International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Beyond Digital Access: An Exposure Audit of Industry 4.0 Learning among 1,025 Students in Malaysian Accredited TVET Programmes

Mohd Nor Azlan Mohamed Sidek[1], Zulkifflee Mohamed[2], Mohammed Reyasudin Basir Khan[3], Mohd Ridhuan Mohd Jamil[4], Zainisah Abdullah[5], Thanapauge Chamaratana[6]

[1,2,3]Tun Razak Graduate School, Universiti Tun Abdul Razak, Malaysia
[4]Faculty of Human Development, Universiti Pendidikan Sultan Idris, Malaysia
[5]Humex Malaysia Skills Development Sdn. Bhd., Malaysia
[6]Faculty of Humanities and Social Sciences, Khon Kaen University, Thailand

Abstract

Digital transformation in technical and vocational education and training (TVET) is often evaluated through technology availability, although access alone does not show whether learners receive sustained and occupationally relevant Industry 4.0 practice. This study audited digital access, learning arrangements, and technology-supported learning exposure among 1,025 students enrolled in Malaysia's Accredited Programme Training System (Sistem Latihan Program Bertauliah; SLaPB) under the Malaysian Skills Certification System. A cross-sectional bilingual online survey captured eight categorical indicators covering prior experience, current programme exposure, learning mode, primary device, internet quality, and four-week use of digital platforms, simulation-related practical activities, and digital assessment. Frequencies, transparent category combinations, and percentage-point contrasts were calculated; no causal or person-centred class claims were made. Moderate or high prior experience was reported by 57.1% of respondents, and 63.5% experienced digital or Industry 4.0-supported learning often or very often. Face-to-face provision remained the main mode for 55.5%, while 44.5% studied in blended, hybrid, or mostly online arrangements. Smartphone-only or shared devices were the primary resource for 31.7%, and 32.1% reported poor or moderate internet access. At least weekly use was reported for digital platforms by 73.8%, simulation-related practical activities by 64.0%, and digital assessment by 74.0%. Thus, simulation-related activity was approximately 10 percentage points less prevalent than platform use and digital assessment at the same threshold. The findings indicate substantial digital reach alongside persistent material constraints and a less intensive layer of authentic technology-supported practice. TVET digitalisation should therefore be monitored through separate indicators of access, learning arrangement, and activity-specific exposure rather than a single technology-adoption measure.

Keywords: Industry 4.0, Technical and Vocational Education and Training, Digital Access, Simulation-Based Learning, Digital Divide, Malaysia

1. Introduction

Industry 4.0 is reshaping occupational work through connected production, automation, artificial intelligence, smart systems, data-intensive decision-making, and digitally mediated collaboration. These developments do not remove the need for occupational expertise; they change how technical knowledge is applied, monitored, communicated, and improved. Reviews of Industry 4.0 skills consistently identify combinations of technical capability, digital competence, problem solving, adaptability, collaboration, and continuous learning [1, 2, 3]. Recent Malaysian TVET studies likewise emphasise the need to prepare future-fit learners for technology-rich workplaces and work-based learning environments [4, 5].

Education 4.0 literature treats digital transformation as a redesign of learning systems rather than a simple procurement exercise. It links technology with flexible provision, authentic problems, learner agency, data-informed feedback, collaboration, and closer relationships between education and work [6, 7, 8]. In TVET, this system perspective is particularly important because learning occurs across classrooms, workshops, laboratories, workplaces, online platforms, and competency assessments. A learning management system can distribute resources, but it does not by itself provide practice with smart equipment. A digital test can make assessment more efficient, but it does not demonstrate that students have operated a simulation, interpreted process data, or solved an authentic occupational problem.

The digital-divide literature provides a useful warning against treating access as a binary condition. Early work highlighted the psychological and capability dimensions that accompany internet access [9]. Subsequent research distinguished physical access from material access, including the quality, autonomy, and suitability of devices and connections, and from inequalities in skills, uses, and outcomes [10, 11]. This layered view is directly relevant to TVET. A student may technically be connected yet depend on a smartphone for tasks designed for a laptop, share a device with others, or have a connection that is adequate for messaging but unreliable for interactive simulation, video demonstration, cloud-based design, or large-file submission. Conversely, a learner with reliable hardware may still receive little exposure to occupationally relevant digital practice.

A second distinction concerns learning arrangement. Face-to-face, blended, and mostly online provision describe where and how learning is organised; they do not provide a direct measure of instructional quality. Face-to-face provision may be indispensable for safety-critical workshop practice and access to specialised equipment. Blended provision may extend preparation, reflection, collaboration, and feedback beyond the workshop. Mostly online provision may support some knowledge and simulation activities while remaining unsuitable for competencies requiring physical tools, materials, or supervised performance. The relevant question is not whether one mode is universally superior, but whether each arrangement gives learners equitable and sufficiently frequent opportunities to engage in the intended competency practices [6, 8].

A third distinction concerns the type and intensity of technology-supported activity. Digital platforms, simulations, virtual laboratories, augmented or virtual reality, technology-supported practical work, and digital assessment serve different educational functions. Simulation can support repeated practice, process visualisation, experimentation with rare or hazardous scenarios, and feedback before performance in a physical environment. Meta-analytic and systematic-review evidence indicates that simulation and immersive environments can support learning when tasks, scaffolding, feedback, and reflection are well designed [12, 13, 14, 15]. Learning factories similarly demonstrate how digital systems can be connected with realistic production tasks [16, 17]. Recent Malaysian evidence on a multimodal virtual-reality and learning-management-system framework further illustrates the value of connecting immersive tools with engagement, practical training, and skill assessment [18]. These benefits cannot be inferred from institutional ownership of technology; they depend on student exposure and pedagogical use.

This issue is prominent in Southeast Asia, where TVET systems are responding to rapid industrial digitalisation while operating across institutions with different resources, instructor capabilities, employer links, and learner populations. Regional analyses call for stronger institutional responses, enterprise partnerships, and attention to digital divides rather than assuming that technology diffusion will be even [19, 20, 21]. Malaysia's National Fourth Industrial Revolution Policy, New Industrial Master Plan 2030, and National TVET Policy 2030 likewise position digital capability, industry relevance, and inclusive skills development as strategic priorities [22, 23, 24]. Student-level evidence is needed to show how these priorities appear in actual learning arrangements.

Existing studies and policy documents provide extensive accounts of required competencies, institutional transformation, digital pedagogy, and readiness. Less attention is often paid to the joint descriptive pattern of students' material access, programme modality, prior experience, and activity-specific frequency. Institution-level claims such as 'digital learning is implemented' can conceal substantial differences between regular platform use and regular simulation-supported practical activity. Overall means for self-efficacy, engagement, or readiness can also obscure the conditions under which learning occurs. Before asking whether digital exposure predicts an outcome, a defensible evidence base should establish what kinds of exposure are present, how frequently they occur, and which access constraints remain.

The present study addresses that descriptive need using profile data from 1,025 students in the Accredited Programme Training System, known in Malay as Sistem Latihan Program Bertauliah (SLaPB), under the Malaysian Skills Certification System (MSCS/SPKM). It conceptualises digital participation as three connected but non-equivalent layers: access resources, learning arrangement, and activity-specific exposure. The article deliberately uses the term profile to mean a sample-level distribution across these layers. It does not claim that statistically distinct latent classes of students were identified, because such a claim requires analysis of joint individual response patterns rather than marginal frequencies.

