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IMMERSIVE LEARNING THROUGH AUGMENTED REALITY: REDEFINING SKILL DEVELOPMENT IN TVET

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Abstract:

The integration of Augmented Reality (AR) in Technical and Vocational Education and Training (TVET) offers significant potential to transform conventional teaching into immersive, skill-focused learning experiences. Yet, the absence of structured pedagogical models constrains its effective implementation in skills-based contexts. Guided by the Design and Development Research (DDR) methodology, this study was conducted in three phases: needs analysis, model construction, and usability evaluation. A total of 120 TVET instructors and nine expert panels from accredited Malaysian training institutions participated. Data collection employed surveys, focus group discussions, and validation workshops, while data analysis applied Thematic Analysis, Interpretive Structural Modelling (ISM), and the Fuzzy Delphi Method (FDM). Results revealed six critical pedagogical elements: interactivity, simulation, performance feedback, remote expert guidance, annotation, and practice-based assessment, achieving expert consensus levels above 80%, with overall agreement reaching 92.3%. The validated AR-T Model encompasses 24 instructional activities categorised under three domains: Content, Instructional Activities, and Assessment. Usability testing confirmed the model's practicality and contextual relevance in enhancing engagement, instructional clarity, and hands-on competency development. The findings not only contribute a novel structured framework for AR integration in TVET pedagogy but also underscore the urgency of policy support, infrastructural readiness, and continuous professional development for instructors. This research provides critical implications for curriculum developers and policymakers in embedding immersive technologies into skills training, thereby aligning with Industry 4.0 workforce demands.

Keywords:

Augmented Reality; Immersive Pedagogy; TVET Instruction; Skill Training; Educational Technology

Introduction

In the framework of the Fourth Industrial Revolution (Industry 4.0), the sphere of Technical and Vocational Education and Training (TVET) is undergoing substantial metamorphosis. The advent of emerging technologies, including Augmented Reality (AR), Artificial Intelligence (AI), and the Internet of Things (IoT), is fundamentally altering industrial requirements and reconfiguring the competencies necessary for the prospective labour force (Ghobakhloo, 2020; Schwab & Zahidi, 2023). Notably, AR has been acknowledged as a potent pedagogical instrument that engenders immersive, interactive, and contextually enriched environments especially advantageous for experiential, skill-centric education (Chiew & Sung, 2022; Wang et al., 2021).

AR enables learners to manipulate virtual objects in real time, engage in high-risk simulations within safe environments, and receive immediate feedback. These capabilities align well with the experiential nature of TVET instruction (Ren et al., 2023). However, despite its promising potential, the adoption of AR in TVET remains fragmented and lacks a structured pedagogical framework. Effective implementation requires more than technological readiness it demands pedagogical guidance to help instructors design and deliver AR-enhanced learning effectively (Czerkawski & Berti, 2021). Hence, there is a growing need for a validated instructional model that positions AR as a catalyst for pedagogical innovation in vocational training.

Although earlier research has shown that augmented reality (AR) applications tailored to different technical fields can be developed (Blanco-Novoa et al., 2018; Quintero et al., 2019), little attention has been paid to the methodical incorporation of AR into technical and vocational education and training (TVET) pedagogical frameworks. Most of the existing literature views Augmented Reality (AR) as a supporting tool rather than a fundamental element of a comprehensive educational system (Salleh et al., 2021; Alzahrani, 2020). Moreover, many TVET instructors lack clear guidance on aligning AR with competency-based education frameworks, resulting in inconsistent adoption or reluctance to use AR in teaching (Matsika & Zhou, 2021).

This gap highlights the need for a structured, theory-driven teaching model that supports immersive pedagogy through AR, particularly within the Malaysian TVET context. As TVET is central to national human capital development and industry readiness (Majlis TVET Negara, 2024; MITI, 2023), the absence of a pedagogically sound model limits the impact of technological integration on instructional quality. The importance of this research is rooted in its capacity to address this disparity by introducing and substantiating an augmented reality (AR) instructional framework that enables educators to adeptly incorporate immersive technologies, consequently improving student involvement, proficiency in skills, and congruence with the demands of Industry 4.0.

Research Objectives

This study aims to propose a validated augmented reality teaching model to support immersive pedagogy in skill-based TVET instruction. The specific objectives are:

1. To explore the perceived needs of TVET instructors in integrating augmented reality into skill-based teaching and learning.
2. To construct an augmented reality teaching model based on expert consensus using systematic modelling approaches.

