



# Awareness and Readiness towards Industry 4.0 Ethiopian Higher Technical and Vocational Education and Training Instructors

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## Abstract

Recognizing that the integration of Industry 4.0 into Technical and Vocational Education and Training systems requires sufficient technological awareness among instructors, adequate professional development exposure and instructional readiness, this study sought to determine the levels of these dimensions among higher-level TVET instructors in Ethiopia. A mixed-methods descriptive design was used, involving 63 instructors who responded to a professionally validated structured questionnaire with both closed- and open-ended items. Data obtained through the questionnaire were analyzed quantitatively using descriptive statistics and correlation analysis, while that obtained through open items were processed qualitatively through inductive thematic analysis. The results indicate that the instructors had varying levels of conceptual awareness to Industry 4.0, which were mostly moderate to high on artificial intelligence and Internet of Things. In contrast, instructional readiness was generally low across various themes, including curriculum alignment, pedagogical adaptation and practical instructional exhibition. Instructional technology use was positively and significantly correlated with instructors' preparation confidence. Qualitative insights also revealed the need for continuous professional development, enhanced industry collaboration and the development of support mechanisms by the institutions. The study, therefore, concludes that Ethiopian higher-level TVET institutions and instructors exhibited conceptual alignment but limited operational preparedness.

## Subject Areas

Higher Education

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## Keywords

Industry 4.0, Technical and Vocational Education and Training (TVET), Instructor Readiness, Professional Development, Curriculum Alignment, Ethiopia

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## 1. Introduction

Digital technologies continue to diffuse at an unprecedented pace creating new realities for teaching and learning environments, new modalities of delivery in higher education and training systems. The contemporary educational digitalization transcends a mere uptake of instructional technologies; it signifies an overall socio-technical metamorphosis re-orienting pedagogies, institutional practices, and learner engagement. There has been an increasing emphasis on learner-channeled experiences over technology, ideally fostering adaptability, interaction, and continuous skill development [1].

Such transformation is strongly linked to the concept of Industry 4.0, which stems from Germany's Digital Agenda created in the early 2010s and later launched internationally. Industry 4.0 refers to the integration of digital, automated and intelligent systems into industrial production and management with broad consequences for efficiency, sustainability, work organization and skill formation [2]. In contrast with previous industrial revolutions that occurred through mechanization, electrification or basic automation, the Fourth Industrial Revolution is marked by the convergence of cyber-physical systems, connectivity and data-driven decision making [3], fundamentally altering how work is performed and goods are produced.

The contribution of education systems to industrial transformation and sustainable development is through the preparation of skilled human capital, innovation capacity building and workforce resilience. Still, the rapid incorporation of automation, artificial intelligence, and cutting-edge manufacturing processes has increased ambiguity over what jobs will exist and what skills will be needed for them in the future. International labor-market data consistently point to a growing misalignment between graduates' skill-sets and employers, particularly in technologically fluid sectors [4], but these pressures are necessitating a shift away from static curricula toward updated and evergreen models of learning in education systems.

In response to this, Higher Education highlights a new pedagogic paradigm for education which aligns the cognitive development of our learners with industry in the Fourth Industrial Revolution. It encourages innovative, interdisciplinary and sustainability-based teaching and learning practices (with faculty acting as facilitators, mentors, and architects of adaptive learning environments) instead of focusing on the replication of technology [5]. This approach is centered around twenty-first-century skills development that emphasizes not only technical com-

munication but also problem-solving, creativity, collaboration and adaptability—going increasingly further to seek competencies resistant to automation [6].

The goal of education is to adapt instructional models have shifted away from traditional classroom-based instruction toward digitally mediated and blended learning environments. Digital literacy and technological adaptability are crucial for employability, lifelong learning and teaching in various educational environments [7]. In technical and vocational areas, workforce readiness necessitates the combination of technical competencies with strategic, social, and personal skills [8].