Three research questions guide the study. RQ1 asks: What levels of prior digital or Industry 4.0 experience and current programme exposure did SLaPB students report? RQ2 asks: How were students distributed across learning modes, primary learning devices, and usual internet-access quality? RQ3 asks: How frequently did students use digital learning platforms, simulation-related practical activities, and digital assessments, and what marginal differences were visible across these activity types? By answering these questions, the study contributes an exposure-audit framework that separates technology reach from authentic practice and from learning outcomes. This distinction can support more precise institutional monitoring, resource allocation, and future person-centred analysis.

2. Conceptual Background

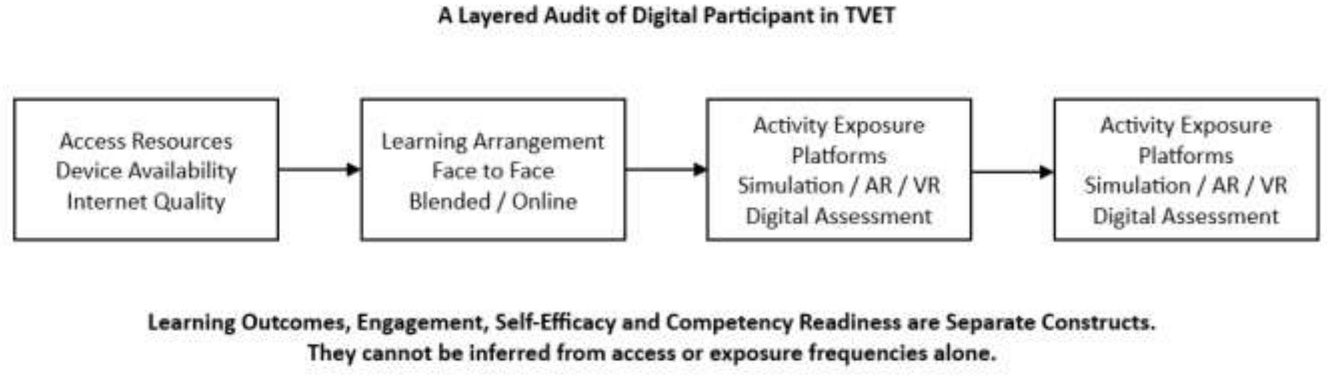
2.1 A Layered View of Digital Participation

Digital participation is frequently compressed into a single indicator such as device ownership, internet access, platform use, or self-rated digital competence. Each indicator captures something important, but none is sufficient by itself. Digital inequality research shows a progression from whether people can connect, to what material resources they can use, to the skills and purposes of use, and ultimately to the benefits obtained [10, 11]. The DigComp framework makes a related distinction by defining digital competence through task domains such as information and data literacy, communication and collaboration, content creation, safety, and problem solving rather than through access alone [25].

For the present study, the first layer is access resources: the device used most often for learning and the quality of the student's usual internet connection. The second is learning arrangement: whether the programme is experienced mainly face to face, through a blended or hybrid arrangement, or mostly online. The third is activity-specific exposure: how often the student uses platforms, simulation-related practical technologies, and digital assessment. The three layers jointly shape opportunity to participate, but they are not a causal sequence established by the data. A learner may, for example, use a campus laboratory despite weak home connectivity, or may have excellent connectivity while enrolled in a largely workshop-based programme.

The framework intentionally stops before engagement, self-efficacy, competency, and employment outcomes. Access and exposure are enabling conditions, not proof of learning. Digital confidence is also conceptually distinct: learners may have access without feeling capable, or feel confident while receiving limited authentic practice [9, 26, 27]. Similarly, perceived competency readiness is not established by frequency alone. This boundary prevents an exposure audit from becoming an untested claim about educational effectiveness.

Figure 1: Layered Access-Arrangement-Exposure Framework Used in the Study



Note. The arrows organise the descriptive layers; they do not represent causal paths tested in this study.

2.2 Material Access: Device Suitability and Connectivity

Material access concerns more than possession. Device type affects screen size, input methods, processing capacity, file management, software compatibility, and the degree of autonomy available to the learner. A smartphone can be highly effective for communication, microlearning, photographs, video, messaging, and quick information access. It may be less suitable as the only device for computer-aided design, coding, complex spreadsheets, detailed technical drawings, multiwindow troubleshooting, or some immersive simulations. A shared device can create scheduling constraints even when the hardware itself is capable. The material-access perspective therefore asks whether the available resource fits the task, not whether one device category is inherently deficient [11].

Connectivity has a similar task-dependent character. A moderate connection may support text and low-resolution media but become unstable during synchronous demonstrations, cloud simulation, large-file upload, or augmented-reality content. The educational consequence depends on instructional design and institutional provision. Downloadable materials, asynchronous alternatives, on-campus connectivity, device-loan schemes, scheduled laboratory access, and low-bandwidth assessment routes can reduce the extent to which household resources determine participation. Whole-institution digital-competence approaches are valuable because they coordinate infrastructure, curriculum, instructor support,

assessment, and partnerships rather than placing responsibility solely on individual students [28]. Recent evidence from corporate technical education similarly identifies communication, instructional design processes, role clarity, and learner characteristics as central to digital transformation [29].
Access measures should also be interpreted in relation to sampling. The present sample included only students who were able to report relevant digitally supported learning. It therefore cannot estimate the prevalence of complete digital exclusion across all SLaPB learners. Its value is different: it identifies material constraints that remain even within an eligible exposure group. Such constraints can affect the intensity, convenience, and autonomy of participation despite nominal inclusion.

2.3 Learning Arrangement Is Not Learning Quality

Modality labels are often used as proxies for digital transformation, but face-to-face, blended, and online arrangements can contain very different instructional experiences. A face-to-face programme may use advanced simulation, smart equipment, digital dashboards, or electronic assessment in workshops. A blended programme may integrate online preparation with authentic supervised performance. Mostly online programme may offer sophisticated virtual laboratories, or it may rely heavily on document distribution. Consequently, learning mode should be analysed as a contextual arrangement rather than a quality ranking.
This distinction is especially important in competency-based TVET. Many occupational standards require observable performance, safe tool use, material handling, teamwork, and judgement under realistic conditions. Digital provision can prepare, extend, document, and enrich those activities, but it may not replace all physical practice. Education 4.0 reviews accordingly emphasise flexible combinations of physical and digital environments, industry connection, authentic tasks, and learner-centred design [6, 7, 8]. The descriptive distribution of learning modes can therefore show how transformation is being organised without assuming that a larger online share is automatically more advanced.

2.4 Activity-Specific Exposure and the Authenticity Gradient

Technology-supported activities differ in proximity to occupational performance. Digital platforms commonly organise content, communication, submissions, feedback, and administrative learning processes. Digital assessments can test knowledge, record evidence, provide feedback, or support competency decisions. Simulations, virtual laboratories, AR/VR, and technology-supported practical activities more directly represent processes, equipment, environments, or decisions that learners may encounter in work. These categories overlap, yet their educational purposes are not interchangeable.
Simulation research suggests that repeated, goal-directed practice can be useful when learners receive appropriate guidance and feedback and can connect simulated decisions to underlying principles and later performance. Across higher education, simulation-based learning has shown positive effects, although design features and outcome measures matter [12]. Immersive virtual environments can increase presence and offer experiences that would otherwise be costly, dangerous, or inaccessible, but unnecessary immersion, cognitive overload, technical friction, or weak pedagogy can reduce value [13, 14]. Earlier meta-analytic evidence on computer-based simulation games likewise indicates that instructional context and comparison conditions affect effectiveness [15].
For an exposure audit, frequency is not a measure of quality, duration, or difficulty. One weekly simulation may be an intensive, well-scaffolded exercise, while several platform logins may be brief administrative interactions. Nevertheless, frequency distributions are useful for identifying where routine participation is more or less common. Comparing activity categories at consistent thresholds - such as at least weekly and several times weekly - can reveal a marginal authenticity gradient. If platform and assessment activity are

widespread while simulation-related practice is less frequent, an institution may have achieved digital administration more fully than digitally enriched occupational practice. That interpretation remains provisional until content, duration, pedagogy, and individual co-occurrence are measured.