Research Questions

1. What are the perceptions and current practices of TVET instructors regarding the integration of augmented reality in skill training?
2. What pedagogical elements and relationships should be included in an AR-based teaching model for skill-based instruction?

Methodology

Research Design

This study adopts the Design and Development Research (DDR) methodology, a systematic and iterative approach aimed at addressing complex educational challenges through the creation and validation of practical solutions such as models, materials, and instructional strategies (Richey & Klein, 2007; Plomp & Nieveen, 2013) as shown in Figure 1. DDR is particularly suited for this study, which focuses on developing a pedagogically grounded Augmented Reality (AR) teaching model tailored for skill-based instruction in Technical and Vocational Education and Training (TVET).

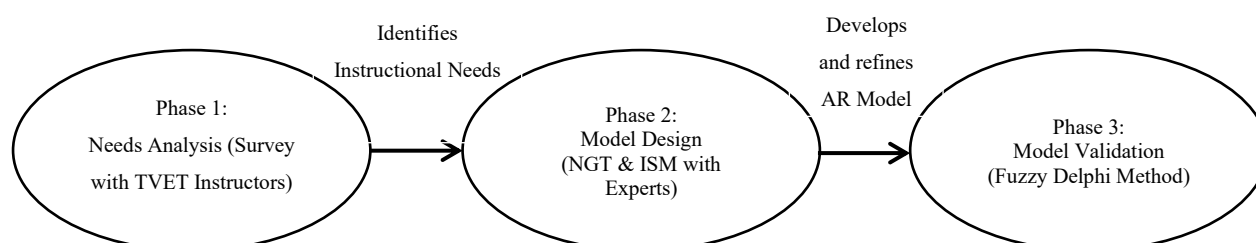


Figure 1. This Study Adopted the Design and Development Research (DDR) Methodology

The DDR approach in this research was carried out in three main phases:

1. Needs Analysis Phase
A quantitative survey was administered to 120 TVET instructors to examine their current practices, perceived challenges, and readiness to integrate AR in skill-based teaching and learning. The data were analysed using descriptive statistics to identify key instructional gaps and inform the model's direction.
2. Design and Development Phase
A series of expert consultations was conducted using the Nominal Group Technique (NGT) to extract, refine, and prioritise essential pedagogical elements of the AR teaching model. These elements were then structurally mapped through Interpretive

Structural Modelling (ISM) to establish interdependencies and inform the model's architecture.

3. Validation Phase

The proposed model underwent empirical validation through the Fuzzy Delphi Method (FDM), whereby a panel of domain experts rated each component's relevance and feasibility. The collected data were defuzzified to determine threshold values, consensus levels, and average fuzzy scores, ensuring the model's rigour and applicability.

The research process was implemented sequentially but with iterative refinement to ensure that the model was both empirically informed and pedagogically sound. Data collection was carried out over six months, involving a combination of face-to-face sessions and online platforms to facilitate participation. FDM analysis confirmed high expert consensus on model usability with threshold values ($d \leq 0.2$), validating the robustness and relevance of the 24 pedagogical components.

Research Sample/Participants

The study targeted TVET instructors from accredited public and private training institutions across Malaysia, given their pivotal role in implementing competency-based programmes aligned with the National Occupational Skills Standards (NOSS). These instructors were regarded as key stakeholders in understanding the pedagogical implications of AR integration in real instructional settings.

Sample Description

A total of 120 instructors participated in the initial survey phase. They represented a diverse range of technical disciplines, including electrical technology, automotive, welding, and mechatronics, thereby ensuring broad representation across key skill-based domains. In the subsequent phases, a panel of nine subject matter experts (SMEs) was engaged in the NGT, ISM, and FDM processes. The selection criteria for these experts included a minimum of 10 years of TVET teaching experience, academic or professional qualifications in education or technology, and demonstrable familiarity with AR or immersive instructional tools.

Sampling Method and Justification

This study employed a purposive sampling strategy in both phases:

1. For the instructor survey, purposive sampling was used to target individuals with hands-on experience in skill-based instruction and likely exposure to AR or instructional technology.
2. For the expert panel, expert purposive sampling ensured the inclusion of participants with recognised expertise in pedagogy, technical training, and immersive learning environments. This aligns with established protocols in design-based and Delphi-type research (Okoli & Pawlowski, 2004), where depth and relevance of input are prioritised over statistical generalisability.