Following the aforementioned changes, Technical and Vocational Education and Training (TVET) institutions are at a strategic position in preparing learners for Industry 4.0 workplaces. Their mandate is not only to impart technical skills but also to provide applied learning, developing digital competence, and aligning with ever evolving industry standards [9]. There is however evidence that vocational institutions rely on traditional pedagogical approaches, have under-utilized digital and multimedia technologies, and lack comprehensive mechanisms for evaluating learning outcomes which prevents technology from being impactful [10]. Such challenges are particularly salient in developing-country contexts where vocational education is critical to economic development, labor market entry and social inclusion [11].

Instructor readiness serves as one of the most crucial determinants of successful Industry 4.0 integration within TVET systems. Instructors are curriculum leaders and skill development facilitators who must embrace new pedagogies, integrate digital tools, and prepare learners for technology-rich workplaces. Empirical research shows that the level of understanding, confidence and exposure to training of instructors remain major factors which affect how far Industry 4.0 concepts are effectively integrated into teaching and learning processes [12].

While these demands are widely acknowledged, many education systems are still struggling with limited digital culture, lack of familiarity with new technologies and sufficient professional development—especially in the Global South. These factors lead to persistent skills gaps, weak employability outcomes and graduate unemployment [13]. Correspondingly, strengthening instructor capacity and pedagogical readiness, therefore, remains a recurrent challenge in aligning technical vocational education and training (TVET) systems with Industry 4.0 requirements [14].

In Ethiopia, plans for national development emphasize industrialization and technological upgrading, rendering the TVET sector a major driver of skilled human-capital formation. Yet, empirical evidence about higher-level TVET instructors' awareness of Industry 4.0 and their preparedness to incorporate related technologies into instructional practice is scarce. This lag hampers initiatives to match vocational education with national industrial transformation objectives and global technological change.

Thus, this study assesses Ethiopian higher level TVET trainer's perception and

preparedness to Industry 4.0; identifies challenges experienced by these TVET trainers' ability for Industry 4.0 and explores strategies to promote instructors capability that are required in the industry. Offering empirical evidence on instructors' awareness of technology, exposure to training and confidence in the use of instructional philosophy, this study contributes toward the literature concerning technical pedagogy and provides policy- and practice-oriented implications that can enhance the responsiveness of vocational education and training systems to Industry 4.0.

## 2. Methodology

### 2.1. Research Design

This study employs a cross-sectional mixed-methods research design employing convergent parallel approach to explore instructors' awareness, training exposure and readiness for the integration of Industry 4.0 in higher Technical and Vocational Education and Training (TVET) institutions in Ethiopia. In this study, "higher-level TVET" refers to post-secondary technical and vocational education programs that provide advanced occupational and technological training beyond basic vocational certification levels in Ethiopian public TVET institutions. "Industry 4.0 awareness" refers to instructors' familiarity with Industry 4.0 concepts and related digital technologies such as artificial intelligence, Internet of Things, and data-driven systems. "Readiness" refers to instructors' perceived pedagogical, technological, and institutional preparedness to integrate Industry 4.0 concepts into teaching and training practices. As grounded in pragmatic research paradigm, the design facilitates using multiple sources of quantitative and qualitative evidence to tackle the complex and any-dimensional nature of Industry 4.0 readiness within a sociotechnical context. This dimension is especially relevant because of the interplay between technologies, humans and organization that this study suggests.

A convergent design allows for concurrent collection and separate analysis of both quantitative and qualitative data, with integration during the interpretation phase. Structured, close-ended questionnaire items were used to collect quantitative data with the intent of identifying patterns, relationships and variations in instructors' awareness, training experiences and readiness levels. Simultaneously, qualitative data were collected using open-ended items to gain insight into participants' explanatory views and contextual information. Using a cross-sectional design provides the opportunity to efficiently assess current conditions and perceptions among a diverse array of instructors at one point in time that adds direct insight into institutional readiness trajectories. Mixed-methods design is often empirically superior since it applies triangulation, which increases the reliability and validity of quantitative results, while also bolstering the credibility and trustworthiness of qualitative evidence.

This study utilizes individual TVET instructors as the unit of analysis where perceptions and experiences offer much needed insights into institutional readi-

ness for Industry 4.0. Moreover, research design is intentionally based on the socio-technical systems framework that enables an integrated analysis of human capabilities as well as technical and organizational training aspects. Such an alignment contributes to deeming Industry 4.0 readiness as an emergent characteristic of interplaying attention that is system elements, rather than a technical one. In accordance with recognized mixed-methods approaches [15], the chosen design offers a strong and integrated approach for investigating how awareness, training exposure and institutional conditions together influence instructors' Industry 4.0 readiness in Ethiopia's TVET setting.