2.5 Prior Experience, Programme Exposure, and Institutional Responsibility

Students enter TVET with unequal prior opportunities. Some have used digital tools or Industry 4.0 technologies in school, work, hobbies, or earlier study; others encounter them for the first time in their current programme. Prior experience can influence familiarity, confidence, speed, and the amount of scaffolding required, but it should not become an informal admission standard. Digital competence can be developed, and education systems have a compensatory responsibility to provide mastery opportunities rather than assuming that young students are uniformly prepared [30, 25].

Current programme exposure must therefore be considered alongside prior experience. A programme can narrow an incoming gap by providing structured orientation, guided practice, peer support, repeated simulation, and access to suitable devices. It can also reproduce an existing gap if tasks assume capabilities or resources that some learners have not had an opportunity to acquire. Regional TVET analyses identify partnerships, institutional capacity, and coherent digital transformation strategies as mechanisms for expanding these opportunities [19, 20].

The descriptive questions in this study do not test whether current exposure compensates for low prior experience, because the available published profile table contains marginal rather than cross-tabulated distributions. They establish the size of the incoming-experience groups and the overall frequency of programme exposure. A subsequent person-centred or longitudinal study can test whether access and programme design combine into distinct pathways and whether those pathways are associated with engagement, self-efficacy, objective competence, or transition outcomes.

3. Method

3.1 Design, Setting, and Data Provenance

The study used a quantitative, cross-sectional, descriptive survey design. It reports profile variables collected for a doctoral study of Industry 4.0-enabled interactive TVET instructional management, student engagement, digital learning self-efficacy, and perceived competency readiness. The present article has a distinct purpose: it analyses the learning-context variables that were reported descriptively in the thesis and does not repeat the companion manuscripts' structural-model hypotheses or principal path results. The unit of analysis was the individual student.

The empirical setting was the Accredited Programme Training System (Sistem Latihan Program Bertauliah, SLaPB), a structured programme route within the Malaysian Skills Certification System (MSCS/SPKM). The broader system is linked to National Occupational Skills Standards and Malaysian skills qualifications under the National Skills Development Act 2006 [31, 32, 33]. The recorded target population was 39,977 current SLaPB students. The study focused on selected programmes at Malaysian Skills Certificate Levels 2 and 3, Malaysian Skills Diploma Level 4, and Malaysian Skills Advanced Diploma Level 5.

3.2 Sampling and Participants

Sampling combined multistage stratified cluster procedures for the accessible public and agency-based component with criterion-based purposive inclusion of selected private institutions. Institutions and classes were selected across certification levels, agency categories, locations, and skills clusters. This approach improved coverage of a geographically and organisationally dispersed population, while the purposive private-provider component means that the study should not be described as a fully national probability sample [34, 35]. No sampling weights were applied.

Eligibility required current enrolment in the selected SLaPB scope and sufficient experience of digitally supported or Industry 4.0-enabled learning to answer the questionnaire meaningfully. Examples in the screening information included digital learning platforms, simulation, virtual laboratories, AR/VR, smart equipment, technology-supported assessment, and online learning applications. Non-students, graduates no longer enrolled, instructors, administrators, candidates in other certification routes, students outside the selected programme scope, and students without relevant current exposure were excluded.

The final dataset contained 1,025 eligible and complete responses. Men comprised 68.0% of the sample and women 32.0%; 92.0% were aged 19-22 years. Most respondents were enrolled at Level 3 (54.8%), followed by Level 4 (24.0%), Level 2 (16.0%), and Level 5 (5.2%). Government institutions accounted for 93.5% of the sample. Institution areas were urban for 52.9%, semi-urban for 27.0%, and rural for 20.1%. Eighty-four per cent had completed industrial training. These characteristics provide broad multi-institutional coverage but also delimit generalisation, particularly to private providers, older learners, students without any current digital exposure, and other Malaysian skills-certification routes.

3.3 Instrument and Profile Variables

Data were collected with a structured bilingual English-Malay questionnaire. Two screening items established eligibility, 20 items described demographic and learning-context characteristics, and four multi-item sections measured the thesis constructs. This article uses eight profile variables, A13-A20. They were designed as categorical or ordinal descriptors and were not treated as reflective latent scales; internal-consistency statistics are therefore neither necessary nor appropriate for these items.

A13 asked about experience using digital or Industry 4.0 tools before the current programme, with none, basic, moderate, and high response categories. A14 recorded how often digital or Industry 4.0-supported learning occurred in the current programme, from never to very often. A15 identified the principal learning arrangement as face-to-face, blended or hybrid, or mostly online. A16 recorded the primary learning device: personal laptop, desktop, tablet, smartphone only, shared device, or other. A17 assessed usual internet quality for study from very poor to very good.

Items A18-A20 used a four-week recall period. A18 asked about use of a learning management system or other online learning application. A19 asked about simulations, virtual laboratories, AR/VR, or technology-supported practical activities. A20 asked about technology-enabled or digital assessment. Response options were never, one time, two to three times, about once a week, and several times a week. In the retained sample, the frequency tables contained no 'never' responses for A14 or A18-A20, consistent with the current-exposure eligibility criterion. This absence must not be interpreted as evidence that no unexposed students exist in the wider SLaPB population.

3.4 Instrument Review and Pilot Work

Before the main survey, face and content review examined clarity, bilingual meaning, relevance to the SLaPB context, category coverage, and distinctions among access, exposure, instructional, learner, and outcome variables. Reviewers included expertise in TVET, educational technology, measurement, and methodology. The profile items were checked for comprehensibility and for response categories that reflected plausible Malaysian learning arrangements.

A pilot study involved 60 students from four Selangor-based training institutions, with 15 students from each institution. Pilot participants were similar to the target population but were excluded from the main sample. The pilot examined completion flow, timing, wording, missing responses, online-form operation, and potential ambiguity. Reliability estimates were calculated for the four multi-item thesis constructs, not for the single profile items used in this article.

3.5 Data Collection and Ethical Safeguards

The questionnaire was administered online through authorised institutional administrators or coordinators after institutional permission. Students received information about the study purpose, eligibility, voluntary participation, expected completion time, confidentiality, and the right to stop before submission. They were told that participation or non-participation would not affect grades, assessment, certification, institutional relationships, or access to training. Electronic informed consent was required before screening and questionnaire completion. The thesis records a scheduled Monday-to-Friday response window; the exact calendar dates should be inserted in the submission version after verification against the original fieldwork record.

Responses were stored securely and reported in aggregate. Individual students and institutions were not identified in the thesis outputs. Questionnaire sections were separated, item wording was construct-specific, and neutral instructions and confidentiality assurances were used to reduce evaluation apprehension and common-method pressure [36]. The final manuscript must state the verified ethics-review body, approval or exemption reference, and approval date.