The use of purposive sampling is justified by the research's emphasis on obtaining rich, informed insights rather than broad population-level generalisations, consistent with the principles of DDR that value informed expert judgement in the development of educational innovations.

Data Collection Method/Instrumentation

This study adopted a multi-phase data collection strategy in alignment with the Design and Development Research (DDR) framework. Each phase was guided by specific research objectives and employed instruments that were purposefully designed to generate data for needs identification, model development, and model validation.

Phase 1: Needs Analysis

In the initial phase, a structured questionnaire was developed to investigate the perceptions, existing practices, and readiness of TVET instructors regarding the integration of Augmented Reality (AR) into skill-based instruction. The instrument was administered to 120 TVET instructors from accredited public and private institutions across Malaysia, covering various vocational disciplines including electrical, mechanical, and automotive technologies. The questionnaire comprised 30 items, grouped under five major constructs:

1. Awareness of AR
2. Current teaching practices
3. Perceived usefulness of AR
4. Readiness for AR integration
5. Perceived challenges and support requirements

All items were measured on a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

Instrument Validity and Reliability

This phase provided the foundation for identifying instructional needs, addressing gaps in practice, and determining systemic requirements for effective AR integration in TVET settings. To ensure methodological rigour, content validity was established through expert review by a panel consisting of three senior TVET educators with over ten years of experience and one AR instructional technology specialist. These experts evaluated each instrument item for clarity, relevance, and alignment with the study objectives. Only items achieving a minimum of 80% agreement were retained for further analysis, following the threshold recommended by the Fuzzy Delphi Method (Cheng & Lin, 2002). A pilot study was then conducted with 30 TVET instructors across accredited training institutions to assess reliability. The results yielded a Cronbach's alpha coefficient of 0.90, indicating strong internal consistency and reliability of the instrument. In addition, Kendall's W coefficient of concordance was employed to measure the degree of agreement among the expert panel, producing a value of 0.82 ($p < .01$), which demonstrates a high level of consensus.

For expert inclusion criteria, participants were selected based on: (i) a minimum of six years of professional experience in TVET or AR-based instructional design, (ii) active involvement in curriculum development or pedagogical innovation projects, and (iii) formal recognition through institutional or ministry-level accreditation. These criteria ensured that only qualified individuals with relevant expertise contributed to the validation process. Through this systematic approach, the study achieved robust validity and reliability, thereby strengthening the credibility of the findings and supporting the construction of the AR-T Model as a practical and evidence-based pedagogical framework.

Phase 2: Model Design

The second phase of this study focused on the systematic development of the Augmented Reality (AR) teaching model, guided by expert input and structured modelling techniques. Two complementary methods were employed: the Nominal Group Technique (NGT) and Interpretive Structural Modelling (ISM).

Nominal Group Technique (NGT)

The initial stage involved a structured NGT session conducted with a panel of nine subject matter experts (SMEs), comprising senior TVET lecturers, instructional designers, and AR technology practitioners. Each expert independently proposed key pedagogical elements deemed essential for inclusion in an AR-based instructional model. Through a collaborative discussion process, the ideas were clarified, consolidated, and subsequently **prioritised** through anonymous voting. This method ensured balanced participation, reduced bias from dominant voices, and fostered a high degree of consensus.

Interpretive Structural Modelling (ISM)

Upon finalising the core pedagogical elements via NGT, the study proceeded with ISM to examine the structural interrelationships among the identified components. Experts were invited to complete pairwise comparison matrices, assessing the directional influence and dependence between each element. The resulting data were analysed using MICMAC software, which generated a multi-level hierarchical model reflecting the influence paths and logical sequencing of the components. This dual-method approach produced a conceptually grounded AR teaching model rooted in practitioner expertise and structurally validated through interpretive modelling. The model's architecture serves as a robust foundation for further validation and future implementation within skill-based TVET instruction.