## 2.2. Population and Sample

The study sampling frame comprised instructors from five public higher-level TVET institutions across selected regions of Ethiopia. Eligible participants were identified with the support of institutional administrators based on their active involvement in technical and pedagogical instruction. Invitations to participate were distributed through institutional communication channels and direct researcher contact. In total, 85 instructors were invited to participate, and 68 questionnaires were returned. Following screening for completeness and eligibility, 63 valid responses were retained for the final analysis. Participants were selected through a purposive sampling strategy in accordance with predetermined eligibility criteria: (i) provision of high-level programs under the TVET scheme, (ii) directly involved in the delivery of technical and/or pedagogical training, and (iii) availability for participation in the study.

This sample includes instructors with a range of technical expertise, pedagogical styles, and teaching experience helping to ensure heterogeneous contextual coverage of responses regarding Industry 4.0 readiness within the TVET system. Although the sampling strategy is not probabilistic and, therefore, does not produce results that can be generalized to populations at large, it is methodologically appropriate for exploratory and mixed-methods research where participants have expert knowledge/specialized domain knowledge relevant to the phenomenon being studied.

While the sampled size is relatively limited but still sufficient to allow for descriptive and exploratory correlation analysis as well as non-parametric statistical methods typically used in educational and social research. When conducting mixed-methods studies, sample adequacy is evaluated on the grounds of statistical power but also whether sufficient integration between quantitative patterns and qualitative insights can be achieved. This presentation aligns with recognized methodological guidance [16], which encourages analytical nuance and contextual interpretation in applied research settings.

## 2.3. Instrumentation

In this study, data were collected through a self-administered structured questionnaire developed to evaluate, in preparation for Institute 4.0 adaptation within the

TVET landscape. The literature on industry 4.0 readiness, vocational education as well as socio-technical systems formed the backbone of items for this instrument which were later adapted and contextualized to reflect on the Ethiopian Technical Vocational Education and Training context. The instrument structure is closely tied to the variables reported in section results, ensuring that what was measured aligned with what is reported.

The questionnaire contained five sections that included both structured and semi-structured items. The demographic variables (gender, age, academic qualification, subject specialization and teaching experience) used in the first section to describe respondent profile as well to aid comparative analysis. Section two involved determining awareness of Industry 4.0 with two components: (i) a five-point Likert-scale item asking respondents how familiar they were with Industry 4.0 concepts, and (ii) a multiple-response-item where respondents selected known Industry 4.0 technologies. Artificial intelligence, Internet of things, programming/software and data analysis were among the technologies listed by those who had been seeking to recruit, mirroring the categories reported in results. The third subsection was regarding training exposure and perceived effectiveness. Training exposure was assessed with a yes/no item regarding whether or not any Industry 4.0-related training programs were attended. A five-point Likert-scale item tapped (for people reporting participation) the perceived effectiveness of such training. This conditional design guaranteed that not everyone answered questions regarding training effectiveness, increasing the validity of responses.

The fourth section evaluated readiness to integrate into Industry 4.0, based on several Likert-scale items representing the essential components of educational and institutional dimensions involved in this process, as per the research results. These used teaching methods effectiveness, frequency of curriculum updates, the degree of fit between curricula and Industry 4.0 requirements, use of instructionally sound technologies and confidence in instructing on industry-related programs as measures. Also, challenges in the integration of Industry 4.0 were identified as multiple-response items, including, limited industry partnership or collaboration, instructor skill gap (training), resources restriction and outdated curriculum etc. These measures reflect operationalization of readiness as a multidimensional construct consisting of pedagogical, technological, and organizational aspects. Specifically, pedagogical readiness was measured through items assessing teaching methods effectiveness and confidence in teaching Industry 4.0-related topics. Technological readiness was represented through instructional technology use. Organizational and curricular readiness were measured through curriculum update frequency, curriculum alignment with Industry 4.0 requirements, and perceived institutional challenges such as limited industry collaboration and insufficient training opportunities.