3.6 Descriptive Analysis

Frequencies and percentages were calculated for each response category using N = 1,025. Because all displayed categories sum to 1,025, no item-level missing-data adjustment was required for A13-A20. Nominal codes were not averaged, and ordinal categories were not treated as interval scores. The analysis was intentionally descriptive: no causal model, hypothesis test, confidence interval, cluster assignment, or association with engagement, self-efficacy, or readiness was estimated for this article.

Several combined indicators were calculated directly from the reported counts to improve interpretation. None and basic prior experience were combined, as were moderate and high prior experience. Often and very often represented regular broad programme exposure. Blended or hybrid and mostly online represented digitally mediated learning arrangements. Smartphone-only and shared-device categories were combined as a material-access constraint indicator, while poor and moderate internet were combined as a connectivity-caution indicator. These combinations do not imply equivalence within each pair; the original categories remain fully reported.

For A18-A20, 'at least weekly' combined about once a week with several times a week. 'Limited during the previous four weeks' combined one time with two to three times. Marginal percentage-point contrasts compared activity types at the same threshold. Percentages derived from counts may differ by 0.1 point from sums of individually rounded table percentages. The contrasts are descriptive and should not be interpreted as statistically significant differences.

A latent class analysis was not performed for the present manuscript. Latent classes require joint person-level response patterns and formal comparison of competing class solutions. Marginal frequency tables cannot establish that specific combinations - for example, smartphone-dependent but simulation-rich learners - exist in the sample. The word profile is therefore restricted throughout to the aggregate distribution of access, arrangement, and exposure indicators.

4. Results

4.1 Sample Context

Table 1 summarises the respondent context relevant to interpretation. The sample was concentrated among young learners, men, Level 3 students, and government institutions. Almost half of the institutions were in semi-urban or rural areas when those categories were combined (47.1%), and most students had completed industrial training. These features are important because digital access and technology-supported learning may differ across programme stage, occupational cluster, provider type, and location, although subgroup comparisons were not available from the reported marginal tables.

Table 1: Participant Context Relevant to the Exposure Audit (N = 1,025)

Profile area	Category	n	%
Gender	Male	697	68.0
	Female	328	32.0
Age	19-22 years	943	92.0
	23-26 years	82	8.0
Current programme	SKM Level 2	164	16.0
	SKM Level 3	562	54.8
	DKM Level 4	246	24.0
	DLKM Level 5	53	5.2
Institution type	Government	958	93.5
	Private	67	6.5
Institution area	Urban	542	52.9
	Semi-urban	277	27.0
	Rural	206	20.1
Industrial training	Not yet started	164	16.0
	Completed	861	84.0

Note. SKM = Malaysian Skills Certificate; DKM = Malaysian Skills Diploma; DLKM = Malaysian Skills Advanced Diploma. Percentages may not total 100.0 within a variable because of rounding.

4.2 Prior Experience and Current Programme Exposure

Before entering the current programme, 107 respondents (10.4%) reported no experience with digital or Industry 4.0 tools, 333 (32.5%) reported basic experience, 432 (42.1%) reported moderate experience, and 153 (14.9%) reported high experience. Based on counts, 440 students (42.9%) therefore entered with none or only basic experience, whereas 585 (57.1%) reported moderate or high experience. The distribution indicates that substantial prior exposure was common but not universal.

Current programme exposure was more frequent. Digital or Industry 4.0-supported learning occurred rarely for 107 students (10.4%), sometimes for 267 (26.0%), often for 401 (39.1%), and very often for 250 (24.4%). Thus, 651 respondents (63.5%) reported often or very often. The marginal distributions are compatible with programmes providing meaningful current exposure to students with varied starting experience, but the available tables do not show whether the students with low prior experience were the same students receiving frequent current exposure.

4.3 Learning Arrangement

Face-to-face learning remained the main arrangement for 569 respondents (55.5%). Blended or hybrid learning was reported by 344 (33.6%), and 112 (10.9%) studied mostly online. Combined, 456 students (44.5%) experienced blended, hybrid, or mostly online provision. Digital transformation in this sample therefore coexisted with a predominantly physical learning mode rather than replacing it. The data do not indicate the amount of digital activity embedded within the face-to-face category.

4.4 Primary Device and Internet Quality

A personal laptop was the principal learning device for 549 students (53.6%). Desktop computers were primary for 95 (9.3%), tablets for 56 (5.5%), smartphones only for 280 (27.3%), and shared devices for 45 (4.4%). Laptop, desktop, and tablet users together represented 700 respondents (68.3%). Smartphone-only and shared-device users represented 325 (31.7%). This combined indicator identifies potential constraints in task fit or autonomy; it does not establish that every student in those categories experienced difficulty.

Internet quality was described as poor by 75 respondents (7.3%), moderate by 254 (24.8%), good by 457 (44.6%), and very good by 239 (23.3%). Good or very good access was reported by 696 students (67.9%), while poor or moderate access was reported by 329 (32.1%). No 'very poor' responses appeared in the retained table. As with device access, the measure is a global self-report and does not distinguish home, campus, mobile, or task-specific connection quality.

4.5 Activity-Specific Frequency

Digital platform use was frequent for most students. During the previous four weeks, 79 respondents (7.7%) used a platform once, 190 (18.5%) used one two to three times, 359 (35.0%) used one about once a week, and 397 (38.7%) used one several times a week. The at-least-weekly total was 756 (73.8%), while 269 (26.2%) reported only one to three uses.

Simulation, virtual laboratory, AR/VR, or technology-supported practical activity was less intensive at the upper frequency levels. One use was reported by 104 students (10.1%), two to three uses by 265 (25.9%), about weekly use by 355 (34.6%), and several-times-weekly use by 301 (29.4%). At least weekly exposure therefore involved 656 students (64.0%), while 369 (36.0%) reported only one to three uses during the four-week period.

Digital assessment showed a distribution close to platform use. One assessment was reported by 85 respondents (8.3%), two to three by 181 (17.7%), about weekly use by 388 (37.9%), and several-times-weekly use by 371 (36.2%). The at-least-weekly total was 759 (74.0%), and 266 (26.0%) reported one to three uses.

Figure 2 and Table 3 compare the common thresholds. At least weekly simulation-related activity was 9.8 percentage points lower than platform use and 10.0 points lower than digital assessment. At the several-times-weekly threshold, simulation-related activity was 9.3 points below platform use and 6.8 points below digital assessment. Conversely, the one-to-three-times category was 9.8-10.0 points more prevalent for simulation-related activity than for the other two categories. These are marginal contrasts; they do not show whether the same individuals used all three types of activity.