Phase 3: Model Validation

The third and final phase of this study involved the validation of the proposed Augmented Reality (AR) teaching model using the Fuzzy Delphi Method (FDM). This technique was selected for its ability to quantify expert consensus while accommodating the subjectivity inherent in expert judgment. The same panel of nine subject matter experts (SMEs) who contributed to the model development in Phase 2 also participated in this validation stage. A structured FDM instrument was developed based on the pedagogical components identified through the Nominal Group Technique (NGT) and Interpretive Structural Modelling (ISM). Experts were asked to assess the importance and relevance of each model component using a 7-point linguistic scale, ranging from *Very Unimportant* to *Very Important*. Each linguistic response was converted into triangular fuzzy numbers to account for the ambiguity in human judgment. The collected data were then defuzzified to determine the level of consensus among experts. The criteria for accepting a component into the final model were as follows:

1. Threshold value $(d) \leq 0.2$
2. Expert agreement $\geq 75\%$

Only components that met both criteria were retained. This validation process ensured that the model was not only conceptually sound but also practically acceptable and relevant within the context of skill-based TVET instruction. The application of FDM provided a robust combination of quantitative precision and qualitative insight, strengthening the model's credibility and usability for future pedagogical applications.

Data Analysis Method

The data analysis procedures in this study were aligned with the Design and Development Research (DDR) framework, which emphasises sequential and iterative analysis across three core phases: exploration, modelling, and validation. Each phase was associated with specific research questions and analysis methods that ensured methodological rigour and coherence in developing the Augmented Reality (AR) teaching model.

Analysis for Research Question 1

Research Question 1 (RQ1):

What are the perceptions and current practices of TVET instructors regarding the integration of augmented reality in skill training?

To address this question, quantitative data from the structured questionnaire administered during the needs analysis phase were analysed using descriptive statistical techniques, including frequency distributions, mean scores, and standard deviations. The analysis was conducted using IBM SPSS Statistics (Version 26).

This statistical summary provided insights into instructors:

- Awareness and understanding of AR technology,
- Current teaching practices,
- Perceived usefulness and readiness for AR integration,
- Anticipated barriers and support needs.

The results formed a foundational understanding of practitioner experiences and expectations, revealing key instructional gaps that directly informed the conceptualisation of the proposed AR teaching model.

Analysis for Research Question 2

Research Question 2 (RQ2):

What pedagogical elements and relationships should be included in an AR-based teaching model for skill-based instruction? To answer this question, a two-stage analysis was conducted using both qualitative synthesis and structural modelling techniques.

1. Nominal Group Technique (NGT):

Data obtained from the NGT session with nine subject matter experts were manually synthesised to identify and categorise recurring pedagogical elements proposed for the AR-based teaching model. A ranking matrix was developed based on expert prioritisation, and thematic coding was applied to group similar elements. Supplementary data from field notes and session transcripts were reviewed to ensure contextual integrity and deepen the interpretation of expert perspectives.

2. Interpretive Structural Modelling (ISM):

To establish the structural relationships among the prioritised pedagogical components, the ISM method was employed. Experts completed a Structural Self-Interaction Matrix (SSIM) through pairwise comparisons of all elements. These comparisons were used to generate a reachability matrix, which was further processed using MICMAC software to conduct level partitioning and determine the hierarchical structure of the model. The resulting framework distinguished between driving, dependent, and linkage elements, providing a clear theoretical map of how components interrelate within the AR-based instructional ecosystem.

This integrated analysis approach enabled the systematic construction of a conceptually sound and pedagogically grounded AR teaching model for skill-based TVET instruction.

Validation of the Proposed Model

The third phase of data analysis focused on validating the proposed Augmented Reality (AR) teaching model through the Fuzzy Delphi Method (FDM). This method was chosen for its ability to combine the rigour of quantitative consensus analysis with the flexibility of expert-driven qualitative input. A panel of nine subject matter experts was engaged to evaluate the relevance and importance of each component in the preliminary model. Expert ratings were captured using a 7-point linguistic scale, which was then converted into triangular fuzzy numbers to reflect degrees of uncertainty and subjectivity in judgment.

The defuzzification process was carried out using Microsoft Excel, applying standard FDM procedures to calculate:

1. The threshold value (d) for each item,
2. The percentage of expert agreement, and
3. The average fuzzy score.

The following criteria were adopted for item retention:

1. Threshold value (d) ≤ 0.2 , and
2. Expert agreement $\geq 75\%$.

Only model components that satisfied both criteria were retained in the final version. This robust validation process ensured the credibility, consensus, and practical relevance of the AR teaching model, affirming its suitability for implementation in skill-based TVET instruction.

Results

Research Question 1: What Are the Perceptions and Current Practices of TVET Instructors Regarding the Integration of Augmented Reality in Skill Training?

The data for Research Question 1 were analysed using descriptive statistics, and the results are presented in two bar charts to visualise the dimensions of (i) awareness and current practice, and (ii) perceived usefulness and readiness for augmented reality (AR) integration in TVET teaching.

