explores the Pakistani policy setting and university activities regarding the Industry 4.0. Section 4 contains empirical findings on the performance and problems of universities. There is a section 5 on strategic implications and recommendations. Section 6 concludes with reflections on the way forward.

### Theoretical Framework and Literature Review

#### Triple Helix model and University Engagement

The Triple Helix model developed by Etzkowitz and Leydesdorff (2000) offers the primary analytical framework in order to understand the role of universities in innovation ecosystems. This model views innovation as arising from dynamic interactions between three spheres of institutional knowledge, the universities (knowledge and human capital), industry (goods and services), and government (policy and public investment). In the context of Industry 4.0 the Triple Helix framework helps to shed light on how universities need to transform from inaccessible knowledge producers to active and engaged actors in innovation networks.

The model identifies three developmental stages of university-industry-government relations: (1) internal transformation within each sphere, (2) influence of one sphere upon another and (3) recursive generation of new hybrid organizations and institutional arrangements. Pakistani universities are currently engaged with (predominantly) stage one and two with little movement towards the generative third stage with innovation laboratories, technology parks and entrepreneurial universities (Khalid and Ali, 2025).

Evidences from the international show that good Triple Helix configurations accelerate Industry 4.0 adoption. German universities of applied sciences (Fachhochschulen) are examples of close co-operation with industry in the form of dual study courses, applied research contracts and joint laboratory arrangements (Kagermann et al., 2013). Similarly, the university system in Singapore has been redesigned to enable the smart nation initiatives by providing specific funding for research, industry co-location, and curriculum co-design with technological employers (Ghobakhloo, 2020). These models form reference points to determine the performance of Pakistani universities.

#### Universities as Knowledge and Human Capital Producers

The role of universities as a foundation of Industry 4.0 promotion is in knowledge production and human capital development. Research universities are the source of the scientific and technological knowledge that is behind the latest manufacturing and automation technologies and digital systems. At the same time, they are preparing the necessary specialized workforce for the development, deployment and operation of Industry 4.0 technologies (Ellahi et al., 2020).

The knowledge production function covers basic research for fundamental understanding, applied research for specific industrial problems and experimental development for turning research results into a practical application. In the context of Industry 4.0, this research covers artificial intelligence, machine learning, robotics, sensor technologies, cyber security and systems integration. The effectiveness of the knowledgment depending upon research infrastructural, funding availability and alignment with industrial needs (Muller et al. 2018).



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Human capital development for Industry 4.0 goes beyond the development of technical competences to include interdisciplinary competencies such as data literacy, systems thinking, creativity and ethical reasoning. Curriculum modernization, experiential learning and lifelong education are the key mechanisms for workforce preparation. International studies focus on the inability of traditional lecture-based instruction to develop Industry 4.0 competencies but instead need project-based learning, a focus on industry immersion, and hand-on experience with advanced technologies (Silva et al., 2020).

### **The key issues in Technology Transfer and Commercialization**

Universities contribute to Industry 4.0 with technology transfer - which is the process of transferring knowledge gained through research in academic laboratories to commercial use. This includes patenting and licensing inventions, setting up spin-off companies, offering technical consultancy and working with industry partners on collaborative research (Perkmann et al, 2013).

Effective technology transfer requires institutional mechanisms that include technology transfer offices, proof of concept funding, incubation facilities and entrepreneurial training of the academics. Cultural factors can also influence the effectiveness of the transfer, especially academic norms around commercial involvement, and the receptiveness of industry to working with universities around it. In developing economies, technology transfer tends to be about adapting the imported technology to local circumstances and not creating breakthrough technologies (Bruneel et al., 2010).

The concept of "absorptive capacity" - the capacity of firm to recognize, assimilate, and put in place external knowledge - mediates university impact on industrial transformation. Pakistani manufacturing firms, especially the small and medium enterprises (SMEs) tend to have little power of absorption notwithstanding the low level of R&D investment, poor technical personnel, and the structure of incentives for innovation (Iqbal and Rahim, 2025). Universities must thus be involved in capacity-building as well as technology transfer in order to ensure successful Industry 4.0 adoption.