Table 2: Full Digital Access, Learning-Arrangement, and Technology-Exposure Profile (N = 1,025)

Variable	Category	n	%
Previous digital / Industry 4.0 experience	None	107	10.4

Variable	Category	n	%
	Basic	333	32.5
	Moderate	432	42.1
	High	153	14.9
Frequency of digital / Industry 4.0-supported learning	Rarely	107	10.4
	Sometimes	267	26.0
	Often	401	39.1
	Very often	250	24.4
Main learning mode	Face-to-face	569	55.5
	Blended or hybrid	344	33.6
	Mostly online	112	10.9
Primary learning device	Personal laptop	549	53.6
	Desktop computer	95	9.3
	Tablet	56	5.5
	Smartphone only	280	27.3
	Shared device	45	4.4
Usual internet access for study	Poor	75	7.3
	Moderate	254	24.8
	Good	457	44.6
	Very good	239	23.3
Digital learning platform use, past four weeks	1 time	79	7.7
	2-3 times	190	18.5
	About once a week	359	35.0
	Several times a week	397	38.7
Simulation / virtual lab / AR-VR / technology-supported practice, past four weeks	1 time	104	10.1
	2-3 times	265	25.9
	About once a week	355	34.6
	Several times a week	301	29.4
Digital assessment, past four weeks	1 time	85	8.3

Variable	Category	n	%
	2-3 times	181	17.7
	About once a week	388	37.9
	Several times a week	371	36.2

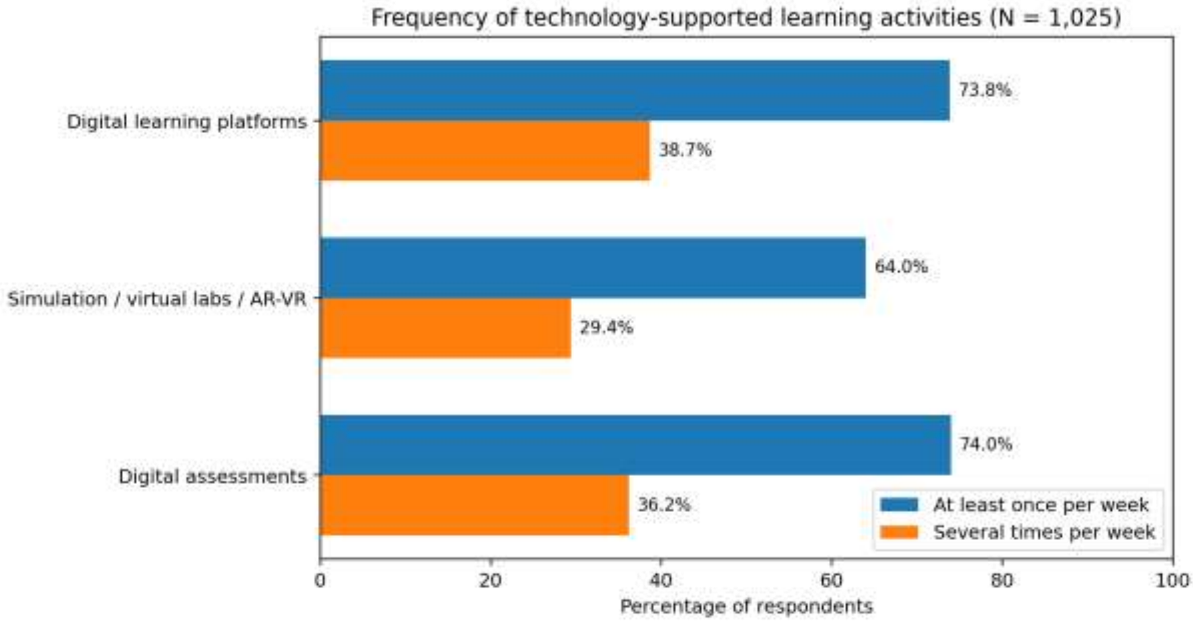
Note. A13 refers to experience before the current programme. A18-A20 refer to the previous four weeks. No 'never' responses appeared in the retained A14 and A18-A20 tables, consistent with the study's current-exposure eligibility criterion. Percentages are reproduced from the thesis and may differ by 0.1 from values recalculated from counts because of rounding.

Table 3: Derived Exposure-Audit Indicators and Marginal Contrasts

Indicator	n	% / difference	Derivation
Moderate or high prior experience	585	57.1	A13: moderate + high
None or basic prior experience	440	42.9	A13: none + basic
Broad programme exposure often or very often	651	63.5	A14: often + very often
Blended, hybrid, or mostly online arrangement	456	44.5	A15: blended/hybrid + mostly online
Smartphone-only or shared primary device	325	31.7	A16: smartphone only + shared device
Poor or moderate internet access	329	32.1	A17: poor + moderate
Digital platforms at least weekly	756	73.8	A18: about weekly + several times weekly
Simulation-related practice at least weekly	656	64.0	A19: about weekly + several times weekly
Digital assessment at least weekly	759	74.0	A20: about weekly + several times weekly
Digital platforms several times weekly	397	38.7	A18: highest observed frequency
Simulation-related practice several times weekly	301	29.4	A19: highest observed frequency
Digital assessment several times weekly	371	36.2	A20: highest observed frequency
Simulation frequency gap versus platforms	-	-9.8 pp	At-least-weekly percentages: 64.0 - 73.8
Simulation frequency gap versus assessment	-	-10.0 pp	At-least-weekly percentages: 64.0 - 74.0

Note. pp = percentage points. Combined percentages were calculated from counts using N = 1,025. Marginal differences are descriptive, not tests of statistical significance, and do not reveal within-student co-occurrence.

Figure 2: Frequency of Technology-Supported Learning Activities



Note. 'At least once per week' combines about once a week with several times a week. The figure presents marginal percentages; the same respondent may contribute to each activity category.

4.6 Integrated Descriptive Profile

Taken together, the distributions do not support a simple digitally included versus excluded interpretation. The dominant pattern at sample level was broad exposure within a mainly face-to-face system, regular use of platforms and digital assessment, somewhat less frequent simulation-related practical activity, and a material-access caution affecting roughly one third of respondents depending on the indicator used. The data therefore distinguish digital reach from the intensity of authentic technology-supported practice.

The profile also reveals why a single digitalisation percentage would be misleading. Reporting only the 63.5% who experienced broad digital or Industry 4.0 activity often or very often would conceal the 31.7% dependent on a smartphone-only or shared device, 32.1% with poor or moderate internet, and the lower frequency of simulation-related activity. Reporting only that 64.0% had at least weekly simulation-related exposure would conceal variation within that broad category and the study's exposure-based screening. A layered set of indicators gives a more defensible account.

5. Discussion

5.1 Collective Interpretation: Digital Reach Exceeded Practice Intensity

The central finding is not that the sampled programmes were either digitally advanced or digitally constrained; both conditions were visible. Most students reported regular digital or Industry 4.0-supported learning, and approximately three quarters used digital platforms and digital assessment at least weekly. At the same time, simulation-related practical exposure was less routine, face-to-face learning remained dominant, and roughly one third of students belonged to a device- or connectivity-caution group. Digital transformation therefore appeared as a layered and uneven educational experience rather than a single institutional state.

The difference between general digital activity and simulation-related practical activity is substantively important for TVET. Platforms and digital assessments can improve organisation, access to content, communication, feedback, and evidence collection. They do not necessarily reproduce the decision environments, equipment interactions, process visualisations, or troubleshooting demands associated with Industry 4.0 work. The marginal frequency gap suggests that the administrative and communicative layer of digitalisation may be more routine than the authentic-practice layer. This interpretation is consistent with Education 4.0 research that treats meaningful transformation as the integration of technology with pedagogy, authentic tasks, and work-relevant capability rather than technology presence alone [6, 8].

The gap should not be overstated. A single simulation session may be longer and more educationally intensive than several platform interactions. The A19 category also combines simulations, virtual laboratories, AR/VR, and other technology-supported practical activities, so the data cannot identify which technologies were used. Nor do the marginal tables establish a within-student sequence. The defensible conclusion is narrower: routine exposure was less prevalent for this practical-technology category than for platforms or digital assessment at the same reported thresholds.