Awareness and Current Practice

As shown in Figure 2, the mean score for awareness of AR among TVET instructors is high ($M = 4.20$), suggesting that most participants are familiar with the concept of AR in education. However, the mean score drops significantly when it comes to actual implementation, with use of AR in the classroom scoring the lowest ($M = 2.35$). Similarly, instructors report limited institutional encouragement for adopting AR ($M = 2.78$) and moderate familiarity with AR tools relevant to their teaching field ($M = 2.91$). This indicates a gap between awareness and active usage, echoing findings by Pathak (2024), who identified institutional and infrastructural limitations as key barriers to technology adoption in vocational education.

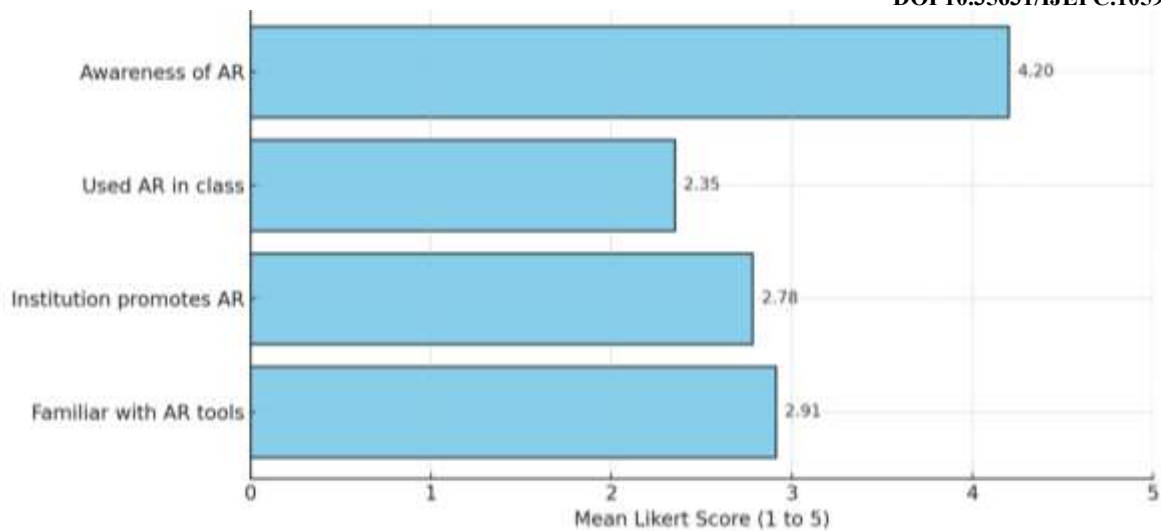


Figure 2. Awareness and Current Practice among TVET instructors

Perceived Usefulness and Readiness

Figure 3 illustrates instructors' perceptions of AR's pedagogical value and their readiness to implement it. AR's role in enhancing student understanding of complex concepts received the highest score ($M = 4.45$), followed closely by its ability to boost learner motivation ($M = 4.32$). These findings align with previous studies (e.g., He & Li, 2024; Indarta et al., 2025) that emphasise the immersive and engaging nature of AR in technical learning.

Despite this perceived usefulness, instructors reported low confidence in using AR themselves ($M = 2.60$) and inadequate training or institutional support ($M = 2.20$). These findings reflect systemic gaps in professional development and underline the necessity of targeted interventions such as structured training programs, mentoring, and provision of AR teaching tools—an issue similarly observed by Osypova et al. (2021) and Lester & Hofmann (2020).

