Transforming Vocational Education Pedagogy: Integrating Extended Reality and Problem-Immersive Experiences to Foster 21st-Century 6C Competencies

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Abstract

Vocational education has been challenged to develop the 21st-century 6C competencies, namely critical thinking, creativity, collaboration, communication, citizenship, and character, especially at a highly fast rate of technological change. Conventional pedagogical models do not have enough of the immersion and real-world engagement that can help to develop these abilities. The current study was research that examined the use of Extended Reality (XR) in conjunction with problem-immersive learning projects to promote the development of 6C competencies in vocational learners. The quasi-experimental design was used, which included 120 vocational students (N=120) and were either placed in experimental group (XR-based learning) or control group (traditional instruction) in a 12-week period. Pre-test and post-test assessment based on observation checklists and competency-based performance test were used to collect data. The ANCOVA and Structural Equation Modelling (SEM) analysis of the results showed that the experimental group had significantly higher improvements in all 6Cs, with significant effects in critical thinking ($\eta 2 = 0.18$), creativity ($\eta 2 = 0.22$), and collaboration ($\eta 2 = 0.15$). The XR simulations and collaborative problem-solving conditions proved to be very effective in terms of communication, character, and citizenship development. The results show that XR and problem-immersive learning integrated can be an effective and applicable model to narrow the gap between theory and industry in vocational education. To make the proposed idea work, this research highlights the importance of specific teacher professional learning in XR pedagogy, redesigning the strategic curriculum, and the supportive policy framework to ensure the broader application of immersive learning models to Technical and Vocational Education and Training (TVET).

1. Introduction

The fourth industrial revolution and accelerated digitalization are changing the industrial sectors and the competencies that the workforce needs in the world. Vocational education, which is a fundamental pillar in training qualified professionals, is now confronted by the need to go beyond technical training to the development of the 21st-century competencies dubbed as the 6Cs, which are critical thinking, creativity, collaboration, communication, citizenship and character. These are the competencies that are core in global policies such as the SDG 4 of the UN on quality education. Nonetheless, the traditional vocational instruction approaches, which usually focus on memorization and training on the procedures, do not offer the real-life experiences of creative problem solving that would foster the development of these skills.

Vocational education is an institution that experiences several issues in the arrival of competitive and flexible graduates to meet industrial advancements. The gap in graduate skills and needs of the industry is one of the primary issues, particularly the 6C Skills (Collaboration, Communication, Critical Thinking, Creativity, Character, and Computational Thinking) which remains low. A significant gap persists between the graduate competencies and industry requirements, especially with the 6Cs. The traditional curricula are often un-interactive and out of context whereas physical barriers such as a lack of tools, laboratory space as well as safety issues in the industrial practice also hinder the successful skill acquisition process. One such solution that can be used is the Extended Reality (XR) technology that can provide an interactive simulated learning environment where students are able to safely engage with industrial processes. XR would allow cultivating technical and critical collaborative skills in combination with problem-immersive pedagogical strategies.

The application of immersive technologies like Extended Reality (XR) in the field of higher education and especially, in Technology and Vocational Education (TVET) has gained momentum in enhancing the quality of experiential education. Although the literature shows that XR technologies such as the Virtual and Augmented Reality can be used to develop technical skills by simulation (Fernández-Cerero et al., 2025; Ilić et al., 2021; Jang et al., 2021; Kuleto et al., 2023; Ota et al., 2024) and that Problem-Based Learning (PBL) can be used in developing critical thinking (Sharma, 2021), there is still a research gap. This is because most studies concentrate on the individual skills or technologies and little has been done to explore the potential synergy of this combination (Jiang et al., 2024; Kuleto et al., 2021; Pregowska et al., 2023). More so, it is thought that this study will be used in other learning institutions to make their technology-based learning environment more adaptable, inclusive, and industry oriented.