5.2 Material Access Remained Consequential within an Exposure-Eligible Sample

The access findings show why nominal connectivity is insufficient. A personal laptop was the primary device for a majority, but 27.3% relied on a smartphone only and 4.4% relied on a shared device. Nearly one third also reported poor or moderate internet. These proportions are notable because the sample was already screened for relevant digital exposure. Material constraints therefore persisted among students participating in digitally supported learning, not only among those entirely excluded.

A smartphone should not be treated as inherently inferior. Mobile devices can support communication, video capture, quick reference, microlearning, augmented-reality overlays, portfolios, and workplace evidence. The issue is task-device correspondence and autonomy. Some occupational learning tasks require a large display, precise input, specialised software, sustained processing, or simultaneous access to instructions and production data. Shared access can also make practice dependent on schedules outside the learner's control. Material-access research accordingly emphasises quality and variety of resources, not ownership alone [11].

The practical response is universal rather than remedial design. Institutions can provide scheduled laboratory access, device loans, browser-based or cross-platform alternatives, downloadable resources, asynchronous options, offline practice packages, and assessment routes that do not penalise unstable connections. Technical requirements should be stated before a module begins, and instructors should know which activities are realistic on the devices students actually use. These measures shift the focus from presumed learner deficit to institutional responsibility for equitable participation.

5.3 Face-to-Face Dominance Can Coexist with Digital Transformation

The dominance of face-to-face learning should not be interpreted as evidence of failed transformation. Competency-based TVET depends on supervised practice, safety procedures, physical materials, specialist equipment, and observable performance. For many occupations, a fully online arrangement would be an incomplete substitute. The more useful policy question is how face-to-face workshop activity is augmented by digital preparation, simulation, data use, feedback, documentation, and reflection.

The 33.6% blended or hybrid share is therefore significant because it indicates a substantial mixed environment, while the 10.9% mostly online group demonstrates that some programmes or learning phases operate primarily through digital channels. A coherent blended sequence might include online pre-briefing, guided simulation, physical workshop practice, digital feedback, and evidence-based assessment. Such a sequence integrates rather than opposes physical and digital learning. Whole-institution approaches can align infrastructure, timetable, curriculum, instructor development, industry partnerships, and assessment around that sequence [28].

5.4 Prior Experience Should Inform Scaffolding, Not Selection

42.9% of the sample entered the current programme with no or only basic prior digital or Industry 4.0 experience. These findings challenge assumptions that young learners arrive uniformly prepared because they use everyday consumer technologies. Occupational digital competence involves task-specific knowledge, safety, information judgement, troubleshooting, data handling, and collaboration, which are not guaranteed by age or routine smartphone use [30, 25].

At the same time, current programme exposure was often or very often for 63.5% of the sample. Although the marginal data cannot demonstrate compensation at individual level, the two distributions show that programmes serve a sizeable group whose starting experience is limited. Orientation, low-stakes guided practice, instructor modelling, peer support, and repeated mastery opportunities are therefore core curriculum responsibilities. Prior experience can be used to differentiate support, but not to justify withholding advanced learning opportunities.

5.5 Contribution to Digital-Transformation Measurement

The study contributes a compact access-arrangement-exposure audit for TVET. First, it separates material opportunity from instructional modality. Second, it separates modality from what students do. Third, it separates exposure from learner beliefs and outcomes. This structure responds to digital-divide research showing that access, uses, and outcomes occupy different analytical levels [10] and to Education 4.0 research calling for systemic rather than equipment-centred evaluation [7, 8].

The framework also clarifies the role of descriptive evidence. Aggregate frequencies are sometimes dismissed as preliminary, yet they can prevent category errors before more complex modelling. A structural relationship between digital learning and readiness is difficult to interpret if 'digital learning' conflates reliable laptop access, occasional platform login, frequent digital assessment, and repeated simulation. An exposure audit identifies which dimensions require separate measurement and were nonlinear, subgroup, or person-centred patterns may plausibly arise.

The framework is intentionally not a maturity index. A higher online proportion is not automatically better; a higher frequency is not automatically higher quality; and simulation is not automatically authentic merely because it is technologically sophisticated. The educational standard remains alignment with occupational competencies, appropriate guidance, feedback, safety, transfer, and inclusive access [12, 13].

5.6 Implications for TVET Institutions and Policy

For institutions, the first implication is to establish a material-access floor. Every technology-supported module should specify minimum device and connectivity requirements and provide an institutional route for students who cannot meet them independently. Device and connectivity data should be collected at programme entry and revisited when task demands change. The goal is not merely to count connected students, but to ensure that students can perform the intended learning tasks.

Second, institutions should establish an authentic practice floor. Monitoring dashboards should distinguish content or platform access, digital communication, digital assessment, simulation, virtual laboratory activity, smart-equipment use, data interpretation, and technology-supported workplace problems. A target such as 'weekly digital activity' is too broad if most activity is administrative. Programme teams should decide what minimum pattern of authentic practice is justified by each occupational standard and document whether students receive it.

Third, instructor development should connect technology with learning design. Simulation and immersive tools are most useful when students understand the goal, receive scaffolding, act on feedback, reflect on decisions, and transfer learning to physical or workplace performance [12, 14]. Professional development should therefore cover task design, facilitation, feedback, accessibility, and assessment rather than software operation alone.

Fourth, equity monitoring should be disaggregated. Institution area, provider type, certification level, programme cluster, industrial-training status, gender, prior experience, device, and internet quality may intersect. The present study cannot estimate those joint patterns, but its distributions justify collecting them. Aggregate national or institution-wide averages can conceal small groups with persistent constraints.

Fifth, enterprise partnerships can expand access to current technologies, authentic datasets, equipment, instructors, and work-based projects. Regional evidence emphasises that TVET providers cannot sustain digital transformation through isolated institutional investment alone [19, 20]. Partnerships should include equitable scheduling and curriculum integration so that exposure is not restricted to a small group of advanced students.

These implications align with Malaysia's National 4IR Policy, New Industrial Master Plan 2030, and National TVET Policy 2030, all of which connect technological transformation with talent development and inclusion [22, 23, 24]. The present findings suggest a practical monitoring principle for those policies: report access, learning arrangement, and activity-specific practice separately, then link them to verified competency evidence.

Table 4: Evidence-to-Action Matrix for TVET Access and Exposure Monitoring

Monitoring domain	**Evidence from this sample**	**Institutional response**	**Suggested next indicator**
Material access	31.7% used a smartphone only or a shared device; 32.1% reported poor or moderate internet.	Specify task requirements; provide device loans, laboratories, institutional connectivity, offline resources, and low-bandwidth alternatives.	Task completion by device/connectivity category; unmet access requests; laboratory and loan utilisation.
Learning arrangement	55.5% studied mainly face to face; 44.5% were in blended, hybrid, or mostly online arrangements.	Design coherent physical-digital sequences rather than treating online share as a maturity score.	Proportion of modules with aligned pre-brief, simulation, workshop, feedback, and assessment components.
Platform use	73.8% used platforms at least weekly.	Move beyond login counts to document the learning purpose, duration, feedback, and active participation.	Purpose-coded platform activities; completion; feedback turnaround; accessibility incidents.