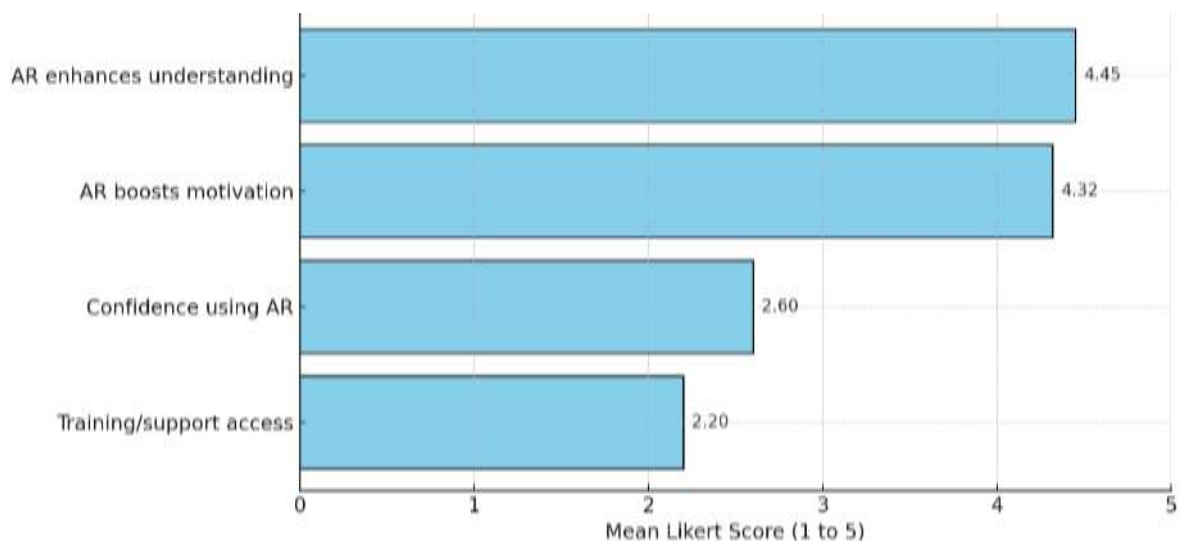


Figure 3: Perceived Usefulness and Readiness among TVET instructors

Research Question 2: What Pedagogical Elements and Relationships Should Be Included in an AR-Based Teaching Model for Skill-Based Instruction?

To address this research question, a two-tiered analysis combining qualitative synthesis and structural modelling was employed. The findings are presented in two distinct parts. First, the core pedagogical elements were identified and prioritised using the Nominal Group Technique (NGT). Second, the relationships among these elements were systematically mapped using Interpretive Structural Modelling (ISM), visualised through a hierarchical model generated using MICMAC software.

Identification of Pedagogical Elements (NGT Analysis)

During Phase 2 of the study, a panel of nine experts comprising senior TVET instructors, instructional designers, and AR developers participated in an NGT session to generate and refine pedagogical elements deemed essential for AR-based teaching in skill training. The session involved individual brainstorming, group clarification, and prioritised ranking. Seven key pedagogical components emerged from this process:

Design (planning and structuring learning)

1. Outcome Alignment – ensuring objectives and content match.
2. Instructional Sequencing – organizing content logically.
3. Cognitive Load Management – reducing unnecessary complexity.

Delivery (engaging and supporting learners)

4. Scaffolding & Feedback – providing guided support.
5. Learner Engagement – promoting active participation.
6. Technological Infrastructure – enabling reliable digital support.

Evaluation (monitoring and improving learning)

7. Real-Time Assessment – continuously measuring progress.

The rankings were tabulated as shown in Figure 4, and thematic analysis of session transcripts and field notes provided additional depth. Experts emphasised that successful AR instruction must balance technological affordances with pedagogical soundness. For instance, one participant noted the importance of “progressive information layers” to avoid overloading learners—an observation directly tied to cognitive load management theory (Sweller, 1988).