The fifth section included two open-ended questions designed to elicit qualitative data on (a) educators' roles in improving Industry 4.0 readiness, and (b) interventions that could be implemented at the system level to support it further.

These responses particularly informed the identification of themes such as professional development, engagement with industry, reforming curriculum, strengthening infrastructure and policy support that helped make the quantitative results richer. All items using a Likert-scale (scale ranging from 1 = very low/not effective to 5 = very high/very effective). The scale had been chosen since it was well established in educational research and balanced sensitivity with response reliability. In general, the development of the instrument aspired to ensure such conformity between conceptual constructs, item measurements and analytical outputs as to augment both validity and interpretability of findings.

To enhance content validity, the questionnaire was reviewed by three experts in TVET, educational research, and Industry 4.0-related fields. The reviewers evaluated item clarity, contextual relevance, and construct alignment. Based on their feedback, minor revisions were made to wording, sequencing, and item organization. A pilot test was conducted with 12 instructors who were not included in the final study sample to assess item clarity, comprehensibility, and feasibility of administration. Feedback obtained during the pilot phase resulted in refinement of several questionnaire items and improvement of response instructions. Internal consistency reliability of the Likert-scale items was assessed using Cronbach's alpha. The overall reliability coefficient for the readiness-related scale was  $\alpha = 0.84$ , indicating good internal consistency and acceptable reliability of the instrument.

Data were acquired using a structured questionnaire in both electronic and paper-based formats to accommodate institutional conditions and participants' accessibility. Data were collected from the selected TVET institutions in Ethiopia over a four-week period during [September-November, 2025]. All participants received a thorough description of the study purpose, procedures and respondents rights before completing the questionnaire. All participants provided informed consent, and were reminded that participation was completely voluntary and they could withdraw at any time without penalty. In order to increase the response rate, reminders for participation were sent during the data collection phase. The researcher collected returned questionnaires and kept them securely for the purposes of analysis. Confidentiality and anonymity were protected by omitting personally identifiable data and utilizing aggregate reporting.

## **2.4. Data Collection Procedure**

The questionnaire was distributed in electronic and paper-based formats, according to institutional access and preference of the participants. Respondents were notified of the study's purpose, assured confidentiality, and given informed consent before participating. All participating institutions were required to collect this data over a predetermined time period.

## **2.5. Data Analysis**

### **2.5.1. Quantitative Analysis**

Quantitative data were analyzed using IBM SPSS Statistics (Version 20). Descrip-

tive statistics (frequencies, percentages, means and standard deviations) were calculated to summarize the key variables of interest in the analyses, including respondents' demographic background characteristics; Industry 4.0 awareness; training exposure and perceived effectiveness; and integration readiness reported in the results.

Categorical variables of interest (gender, age group, educational qualification, subject area, participation in training) as well as Likert-scale responses distributions on familiarity and perceived effectiveness were described using frequencies and percentages. For the continuous Likert-scale variables (familiarity with Industry 4.0; perceived training effectiveness; effective teaching methods; frequency of curriculum update based on Industry 4.0 developments; curriculum alignment with modern demands/industry inputs) as well as use of instructional technology and teaching confidence, mean scores and standard deviations were computed.

In multiple-response items, like identification of Industry 4.0 technologies and perceived challenges in integration, percentage of cases method was used to accurately present information on the proportion of respondents who selected each choice. This might make possible the identification of dominant technologies (for example, artificial intelligence, Internet of Things) and key institutional challenges (for instance, limited industry collaboration and insufficient instructor training), as we show in the results.

Shapiro-Wilk (SW) test, alongside the inspection of skewness and kurtosis values was applied to assess normality before conducting inferential analysis for pertinent variables especially instructional technology use as well as teaching confidence. This justified the use of non-parametric techniques, since the results showed non-normal distributions. Thus, Spearman's rank-order correlation coefficient ( $\rho$ ) was used to assess the relationship between the use of instructional technology and instructors' self-efficacy in teaching Industry 4.0-related topics. The association was analyzed to interpret the strength of relationship based on traditional cut-off values: a moderate, positive correlation. Then  $p < 0.05$  for statistical significance was used. 05 level while maintaining strictness methodological, at the appropriate inference.