### **Barriers to University-industry Collaboration**

Literature identifies a number of items that pose obstacles to successful university-industry collaboration that will also be relevant to developing economy contexts. Orientation differences lead to basic tensions: there is a focus on knowledge publication and academic prestige in universities as well as a focus on proprietary competitive advantage and immediate problem-solving in industries (Tassey, 1989). Transaction barriers involve issues with intellectual property, diverging time frames and mismatched expectations of research results.

In developing countries like Pakistan, there are further barriers from institutional weaknesses. These include the lack of research funding to limit the capability of universities, poor protection of intellectual property to limit the willingness of industry to collaborate, cultural distance between academic and business communities, and policies by the government which do not provide sufficient incentives for government to encourage partnerships (Kousar et al., 2017). The lack of sustained traditions of collaboration exists with trust deficits hindering the formation of relationships despite the elimination of structural barriers (Schofield, 2012).

### **Context of the Policy and University Initiatives in Pakistan**

#### **National Policy Framework for Industry 4.0**

Pakistan's policy framework of Industry 4.0 has evolved enormously in the past decade, where universities are being recognised as an important implementation agent. The Pakistan Vision 2025 launched by Ministry of Planning, Development and Reform stated in 2014, identified knowledge economy transition to be a strategic priority which defined targets with respect to research and development investment, university-industry linking and technology enabled productivity growth.

The Science, Technology and Innovation Policy 2022 has placed artificial intelligence as prime research priorities at the national levels and has mapped the emerging technologies on top via 61 policy measures towards strengthening the innovation ecosystem (Ministry of Science and Technology, 2022). This policy specifically requires universities to increase research commercialization, create industry-relevant curricula and create technology transfer mechanisms. The National Research Agenda 2017 was formulated by the Pakistan Council of Science and Technology (PCST) identifying the sectors of information and communication technologies and robotics as priority areas taking into account that through their teaching and research activities, research institutes, academia and the private sector was helping Pakistan to embrace the fourth industrial revolution (PCST, 2017).

The Corporations or institutions Higher Education Commission Has implemented these policy directions through select initiatives. The Higher Education Development Project (HEDP) initiated in 2019 with the support of World Bank has made a heavy investment in digital infrastructure, faculty development and institutional modernization (Dawn,



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2025). This project created the Pakistan Education and Research Network (PERN) that linked more than 300 universities to the high-speed internet and international research resources and deployed Maktab enterprise resource planning system to digitize administrative operations.

### **Specialized Research Centers & Infrastructure**

Pakistani universities have set up special research centers for promoting the technologies and uses of Industry 4.0. The Higher Education Commission set up six national centers under the Public Sector Development Program (2018-19) with the goals to build national capacity for research and development in modern technologies, solve local problems, provide common services to the academia and the industries, and to develop "an advanced human resource with training and applied work" (HEC Pakistan, 2024).

The National Centre of Artificial Intelligence (NCAI), based out of national University of Science and technology (NUST), Islamabad is the flagship initiative. NCAI has nine research laboratories in six major universities, providing facilities to local industry, HEC and government departments in the area of artificial intelligence and machine learning/deep learning/ image recognition and automatic speech recognition. The Sino-Pak Center for Artificial Intelligence is a complimentary capability in the areas of intelligent biomedical applications, smart city planning, smart agriculture, computer vision, robotics and natural disaster management (Council for Science and Technology, 2025).

These centers have proven to boost this output of research powerfully because the Pakistani scholars have published nearly 18,365 number of research contributions during the span of 2000-2024, including nearly 11,000 papers in the area of computer science, over 2,200 papers in the field of telecommunication and nearly 750 papers in the field of robotics. (Web of Science database). However, the translation of such research activity to industrial use is also limited - few patents, spin-offs, or licensed technologies are coming out of university laboratories.