Monitoring domain	Evidence from this sample	Institutional response	Suggested next indicator
Authentic digital practice	64.0% reported at least weekly simulation-related practice; only 29.4% reported several-times-weekly use.	Define an occupation-specific minimum practice pattern and ensure equitable scheduling.	Hours and repetitions by simulation/practical technology; task authenticity; instructor scaffolding; transfer activity.
Digital assessment	74.0% experienced digital assessment at least weekly.	Align digital assessment with occupational standards and provide alternatives when access fails.	Assessment type, competency alignment, accessibility, technical failure, and feedback quality.
Equity and partnerships	The marginal profile suggests access and exposure may vary, but joint subgroup patterns were not estimated.	Disaggregate monitoring and build enterprise-provider partnerships for current equipment, data, projects, and instructor development.	Access/exposure by level, cluster, location, provider and learner characteristics; partnership reach and utilisation.

Note. The responses are recommendations derived from the descriptive pattern and relevant literature; the study did not test their causal effects.

5.7 Limitations

Several limitations define the interpretation. First, the sample was large and multi-institutional but not a fully national probability sample. The private-provider component was purposive, 93.5% of respondents were in government institutions, and the sample was concentrated among men and 19-22-year-old students. Findings should be generalised to the selected SLaPB frame with caution rather than to every Malaysian TVET provider or certification route.

Second, eligibility required relevant current digital exposure. The absence of 'never' responses in the retained activity tables is therefore partly a design feature. The study cannot estimate how many students in the wider population receive no digital or Industry 4.0-supported learning. The percentages describe variation among exposure-eligible respondents and may overstate reach relative to an unrestricted population.

Third, all indicators are self-reports. Frequency judgements may be affected by four-week recall, different interpretations of technology categories, or social desirability. A login, a completed learning activity, and a lengthy practical session may all be counted as one occasion. Future work should combine surveys with platform logs, timetables, simulation records, assessment metadata, and institutional technology inventories.

Fourth, only marginal distributions were available for this manuscript. The results cannot show whether smartphone-only students also had poor connectivity, whether low-prior-experience students received intensive simulation, or whether blended learners had broader exposure. They also cannot identify latent classes or test differences in engagement, self-efficacy, perceived readiness, objective competence, or employment outcomes.

Fifth, the broad A19 item combines simulations, virtual laboratories, AR/VR, and other technology-supported practical activities. These approaches differ in cost, immersion, pedagogical function, and occupational relevance. Subsequent instruments should separate them and record duration, task complexity, scaffolding, feedback, and authenticity. Finally, the cross-sectional design provides a snapshot and cannot establish change across programme stages.

5.8 Future Research

The next analytical step should use the original row-level dataset to examine joint response patterns. Because A13-A20 are categorical or ordinal, latent class analysis is more appropriate than conventional continuous latent profile analysis. Competing two- through six-class solutions should be evaluated using information criteria, likelihood-based evidence where available, entropy, class size, replicability across random starts, and substantive interpretability [37, 38]. Class labels should be assigned only after inspecting conditional-response probabilities.

Covariates such as certification level, programme cluster, institution area, provider type, industrial-training status, gender, and prior qualification could then be related to class membership using a bias-aware three-step approach. Engagement, digital learning self-efficacy, instructional-management perceptions, perceived readiness, and objective competency measures could be compared as distal outcomes while accounting for classification uncertainty [39, 40]. A split sample or external replication would be preferable to select a class solution solely on the full dataset.

Longitudinal designs should examine whether low-prior-experience students gain access, confidence, and competence over time and whether simulation intensity predicts later workshops or workplace performance. Multilevel studies can separate student access from programme and institution resources. Experimental or quasi-experimental studies can compare instructional sequences rather than mere technology presence. The strongest future evidence would integrate student experience, digital traces, instructor practice, assessed competency, and work-based outcomes.

6. Conclusion

Digital transformation in TVET cannot be evaluated through a single question about access or technology use. Among 1,025 SLaPB students in the selected Malaysian sample, broad digital or Industry 4.0-supported learning was common, and digital platforms and assessments were routine for many learners. Yet frequent simulation-related practical activity was less prevalent, face-to-face learning remained the dominant arrangement, and approximately one third of respondents reported a material-access caution through smartphone-only or shared-device dependence or poor-to-moderate internet quality.

These findings do not show that one learning mode or technology is superior, nor do they establish student-level profiles or competency effects. They show that technology reach, material resources, learning arrangement, and authentic-practice frequency are empirically different. Treating them as one digitalisation measure can make administrative adoption look like occupational transformation and can conceal persistent access constraints.

A more credible TVET transformation strategy begins with a layered audit: Can students use a suitable device and connection? How is learning organised? What technology-supported activities do they actually undertake, how often, and with what instructional purpose? Only after those questions are answered should institutions assess how exposure relates to engagement, self-efficacy, demonstrated competence, and transition to work. Separating these layers makes Industry 4.0 policy more measurable, learning design more purposeful, and inclusion more than a statement of intent.

Acknowledgement
The authors acknowledge the SLaPB institutions, authorised coordinators and students who contributed to the doctoral research from which this manuscript was developed. Appreciation is also extended to the academic supervisors, expert reviewers and institutional stakeholders who supported instrument review and field administration.

Shared-Dataset Disclosure. This article uses the same 1,025-participant doctoral dataset as companion manuscripts on instructional management, engagement, digital learning self-efficacy, and perceived readiness. The present manuscript addresses descriptive access and exposure conditions and does not duplicate the companion articles' principal structural-model analyses.

Use of Generative AI or AI-Assisted Technologies. AI-assisted tools were used for language refinement, reference organisation, figure preparation, and document formatting. The authors remain responsible for verifying all data, citations, interpretations, and declarations and should adapt this disclosure to IJFMR's current policy.

References

1. Benešová, A., & Tupa, J. (2017). Requirements for education and qualification of people in Industry 4.0. Procedia Manufacturing, 11, 2195-2202. https://doi.org/10.1016/j.promfg.2017.07.366
2. Chaka, C. (2020). Skills, competencies and literacies attributed to 4IR/Industry 4.0: Scoping review. IFLA Journal, 46(4), 369-399. https://doi.org/10.1177/0340035219896376
3. van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2020). Determinants of twenty-first-century skills and twenty-first-century digital skills for workers: A systematic literature review. SAGE Open, 10(1), 1-14. https://doi.org/10.1177/2158244019900176
4. Mazlan, M. H., Puteh, S., Mohamad, Z., Sulaiman, N. L., Mohd Salleh, K., Wan Omar, W. R., Buhari, R., Bahrum, M. I. H., & Nasuha, A. (2026). Future-fit TVET students for Industry 4.0: Exploring talent domains and components through WBL and applied research in higher education. Higher Education, Skills and Work-Based Learning, 16(3), 549-565. https://doi.org/10.1108/HESWBL-05-2025-0205
5. Wong, G. S., & Abdullah, N. S. (2025). Job readiness level to address 4.0 skills: An empirical study on TVET students in the electrical and electronics field. Journal of Technical Education and Training, 17(1). https://doi.org/10.30880/jtet.2025.17.01.005
6. Bonfield, C. A., Salter, M., Longmuir, A., Benson, M., & Adachi, C. (2020). Transformation or evolution? Education 4.0, teaching and learning in the digital age. Higher Education Pedagogies, 5(1), 223-246. https://doi.org/10.1080/23752696.2020.1816847
7. González-Pérez, L. I., & Ramírez-Montoya, M. S. (2022). Components of Education 4.0 in 21st century skills frameworks: Systematic review. Sustainability, 14(3), Article 1493. https://doi.org/10.3390/su14031493
8. Mukul, E., & Büyüközkan, G. (2023). Digital transformation in education: A systematic review of Education 4.0. Technological Forecasting and Social Change, 194, Article 122664. https://doi.org/10.1016/j.techfore.2023.122664