### 2.5.2. Qualitative Analysis

Qualitative data obtained from the two open-ended questions were analyzed using an inductive thematic content analysis approach. The analytical process was systematic and iterative, consistent with the qualitative findings reported in the study. A total of 58 respondents answered the first open-ended question concerning instructors' roles in supporting Industry 4.0 readiness, while 55 respondents responded to the second question regarding strategies for improving system-level readiness. The coding process was conducted by the researcher through repeated reading of responses and open coding procedures to identify meaningful patterns and recurring ideas. To enhance coding consistency, codes and thematic categorizations were continuously reviewed and compared across responses to ensure conceptual coherence and alignment. Where ambiguities or overlaps emerged,

coding categories were refined through iterative examination and reorganization of the data.

First, responses were initially read and repeatedly re-read to familiarization with the data. Secondly, open coding was performed to extract meaningful segments related to instructors' roles and system-level improvement needs. Third, similar codes were categorized into broader conceptual categories based on semantic similarity. These categories were then synthesized into higher-level themes, which were reported descriptively.

This process led to distinction of the main themes described in the results, which relate to: continuous professional updating; practice-oriented instruction; engagement with industry; curriculum alignment; change facilitation; reform of curricula; development of trainers capacity building; infrastructure and resources; as well as policy and funding support. These themes represent the person levels and system level aspect of Industry 4.0 preparation.

## 2.6. Ethical Considerations

The ethical principles of voluntary participation, informed consent and confidentiality were upheld during the study. No personal information was collected, and data were used for research purposes only.

## 3. Results

The results of the study are shown in this section, using descriptive quantitative analysis strengthened by qualitative responses summarized. Results are categorized according to the research objectives across four domains: (1) demographic characteristics, (2) awareness of Industry 4.0, (3) training exposure and perceived effectiveness, and (4) integration readiness for Industry 4.0. (5) Qualitative results based on open-ended responses are reported descriptively in a separate subsection.

### 3.1. Demographic Characteristics of Respondents

Overall demographic profile of respondents ( $n = 63$ ) is presented in **Table 1**. Over half of the participants were male (84.1%) and receiving users aged 35 - 44 years old (60.3%). Most respondents possessed master's degree (77.8%); 22.2% had doctoral qualifications. The most, at 71.4%, were technical based teachers. Almost half of the participants (47.6%) had over 15 years of teaching experience.

**Table 1.** Demographic profile of respondents ( $N = 63$ ).

Variable	Dominant group (%)	Other groups (%)
Gender	Male (84.1)	Female (15.9)
Age	35 - 44 (60.3)	45 - 54 (20.6); 25 - 34 (14.3); 55+ (4.8)
Education	Master's (77.8)	PhD (22.2)
Subject area	Technical (71.4)	IT (11.1); Pedagogy (9.5); Math/Science (1.6)

### 3.2. Awareness of Industry 4.0

#### 3.2.1. Familiarity with Industry 4.0

Mean reported familiarity was 3.56 (SD = 1.15) on a five-point scale among respondents (Table 2). The majority of respondents (84.2%) showed moderate or higher awareness of Industry 4.0 concepts.

**Table 2.** Familiarity with Industry 4.0 (N = 63).

Familiarity level	N	%
Not familiar at all	4	6.3
Slightly familiar	6	9.5
Moderately familiar	19	30.2
Familiar	19	30.2
Very familiar	15	23.8
Mean (SD)	—	3.56 (1.15)

#### 3.2.2. Awareness with Industry 4.0 Technologies

As shown in Table 3, respondents identified the Industry 4.0 technologies. The most commonly identified technology was artificial intelligence (73.8%) and Internet of Things (54.1%).

**Table 3.** Industry 4.0 technologies identified by respondents (multiple responses).

Technology	n	% of cases
Artificial intelligence	45	73.8
Internet of things	33	54.1
Programming & software	18	29.5
Soft skills	18	29.5
Data analysis	16	26.2
Other	3	4.9

### 3.3. Training Exposure and Perceived Efficacy

Table 4 shows respondents' participation in Industry 4.0-related training and perceived effectiveness of training. Of the respondents, 55.6% stated that they had participated in at least one Industry 4.0 training program. For trained respondents (n = 35), the average perceived effectiveness score of the training was 3.43 (SD = 1.16).