### **University industry Technology Support Program**

The University Industry Technology Support Program (UITSP) is an excellent example of the efforts put forth by HEC to strengthen the linkages between the academia and the industry. This competitive grant program grants high-level industrial research projects that can be of direct use to the current industry needs and that will require collaboration between the public-sector researches from universities and professionals from industries (HEC, 2025). UITSP has a focused on discrete and continuous manufacturing sectors in which Pakistan has competitive potential in the world trade and aims to reduce the import of raw material and improve the export of finished products by improving the process and products.

UITSP Grants support up to Rs. 6 million for two year projects and support researchers coming from doctoral qualifications and international professional affiliations. While the program is considered a step forward in incentivizing collaboration, empirical evaluations suggest staying reluctance in amongst industrial top management to expand with academia (Khalid et al, 2024). Structural barriers such as intellectual property characters, mismatched timelines, and divergent organizational cultures continue to be an impediment to successful partnership arrangements despite availability of funds.

### **Digital revolution of higher education**

Pakistani universities have made considered digital transformation for Industry 4.0 education and research. The HEDP initiative has set-up two cutting-edge data centers (Astrolabes) in Lahore and Karachi that offer secure cloud storage, data management and processing capabilities to facilitate modern academic applications (Dawn, 2025). Through the National Academy of Higher Education (NAHE), HEC has trained more than 1100 faculty and 900 administrative staff members in digital tools, online teaching, and oriented staff in new academic management practices.

Research on digital transformation in the institutions of higher education of Pakistan finds positive effects in terms of operational effectiveness, academic quality, institutional responsiveness, and service provision (Khalid and Ali, 2025). One of the studies conducted using Partial Least Squares Structural Equation Modeling (PLS-SEM) with 210 employees and students in public and private HEIs showed that digital transformation can explain 68.2% of variances in institutional performance. However, some major challenges remain such as unawareness of implementation across institutions, resistance to change in some universities and technical difficulties in areas with poor internet connectivity.

E-learning strategies increased enormously especially after the disruptions from the pandemic of Covid-19. Studies indicate that while the implementation of e-learning has helped to increase access to education, there are still many obstacles such as infrastructure shortcomings, uneven digital skills among faculty, and resistance to fully online study methods in students (Qurat-UI-Ain et al., 2025). The effectiveness of digital transformation for the preparation of Industry 4.0 to come depends upon the move from administrative digitization, to the integration of advanced technologies into curricula and research.

### Empirical Evaluation of University Performance

#### Productivity and relevance of research

Quantitative evaluation of research in Pakistani universities shows considerable activity and scant importance for the industry. Bibliometric analysis shows that there has been significant increase in publications in the areas of computer science engineering and similar areas though the number of patents and technology commercialization is negligible. The performance evaluation reports of the HEC show that university research centers have achieved more than 95% of predetermined targets in infrastructure building and training delivery, however metrics on industry adoption and economic impact are less positive (Dawn, 2025).

**Table 1:** *SWOT Analysis of Pakistani Universities for Industry 4.0 Promotion*

Dimension	Factor	Mean Score	Strategic Weight	Weighted Score
Strengths	University willingness to support Industry 4.0 programs	3.42	0.238	0.814
	Presence of experts and staff to develop specialized talents	3.22	0.203	0.653
	Matured computer science and engineering departments	3.41	0.108	0.368
	Internet accessibility and speed within universities	3.80	0.212	0.806
	Support for inventions and patent generation	3.67	0.064	0.235
	Digital transformation improving international competitiveness	3.99	0.106	0.423
Weaknesses	Collaboration between university laboratories	3.30	0.076	0.251
	Funded projects related to Industry 4.0	3.27	0.170	0.556
	Collaboration between university and industries	2.24	0.183	0.410
	Staff with industrial experience	3.39	0.126	0.427
	Strategies to promote Industry 4.0 awareness	3.23	0.092	0.297
Opportunities	Market growth for Industry 4.0 technologies	3.54	0.149	0.528
	Worldwide popularity and acceptance of Industry 4.0	3.56	0.234	0.833
	Skill development initiatives	3.68	0.211	0.776
	Smart factories and intelligent applications demand	4.01	0.117	0.469
	International collaborations potential	3.86	0.289	1.115
Threats	Security issues and cyber threats	3.59	0.213	0.765
	Intangible roadmap and strategic framework	3.20	0.349	1.117