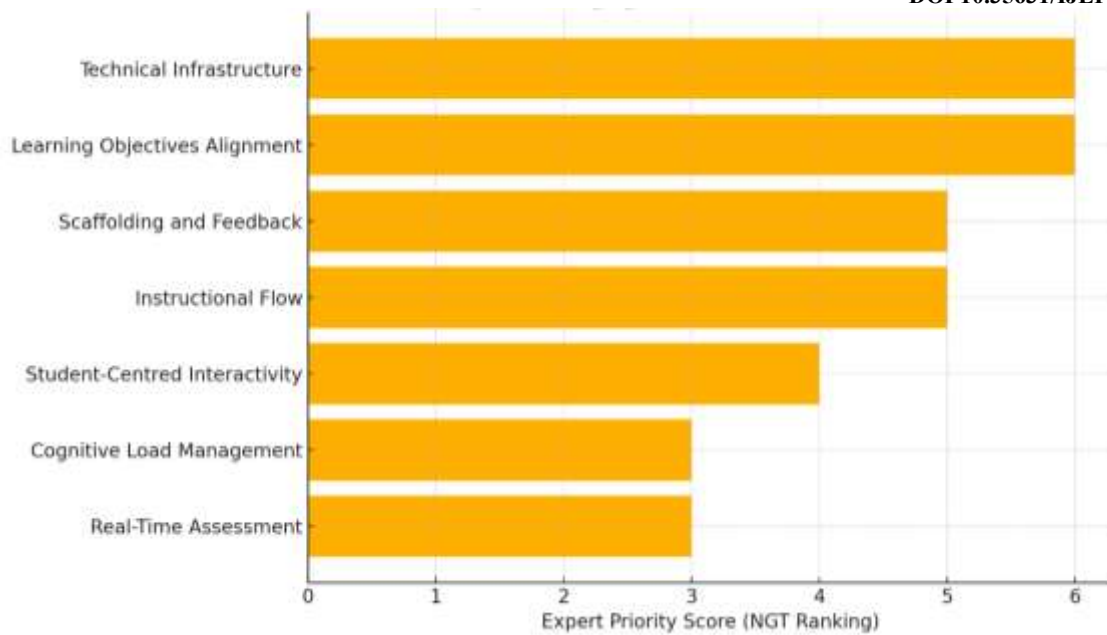


Figure 4: Priority of Pedagogical Elements for AR Based TVET Instruction

Structuring Pedagogical Relationships (ISM Analysis)

Following the identification of elements, an Interpretive Structural Modelling (ISM) process was conducted to analyse the interdependencies among them. Experts completed a Structural Self-Interaction Matrix (SSIM) through pairwise comparisons of each pedagogical element. These relationships were encoded and processed using MICMAC software to derive a reachability matrix and perform level partitioning. The ISM analysis revealed a three-level hierarchy:

1. Level 1 (Driving Elements):
 - a. Outcome Alignment
 - b. Technological Infrastructure
2. Level 2 (Linkage Elements):
 - a. Instructional Sequencing
 - b. Scaffolding & Feedback
 - c. Learner Engagement
3. Level 3 (Dependent Elements):
 - a. Real-Time Assessment
 - b. Cognitive Load Management

The findings from the Nominal Group Technique (NGT) revealed seven key pedagogical elements that experts identified as essential in developing an augmented reality (AR)-based teaching model for skill-based TVET instruction. The highest-rated elements were Outcome Alignment and Technological Infrastructure, indicating that any AR integration must begin with clear educational goals and strong technological readiness.

Mid-ranked components, such as Instructional Sequencing, Scaffolding & Feedback, and Learner Engagement, highlight the importance of structured content delivery, guided learning support, and active participation, all of which are closely linked to constructivist learning theories and cognitive design principles.

Meanwhile, Real-Time Assessment and Cognitive Load Management were ranked lower, likely due to current limitations in AR tool capabilities and the abstract nature of these concepts. However, these components remain important for future enhancements as AR technologies mature. Comparisons with previous studies affirm the significance of aligning AR use with pedagogical frameworks, though variations exist depending on context and technological readiness. Collectively, these results imply that any AR-based instructional model should begin with foundational pedagogical and infrastructural considerations, be progressively supported by structured sequencing, scaffolding, and engagement, and eventually incorporate assessment and cognitive optimization.

The AR-T model comprises 22 instructional activities classified under three pedagogical domains: AR Contents (e.g., concept explanation, equipment overview), AR Activities (e.g., simulation tasks, virtual manipulation), and AR Assessment (e.g., performance tracking, AR-based quizzes). The augmented reality model for skills training is illustrated in Figure 5.