**Table 4.** Industry 4.0 training exposure and perceived effectiveness.

Indicator	N	%
Training participation		
Yes	35	55.6
No	28	44.4

**Continued**

Perceived effectiveness (n = 35)		
Not effective at all	2	5.7
Slightly effective	3	8.6
Moderately effective	12	34.3
Effective	10	28.6
Very effective	8	22.9
Mean (SD)	—	3.43 (1.16)

**3.4. Integration Readiness for Industry 4.0****3.4.1. Factors Related to Teaching Methods and Curriculum**

**Table 5** shows the rating of respondents for each teaching methods effectiveness and how often is curriculum updated, also how aligned to Industry 4.0 the curriculum are in their opinion found. Mean scores varied from 2.73 to 2.94.

**Table 5.** Teaching methods and curriculum readiness indicators (N = 63).

Indicator	Mean	SD
Teaching methods effectiveness	2.94	0.97
Curriculum updates frequency	2.87	1.04
Curriculum alignment with Industry 4.0	2.73	1.05

**3.4.2. Challenge in Integration of Industry 4.0**

This can be observed in **Table 6**, which presents the problems faced by respondents in including Industry 4.0 into TVET programs. The most frequently reported challenges were as follows: limited collaboration with industry (45.2%), insufficient training of the instructors (29.0%).

**Table 6.** Challenges in integrating industry 4.0 into TVET (multiple responses).

Challenge	n	% of cases
Limited industry collaboration	28	45.2
Insufficient instructor training	18	29.0
Lack of resources/equipment	11	17.7
Outdated curriculum standards	5	8.1
Other	2	3.2

**3.4.3. Using Technology and Confidence in Instructions**

Spearman's rank-order correlation analysis revealed a statistically significant moderate positive association between instructional technology use and confidence in teaching Industry 4.0-related topics ( $\rho = 0.53$ ,  $p < 0.001$ ,  $n = 63$ ). This finding suggests that higher levels of instructional technology utilization were associated with greater perceived instructional confidence among respondents (See **Table 7**).

**Table 7.** Technology use and instructional confidence related to **industry 4.0** (N = 63).

Variable	Mean	SD	1	2
Use of instructional technologies	3.43	0.96	—	
Confidence in teaching industry 4.0 topics	3.41	1.01	$\rho = 0.53, p < 0.001$	—

### 3.5. Qualitative Results

Open-ended responses also focused on (a) perceived roles of TVET trainers in terms of Industry 4.0 readiness, and (b) suggestions for actions to increase system-level readiness. We used inductive thematic content analysis to analyze responses. Responses were coded and categorized according to their semantic similarity (*i.e.*, identifying recurrent response patterns). Findings are presented descriptively (See **Table 8**).

**Table 8.** Summary of qualitative categories identified from open-ended responses.

Theme	Description
Continuous professional updating	Regular upgrading of trainers' technical and digital skills
Practice-oriented instruction	Use of hands-on, project-based, and applied learning approaches
Industry engagement	Collaboration with industry and exposure to real work practices
Curriculum alignment	Alignment of training content with Industry 4.0 requirements
Change facilitation	Supporting adaptation to technological change
Curriculum reform	Revision of curricula to integrate Industry 4.0 concepts
Trainer capacity building	Professional development and training-of-trainers
Infrastructure and resources	Modern equipment, laboratories, and digital tools
Policy and funding support	Strategic leadership, policy clarity, and resource allocation

Integration of the quantitative and qualitative findings revealed a consistent pattern regarding limited Industry 4.0 readiness within Ethiopian TVET institutions. Quantitative results demonstrated moderate awareness levels but comparatively lower readiness indicators related to curriculum alignment, instructional preparedness, and institutional collaboration. These findings were reinforced by qualitative responses emphasizing insufficient professional training, weak industry engagement, limited infrastructure, and the need for curriculum reform. Together, the two datasets suggest that while instructors conceptually recognize the importance of Industry 4.0, institutional and structural constraints continue to limit practical implementation readiness.