*Source: Adapted from sustainability assessment frameworks for Industry 4.0 in higher education (Ellahi et al., 2020)*

The SWOT analysis shows that Pakistani universities have a high willingness and the basic infrastructure for the promotion of Industry 4.0, which has a major strength in the field of internet accessibility and expert availability. However, there are critical weaknesses in university-industry collaboration (mean score 2.24) and funded projects which suggests that there are structural barriers in transferring technology. The high strategic weight of international collaborations (0.289) and intangible roadmaps (0.349) suggest priorities of intervention.

#### Modernizing the Curriculum and Developing the Workforce

Industry 4.0 entails fundamental transformation of the curriculum in engineering, computer science, and business disciplines. Pakistani universities have started curriculum revisions being done into data analytics, artificial intelligence, IoT, robotics, and cloud computing (Ellahi et al. 2020). However, implementation is still inconsistent and many institutions continue with the traditional approaches based on the theoretical level of knowledge rather than the application level of competences.

The mismatch between the requirements of the university and those of industry is one of the key obstacles to developing an Industry 4.0 workforce. Employer surveys show that the graduates are lacking in practical experience in the sound of advanced manufacturing technologies, systems integration abilities and interdisciplinary problem solving (Khalid

et al., 2024). University programs focused on rote learning and evaluation based on examination do not equip students with the creative skills, adaptability, and collective skills of people deemed necessary for Industry 4.0 environments.

Project-based learning, industry internships and experiential education have not been as well developed as they need to be despite their acknowledged importance. The UITSP program and others like it are trying to remedy this gap through funding collaborative projects, but the scale required to make a difference in national workforce preparation is still not there. Faculty development is another parallel challenge with many academic without industry experience and with up-to-date tech knowledge needed for Industry 4.0 education.

### Constraints for University-Industry Collaboration

Empirical research on university industry linkages in Pakistan shows that there are several constraints preventing effective University-industry collaboration. A survey of 198 Pakistani firms revealed that the unwillingness of top management to engage with academia is one of the main obstacles, which is rooted in the mismatch between the research conducted by academia and the needs of the industry (Khalid et al., 2024). Quantitative analysis using Probit regression confirmed that proper maintenance of university-industry linkages proved important to innovation, but the linkages are still underdeveloped.

**Table 2: Constraints in University-Industry Collaboration in Pakistan**

Constraint Category	Specific Barrier	Prevalence	Impact Level
Infrastructure & Resources	Paucity of research infrastructure	High	Critical
	Inadequate laboratory equipment	High	High
	Limited funding for collaborative projects	Very High	Critical
Motivational & Cultural	Low motivation among faculty for industry engagement	Moderate	High
	Trust deficit between university and industry	High	Critical
	Lack of interest from industry partners	Very High	Critical
Policy & Governance	Missing policy regarding university-industry linkage	High	Critical
	Intellectual property disputes	Moderate	High
	Divergent time horizons and objectives	High	High
Capacity & Capability	Lack of staff with industrial experience	High	High
	Limited absorptive capacity in SMEs	Very High	Critical
	Inadequate technology transfer offices	Moderate	Moderate

Source: Synthetically based on Empirical studies on University-Industry collaboration in Pakistan (Khalid et al 2024 & Khalid et al 2021)

A thorough analysis of 1070 faculty members from universities of Punjab province based on interviews of 11 Office of Research, Innovation and Commercialization (ORIC) members and 12 industrialists, strong infrastructure lacunae, motivational barriers, lack of trust and policy lacunae were identified as major constraints (Khalid et al., 2024). Recommendation of government and cooperative agency funding for research and development, industry co-funding mechanisms, and formalization of collaboration policies to strengthen university-industry connections were recommended in the study.