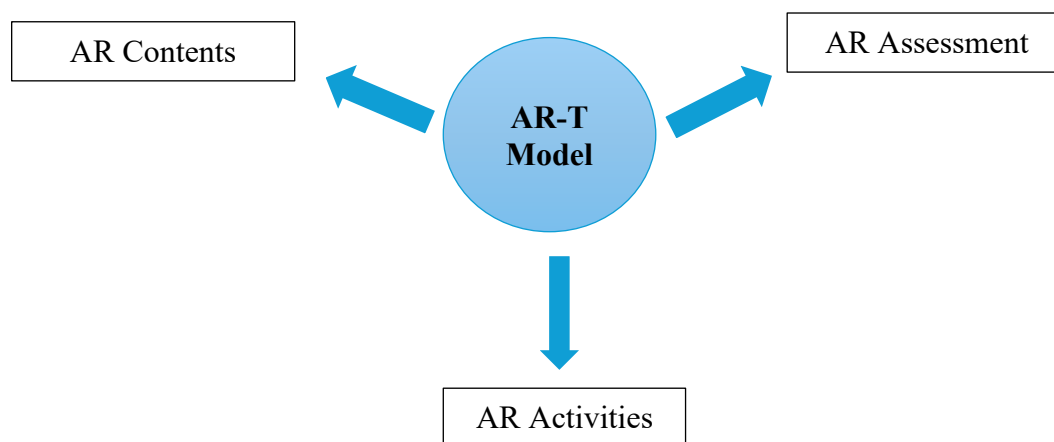


Figure 5: The Main Category of AR-T Model

Discussion

The findings of this study reveal strong expert consensus on the essential pedagogical elements required for AR integration in TVET, validating the AR-T Model as a structured and contextually relevant framework. With consensus levels exceeding 80% across all six elements and three domains, the model demonstrates high credibility and applicability within skills-based training. These results align with prior research, such as Mustapha et al. (2019) and OECD (2020), which emphasise that early adoption of immersive technologies enhances learner engagement, knowledge retention, and skill transfer. Beyond validating the AR-T Model, the study highlights broader implications for AR pedagogy in TVET. International experiences demonstrate that AR adoption is not solely about technological tools but also about systemic readiness and teacher competency. For instance, Finland's vocational education

system integrates AR with problem-based learning to develop adaptive skills for Industry 4.0, while Singapore's Institute of Technical Education (ITE) combines AR with simulation labs to strengthen practical training. Similarly, Germany has advanced "dual system" programs embedding AR in apprenticeship schemes to enhance workplace realism. These cases illustrate that AR pedagogy must be embedded in holistic training ecosystems supported by policy, infrastructure, and continuous instructor development.

However, the Malaysian context presents challenges that must be critically acknowledged. Unequal access to digital infrastructure, particularly in rural training centres, risks widening the digital divide. Teacher readiness also emerges as a critical barrier; instructors may possess limited confidence or pedagogical training in integrating AR tools effectively, echoing Sharma et al. (2022). Additionally, curriculum overload could hinder the systematic adoption of AR-based pedagogy unless clear guidelines and time allocations are introduced. Without addressing these barriers, the AR-T Model's transformative potential may remain underutilised. Nevertheless, the study demonstrates that with targeted investment in professional development, infrastructure, and curriculum alignment, AR has the potential to significantly elevate TVET pedagogy. By situating Malaysia's approach within global best practices while adapting to local realities, the AR-T Model provides a roadmap for embedding immersive technologies in skills training. From a policy perspective, the findings highlight the urgency for structured national strategies that support scalability, ensure equitable access, and integrate AR pedagogy into future curriculum reforms. This will not only strengthen Malaysia's TVET system but also align it with the broader competencies demanded by Industry 4.0.

Conclusion

This study set out to design and validate an augmented reality (AR)-based teaching model to support immersive pedagogy in skill-based Technical and Vocational Education and Training (TVET). The research specifically aimed to explore the instructional needs of TVET instructors and identify core pedagogical elements required for effective AR integration (Chiew & Sung, 2022). Key findings highlight that the alignment of AR applications with learning objectives and the availability of adequate technical infrastructure were considered foundational by expert participants (Indarta et al., 2025; He & Li, 2024). In addition, instructional flow, scaffolding, and student-centred interactivity emerged as pivotal in supporting meaningful and engaging skill-based learning experiences (Pathak, 2024; Krüger & Bodemer, 2022).

Through Interpretive Structural Modelling (ISM) and validation via the Fuzzy Delphi Method (FDM), the study successfully established a pedagogically sound and expert-endorsed AR teaching model (Richey & Klein, 2007; Okoli & Pawlowski, 2004). The findings affirm that the successful integration of AR in TVET instruction must be grounded in structured pedagogical design, supported by systemic readiness and expert consensus (Garzón et al., 2019; Czerkowski & Berti, 2021).

This study contributes to the growing body of knowledge on immersive learning technologies in vocational education by offering a validated framework that can inform instructional design, policy development, and institutional planning (Ghobakhloo, 2020; Majlis TVET Negara, 2024). It also underscores the necessity of professional development initiatives to equip instructors with the competencies required to adopt AR effectively (Osypova et al., 2021; Lester & Hofmann, 2020). Nonetheless, the study is limited by its context-specific scope and

relatively small expert sample, which may constrain the broader applicability of its findings (Akçayır & Akçayır, 2017). Future research should examine the model's effectiveness across diverse institutional and cultural contexts using larger, multi-stakeholder samples and longitudinal evaluations of classroom implementation outcomes (Alzahrani, 2020; Ren et al., 2023).

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