## 4. Discussion

The study explored higher TVET instructors' awareness and training exposure

towards, and readiness for the integration of Industry 4.0 into the Ethiopian vocational education context. This discussion is framed in a parallel formation to the Results section such that there is a clear line of causation between empirical evidence and typification whilst anchoring findings within salient TVET practice and policy considerations.

#### **4.1. Demographic Characteristics and Implications for Industry 4.0 Readiness**

The demographic profile indicates a predominantly mid-career, technically heavy TVET instructional workforce with significant years of teaching experience. These features reflect institutional continuity and the accumulation of pedagogical expertise, which might provide a stabilizing force to the system through periods of technological transformation. Yet, Industry 4.0 measures the extent to which academic institutions with tenured faculty who have some experience in teaching are equipped to respond, while also arguing that merely teaching does not automatically lead to readiness for Industry 4.0 and highlighting the centrality of continuous learning, where constant exposure to emerging technology is needed through ongoing professional experience.

The notable underrepresentation of younger instructors and women suggests that there may be systemic imbalance in our instructor universe which could limit diversity of perspectives and diminish institutional agility. Limited demographic diversity within TVET will likely hinder pedagogical experimentation and innovation due to a narrow mindset and unwillingness to try new approaches in this era of rapid technological evolution.

#### **4.2. Awareness of Industry 4.0 and Its Technological Dimensions**

The results suggest that teachers have an idea about Industry 4.0 concepts, more evident for the well-characterized technologies such as: AI (artificial intelligence) and IoT (internet of things). Conversely, lower prioritization of transversal competencies, including data analytics and integrated software systems indicates selective rather than holistic digital awareness. This pattern indicates that Industry 4.0 exposure may be mediated by popular narratives, short-term training projects and media-oriented focus on flagship technologies instead of ongoing interaction with the wider technological fabric upon which Industry 4.0 is built. Such a fragmented awareness may hinder instructors from developing integrated, systems-oriented learning experiences that are aligned with current cyber-physical and data-driven industrial environments.

#### **4.3. Training Exposure and Perceived Effectiveness**

Instructor participation in training was moderate and perceived effectiveness varied widely. This variation suggests that current training bullets may vary greatly in respect of relevance, level of depth and application to instructional contexts. Indeed, evidence emerging from the professional development literature suggest

that to effectively prepare educators for Industry 4.0 readiness there needs to be models of training that embed technologies in pedagogical adaptation and support for sustained collaboration with industry rather than focusing on workshops with incidental engagement or abstract theoretical learning [17]. Therefore, training pedagogies that integrate these elements together help to increase teaching confidence and facilitate authentic classroom delivery of Industry 4.0 topics.

#### **4.4. Readiness for Industry 4.0 Integration**

##### **Factors Related to Teaching methods and the Curricula**

The range of intermediate levels indicates that considerations regarding Industry 4.0 are beginning to permeate instructional practice, particularly in methods of teaching, practices for updating the curriculum, and alignment between the curriculum and pedagogical approaches, but have as yet not fully synthesized into a coherent approach to institutionalizing this consideration across courses or disciplines. In technology-heavy industries, curriculum alignment is inherently iterative and reliant on industry feedback in a timely fashion as demand for skills evolve. Instructors reporting moderate readiness may be facing structural limitations, such as centralized processes for revising a course curriculum that lack the nimbleness to adapt to rapidly advancing technologies. Without mechanisms that allow instructors to modify the curriculum with relative ease, they may resort to piecemeal pedagogical modifications instead of more systematic, instructional redesign.

##### **Structural and Institutional Challenges**

Reported obstacles, such as limited industry engagement and lack of instructor training opportunities, suggest systemic challenges rather than individual failings. Weak institutional connections with industry may limit teachers' access to real-world technology implementations, and insufficient professional development opportunities can stall the cultivation of instructional confidence toward Industry 4.0 readiness. Resolving these challenges involves institutional-level approaches that prioritize sustained engagement with industry collaborators and working professionals as well as organized professional development integrated into current technological practices.