### Regional and Institutional Differences

Industry 4.0 promotion capacity is a huge distance away from Pakistani universities and regions. Elite institutions such as NUST, Lahore University of Management Sciences (LUMS) and Pakistan Institute of Engineering and Applied Sciences (PIEAS) have advanced infrastructure, international linkages and research productivity up to the standard of international standards. However, most public sector universities, especially in small cities and rural areas, do not have basic facilities related to research and education of Industry 4.0 (Khalid and Ali, 2025).

Regional inequalities are a sign of greater economic and infrastructure inequalities. Universities in Islamabad, Lahore and Karachi have the advantage of being located close to technology parks, industrial clusters and corporate head offices, thus enabling interaction with Industry 4.0 applications. Institutions in Khyber Pakhtunkhwa, Balochistan, and rural Sindh are faced with compounded issues such as security issues, lack of infrastructure, and industrial presence (Iqbal, 2021).

Private universities have been more agile in the modernization of their curriculum and more engaged with industry driven by market competition and flexible governance. However, their research contributions are quite limited compared to the public research universities having an established research graduate program and research funding. The most suitable arrangement for the promotion of Industry 4.0 seems to be differentiated roles, the former (research-oriented public universities) work on developing basic technologies, the latter (private and teaching-oriented institutions) focus on skills building and industry partnerships.

### Strategic Recommendations for Improved University Impact

#### Strengthening Triple Helix Configuration

Effective Industry 4.0 promotion involves evolution towards the generative Triple Helix stage of recursive interactions and hybrid institutional forms. Pakistani policymakers should create technology parks and innovation districts sharing a location with university research centres, industry research and development centres as well as government support agencies. The Special Technology Zones Authority (STZA), created in 2020 to build IT sector infrastructure, gives some basis to such clustering but demands the integration of universities beyond the existing arrangements (Council for Science and Technology, 2025).

Government funding mechanisms should encourage cooperative research specifically. The current UITSP program is a good model and has to be scaled up and refined in structure. Funding allocation is guided to proposals that exhibit a true incidence of industry collaboration, with industry contributions being made in regard to commitment in the form of matching funds. Intellectual property frameworks need to be made clearer in order to address concerns between universities and industries over rights of ownership and commercialization.

#### Curriculum Change and Experiences

Universities need to carry out a system wide curriculum reform that is geared to the requirements of Industry 4.0 competency. This goes beyond the inclusion of additional specialized courses and includes fundamental pedagogical change focused on project-based learning, interdisciplinary collaboration, and a problem-solving orientation. Recommendation includes:

**Table 3:** *Proposed Industry 4.0 Curriculum Framework for Pakistani Universities*

Competency Domain	Core Components	Delivery Mechanism	Assessment Approach
Technical Foundations	Data analytics, AI/ML, IoT, robotics, cloud computing, cybersecurity	Integrated laboratory modules, virtual simulations, remote labs	Project portfolios, technical certifications
Systems Integration	Cyber-physical systems, digital twins, smart manufacturing platforms	Capstone projects with industry partners, hackathons	System prototypes, industry evaluation
Interdisciplinary Skills	Design thinking, sustainability, ethics, entrepreneurship	Cross-disciplinary studios, industry mentorship programs	Innovation challenges, business plan competitions
Professional Capabilities	Communication, teamwork, project management, lifelong learning	Collaborative projects, internships, professional workshops	360-degree feedback, reflective portfolios
Applied Experience	Industry immersion, live projects, technology commercialization	Mandatory internships, co-op programs, spin-off incubation	Employer assessments, venture outcomes

Source: Modified after international best practices with respect to Industry 4.0 education (Silva et al., 2020; Ellahi et al., 2020)

There should be mandatory not optional experiential learning components comprising structured internships, co-operative education programs, as well as industry-sponsored projects that form integral elements of curriculum. University-industry co-design of curricula so that they are relevant. industry professionals are involved in advisory boards, guest lecturing and as project supervisors.