9. Eastin, M. S., & LaRose, R. (2000). Internet self-efficacy and the psychology of the digital divide. Journal of Computer-Mediated Communication, 6(1). https://doi.org/10.1111/j.1083-6101.2000.tb00110.x
10. Scheerder, A., van Deursen, A., & van Dijk, J. (2017). Determinants of Internet skills, uses and outcomes: A systematic review of the second- and third-level digital divide. Telematics and Informatics, 34(8), 1607-1624. https://doi.org/10.1016/j.tele.2017.07.004
11. van Deursen, A. J. A. M., & van Dijk, J. A. G. M. (2019). The first-level digital divide shifts from inequalities in physical access to inequalities in material access. New Media & Society, 21(2), 354-375. https://doi.org/10.1177/1461444818797082
12. Chernikova, O., Heitzmann, N., Stadler, M., Holzberger, D., Seidel, T., & Fischer, F. (2020). Simulation-based learning in higher education: A meta-analysis. Review of Educational Research, 90(4), 499-541. https://doi.org/10.3102/0034654320933544
13. Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. Educational Psychology Review, 33, 937-958. https://doi.org/10.1007/s10648-020-09586-2
14. Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers & Education, 147, Article 103778. https://doi.org/10.1016/j.compedu.2019.103778
15. Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. Personnel Psychology, 64(2), 489-528. https://doi.org/10.1111/j.1744-6570.2011.01190.x
16. Abele, E., Metternich, J., Tisch, M., Chryssolouris, G., Sihn, W., ElMaraghy, H., Hummel, V., & Ranz, F. (2015). Learning factories for research, education, and training. Procedia CIRP, 32, 1-6. https://doi.org/10.1016/j.procir.2015.02.187
17. Baena, F., Guarin, A., Mora, J., Sauza, J., & Retat, S. (2017). Learning factory: The path to Industry 4.0. Procedia Manufacturing, 9, 73-80. https://doi.org/10.1016/j.promfg.2017.04.022
18. Li, L., Lim, C. K., Yan, Z., & Rus, R. C. (2026). Digital transformation and sustainable education: A framework for integrating multimodal VR into TVET. Sustainability, 18(4), Article 2007. https://doi.org/10.3390/su18042007
19. Niwamanya, G., Zhong, Z., Matola, C. A., Eliachu, D., Ravindra, S., & Fahn, J. B. (2025). Bridging the digital divide through enterprise-TVET provider partnerships: Strategic insights on digital transformation in TVET in developing nations. Vocation, Technology & Education. https://doi.org/10.54844/vte.2025.0977
20. Paryono, P., & Mashod, H. (2025). Responses of technical and vocational education and training institutions to the needs of industry's digital transformation in South-East Asia (ILO Working Paper 138). International Labour Organization. https://doi.org/10.54394/BJOX6123
21. Schröder, T. (2019). A regional approach for the development of TVET systems in the light of the 4th industrial revolution: The regional association of vocational and technical education in Asia. International Journal of Training Research, 17(Suppl. 1), 83-95. https://doi.org/10.1080/14480220.2019.1629728
22. Economic Planning Unit Malaysia. (2021). National Fourth Industrial Revolution (4IR) policy. Prime Minister's Department. https://ekonomi.gov.my/sites/default/files/2021-09/4IRvol2_FA_ENG.pdf

23. Majlis TVET Negara. (2024). Dasar TVET Negara 2030 [National TVET Policy 2030]. Government of Malaysia. https://www.tvet.gov.my/media/dasar_tvet_negara_2030.pdf
24. Ministry of Investment, Trade and Industry Malaysia. (2023). New industrial master plan 2030. Government of Malaysia. https://www.nimp2030.gov.my/
25. Vuorikari, R., Kluzer, S., & Punie, Y. (2022). DigComp 2.2: The digital competence framework for citizens. Publications Office of the European Union. https://doi.org/10.2760/115376
26. Getenet, S., Cantle, R., Redmond, P., & Albion, P. (2024). Students' digital technology attitude, literacy and self-efficacy and their effect on online learning engagement. International Journal of Educational Technology in Higher Education, 21, Article 3. https://doi.org/10.1186/s41239-023-00437-y
27. Prior, D. D., Mazanov, J., Meacheam, D., Heaslip, G., & Hanson, J. (2016). Attitude, digital literacy and self-efficacy: Flow-on effects for online learning behavior. The Internet and Higher Education, 29, 91-97. https://doi.org/10.1016/j.iheduc.2016.01.001
28. Zhong, Z., & Juwaheer, S. (2024). Digital competence development in TVET with a competency-based whole-institution approach. Vocation, Technology & Education. https://doi.org/10.54844/vte.2024.0591
29. Wintersberg, L., & Pittich, D. (2025). Digital transformation of corporate technical education and training: A case study on instructional designers' perceptions. Vocations and Learning. https://doi.org/10.1007/s12186-025-09360-x
30. Falloon, G. (2020). From digital literacy to digital competence: The teacher digital competency framework. Educational Technology Research and Development, 68, 2449-2472. https://doi.org/10.1007/s11423-020-09767-4
31. Department of Skills Development Malaysia. (n.d.-a). National Occupational Skills Standard (NOSS). Ministry of Human Resources Malaysia. https://www.dsd.gov.my/ms/perkhidmatan/standard-kemahiran-pekerjaan-kebangsaan-noss
32. Department of Skills Development Malaysia. (n.d.-b). Sistem Latihan Program Bertauliah (SLaPB). Ministry of Human Resources Malaysia. https://www.dsd.gov.my/en/service/accredited-program-training-system-slapb
33. Laws of Malaysia. (2006). National Skills Development Act 2006 (Act 652). Attorney General's Chambers of Malaysia. https://lom.agc.gov.my/ilims/upload/portal/akta/LOM/EN/Act%20652.pdf
34. Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: Complex or simple? Research case examples. Journal of Research in Nursing, 25(8), 652-661. https://doi.org/10.1177/1744987120927206
35. Creswell, J. W., & Creswell, J. D. (2023). Research design: Qualitative, quantitative, and mixed methods approaches (6th ed.). SAGE.
36. Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: A critical review of the literature and recommended remedies. Journal of Applied Psychology, 88(5), 879-903. https://doi.org/10.1037/0021-9010.88.5.879
37. Collins, L. M., & Lanza, S. T. (2010). Latent class and latent transition analysis: With applications in the social, behavioral, and health sciences. Wiley. https://doi.org/10.1002/9780470567333
38. Nylund, K. L., Asparouhov, T., & Muthén, B. O. (2007). Deciding on the number of classes in latent class analysis and growth mixture modeling: A Monte Carlo simulation study. Structural Equation Modeling: A Multidisciplinary Journal, 14(4), 535-569. https://doi.org/10.1080/10705510701575396

39. Asparouhov, T., & Muthén, B. (2014). Auxiliary variables in mixture modeling: Three-step approaches using Mplus. Structural Equation Modeling: A Multidisciplinary Journal, 21(3), 329-341. https://doi.org/10.1080/10705511.2014.915181
40. Vermunt, J. K. (2010). Latent class modeling with covariates: Two improved three-step approaches. Political Analysis, 18(4), 450-469. https://doi.org/10.1093/pan/mpq025