##### **Technology Utilization and Pedagogical Self-efficacy**

The use of instructional technologies is positively correlated with confidence in teaching Industry 4.0 topic areas, implying that hands-on exposure to digital tools serves a reinforcing influence on instructor preparedness. Taken together these studies suggest that the regular use of instructional technologies may reinforce both technical familiarity and pedagogical self-efficacy. These findings indicate that professional learning environments in which there is a substantial emphasis on hands-on experimentation and contextualized use of technology can make a meaningful contribution to instructional confidence and classroom effectiveness.

#### **4.5. Qualitative Insights on Roles and System-Level Improvement**

Qualitative responses further illuminate quantitative results by underscoring in-

structors' perceptions of their roles in support of Industry 4.0 readiness. Trainers stressed the need for regular professional upskilling, practice-based teaching, and greater industry engagement as part of an active role in institutional change rather than passive implementation of policy. At the level of the system, policy priorities like curriculum overhaul, training capacity injection, infrastructure building and policy support suggest some awareness that Industry 4.0 readiness is less a component game than an ecosystem one. These priorities reflect international TVET reform frameworks which identify coherent policy direction, sustained investment and coordinated stakeholder engagement as preconditions for digital transformation [18]. The synergetic effects of qualitative and quantitative findings reinforce the trustworthiness of the study's conclusions and highlight how mixed-methods approaches can be beneficial for exploring Industry 4.0 readiness in TVET settings. Despite being specific to the Ethiopian TVET system, the analytical insights presented can have more generalized relevance for other developing-country settings experiencing institutional and technological constraints.

#### **4.6. Limitations of the Study**

This study has several limitations that should be considered when interpreting the findings. First, the use of purposive sampling and the relatively small sample size limit the generalizability of the results beyond the participating institutions. Second, the study relied primarily on self-reported perceptions of awareness and readiness, which may be influenced by social desirability bias or subjective interpretation. Third, the cross-sectional design captured participants' views at a single point in time and therefore does not allow examination of changes in readiness over time or causal relationships among variables. Despite these limitations, the mixed-methods approach provided valuable contextual and exploratory insights into Industry 4.0 readiness within Ethiopian higher-level TVET institutions.

#### **5. Conclusions**

The present study is about the perception and preparedness of Ethiopian higher TVET instructors regarding Industry 4.0 in the dimensions which include conceptual awareness, training opportunities, pedagogical practices, curriculum alignment and integration of instructional technologies. The results indicate that educators generally hold moderate to high awareness of the concepts, particularly those defined by Industry 4.0 from artificial intelligence (AI) and Internet of Things (IoT); however, their overall readiness to teach or deliver curricula using this technology is still limited. Plus, this awareness-readiness gap represents a system in transition with inadequate levels of structural, technological, and pedagogical support to move toward full Industry 4.0 alignment. Training opportunities for most of the participants are indeed available, but there is significant variability in both quantity and quality, suggesting that a standardized and systematic framework on professional development is missing. In the same light, low performance on curriculum updates and alignment with Industry 4.0 standards are observed as

persistent weaknesses of Ethiopian TVET teaching and curricula infrastructure. Compounding these limitations are systemic barriers in the form of poor industry collaboration, inadequate trainer upskilling and limited access to technological resources.

Given these challenges, instructors show positive perceptions about technology use and the strong correlation between confidence in using technologies and practice suggests that increased exposure to digital tools will bolster overall readiness. The strategies that are already in use—namely, partnerships with industry and professional development—are promising avenues for improvement but need to be bolstered by institutional- and policy-level support for sustainable change. In general, the study finds Ethiopian higher TVET institutions to be conceptually aligned but practically under preparation for the Industry 4.0 imperatives. Closing this gap will need coordinated action by policymakers, training institutions and industry partners. They need targeted investments in trainer development, curriculum reform and technological infrastructure that allow TVET instructors to gain the skills required to train a future-ready workforce aligned with Ethiopia's ambitions of industrialization; structured industry engagement that provides an effective feedback mechanism so curricula remain relevant; and institutional capability-development resources that improve their training abilities.

### Author Contribution

The authors confirm sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

### Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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