#### Research Commercialization and Entrepreneurship

Universities need to have enhanced translated research into industrial application. The technology transfers offices (TTOs) set up under ORIC structures require professionalization along with staff who have technical and business skills Proof-of-concept funding should gap between the research conducted in laboratory to achieving commercial viability is funding for prototype development, market validation, etc.



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Entrepreneurship education and incubations can cause the formation of Industry 4.0 startups. Universities should create specialized incubators for building advanced manufacturing, AI applications and IoT solutions, seed funding, technical infrastructure and mentorship. Success metrics must focus more on venture creation, job creation, and use of technology by existing industries, as opposed to the number of publications.

### **Faculty Development and Incentive Restructuring**

Academic career incentives have to be realigned in order to reward Industry 4.0 relevant activities. Current promotion criteria that give extra weight to publications in high impact journals fail to give due appreciation for patenting, technology transfer, collaborations with industry, and entrepreneurial engagement. HEC must update performance evaluation frameworks so that there is sufficient weight on industry participation, applied research outputs, and impact to society in addition to more conventional performance evaluation metrics.

Faculty development programs must ensure that current academics have contemporary knowledge of Industry 4.0. Sabbatical arrangements to allow immersion into industry, international training in cutting-edge manufacturing environments and continuous professional development in developing new technologies, is essential. Industry practitioners must be facilitated to join the faculty of academia to bring current experience and professional networks.

### **Infrastructure and Digital Investment**

Sustained investment in research infrastructure is the prerequisite admission for effective Industry 4.0-promotion. The HEDP initiative offers a model for digital infrastructure development with the need for extension to advanced manufacturing equipment, testing facilities similar to advanced manufacturing equipment and industry-scale demonstration plants. Shared research infrastructure across groups of universities can provide maximum use and share cost outside of individual institutional capacity.

The PERN network expansion must focus on bandwidth and connectivity for remote and underserved institutions that will reduce digital divides that put regional universities at a disadvantage. Access to cloud computing resources, high-performance computing installations and licensed software for advanced design and simulation should be made centrally available to prevent duplication and lack of equity of access between institutions.

### **Conclusion**

Pakistani Universities have a central role to play in national Industry 4.0 strategy with a demonstrated potential and significant success in research infrastructure, specialist center establishment and policy alignment. The Higher Education Commission's initiatives such as the National Centres of Artificial Intelligence, University Industry Technology Support Program, and Higher Education Development Project offer bases for such transformational impact. Digital transformation not only of the administrative but also the educational processes has developed considerably while including improvements in institutional performances in a measurable way.

However, critical challenges still remain that limit the effectiveness of universities in driving industrial transformation. University-industry collaboration is under-developed in spite of policy emphasis and there are issues of trust deficits, cultural distances, and structural barriers that hinder the establishment of partnerships. Modernization of the curriculum, although taken up, has not been existing on the scale or depth required for workforce transformation. Research commercialization mechanisms are weak with limited translation of academic output into industrial application. Regional and institutional inequalities result in disparities in capabilities across the higher education system.

To meet these challenges constitutive systemic reforms are needed so that the Triple Helix configuration becomes stronger with co-located infrastructure of innovation, incentivized finance for cooperation and clarified intellectual property frameworks. Curriculum transformation will have to go further than course addition for fundamental pedagogical reform manifested in experiential learning and interdisciplinary integration. Faculty incentivizing this change involves realignment and rewarding industry engagement and applied impact alongside standard academic measurements of faculty. Sustained investment in infrastructure, especially in common research facilities and digital connections, is also key.

The path of Pakistani Universities in the promotion of Industry 4.0 will have a huge impact on the economic development within nations and the competitiveness of countries at a global level. With strategic investments, policy refinements and institutional reforms, universities have the potential to achieve what they can as drivers of the fourth industrial revolution. Without such interventions, the risk of being perpetually dependent on technological approaches and missing opportunities for development are of high risk. The time window for effective action is decreasing with more and more global industry 4.0 adoption, which means both immediate and long-term commitment to university capacity building is an imperative for Pakistan's economic future.



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