The novelty of this study is developing an XR-based learning model that is not only concerned with technical skills but also trains the 6C competencies that are critical during the industrial revolutions of 4.0 and 5.0. Moreover, this study will deal with the constraints that are frequently experienced in vocational training, including absence of realistic teaching tools, insufficient laboratory room, and safety considerations, through a realistic, interactive, and problem-solving-oriented XR-based industrial simulation. In this style, this study will not only be a part of the innovation of digital learning but also enhance the theoretical background on the efficiency of immersive technology in equipping graduates who are more adaptive, creative and prepared to meet the requirements of the contemporary industry. The contribution of this study is two-fold. Theoretically, it is relevant to the body of digital pedagogy and competency development because it offers a proven framework on how to incorporate immersive technology with constructivist theory of learning to develop 6Cs. In practice, it provides an operational XR-integrated model of learning instruction to teachers, a way of overcoming resource and safety limitations in institutions teaching vocational skills, and proofs that can be used by policymakers to make vocational education more up to date. In so doing, this study aims at preparing graduates to be adaptive, innovative and collaborative to meet the future job market. The proposed study is going to fill this gap by designing and testing an integrated XR and problem-immersive model of learning. The research is guided by the following questions:

- How to develop the Problem-Immersive Experience (PIE) integrated Extended Reality (XR) to enhance 6C competencies in vocational education?
- How does the developed model of Problem-Immersive Experience based integrated XR technology effectively improve the competencies of the 6C attributes of the students relative to the traditional delivery methods?

2. Literature Review

2.1 Extended Reality (XR) for Learning

Extended Reality or XR refers to a variety of immersive technologies. XR combines several different technologies including virtual reality, augmented reality, and mixed reality. It is used for various training purposes. XR supports theories of learning for example, constructivist and experiential approaches whereby authentic tasks can be deployed. Situated problem solving is also made possible along with embodied interaction with complex phenomena that cannot otherwise be accomplished because of it being hazardous, expensive, or inaccessible

(Fernández-Cerero et al., 2025). Although XR has those benefits, their effectiveness is moderated by cognitive load considerations. Solutions that optimally engage the senses (e.g., immersion and presence) can lead to greater engagement and motivation to learn. The educational affordances of it can be divided into three thematic domains, namely, learning affordances, design principles, and barriers.

- XR Affordances

  XR makes situated learning and embodied cognition possible since it allows learners to engage with moving phenomena in the real world. Research indicates that XR can be effectively used to facilitate engagement, presence, and motivation together with reflective and generative learning tasks, including self-explanation or teaching-back (Kuleto et al., 2023). In the case of TVET, the affordances of XR are a procedural training, safety and risk simulation, spatial reasoning, and teamwork development - all of which are related to the industry required competencies.

- Design Principles

  Good XR design (conforms to such principles as goal orientation, scaffolding, and reflective debriefing. The principles make sure that immersive experiences are not experiential per se but cognitively organized. According to the immersion-plus-guidance paradigm, the best learning results can be achieved in the instances where immersion experiences are supplemented by the instructional cues, timely feedback, and metacognitive reflection (Sharma, 2021). Meaningful interactivity should replace immersion per se as instructional designers should regard this type of interaction as a predictor of effective learning, as controllability, feedback timing, and relevance to learning goals are such.

- Barriers and Constraints

  Regardless of these benefits, the XR integration encounters systemic issues in the form of high hardware prices, lack of faculty preparedness, and curriculum mismatch (Jang et al., 2021; Kuleto et al., 2021). The cognitive overload can also set in when scaffolding of immersive tasks is not done in the right way. These obstacles in TVET settings need to be countered with institutional support, professional development, and cross-disciplinary collaboration.

2.2 Problem-Based Learning as Based Model for Problem-Immersive Experience (PIE) Model

Problem-Based Learning (PBL) is a learner-centred strategy based on the authentic inquiry, collaboration, and reflection (Aslan, 2021). The philosophy of PBL is expanded into immersive, technology-enhanced environments in the Problem-Immersive Experience (PIE) model, which increase the level of immersion and engagement. Where PBL aims at the cognitive inquiry by real world problems, PIE adds another dimension of embodied interaction and digital immersion, by letting learners live through the problem scenario. By using these characteristics, PIE uses XR technologies to deliver authentic, safe, and performance-based learning, which reflects workplace requirements. It similarly deals with PBL limitations, including imbalance in facilitator knowledge and novices' congestion (Kirschner et al., 2006) through enactment of adaptive scaffolds and incremental complexity. The model will help develop the 6C competencies of Collaboration, Communication, Critical Thinking, Creativity, Character, and Computer Thinking with authentic and immersive problem solving that meets the expectations of Industry 4.0 (Hmelo-Silver, 2004; Savin-baden, 2014).

Problem-Immersive Experience (PIE) model builds based on Problem-Based Learning (PBL) by incorporating elements of immersive technologies to increase authenticity and immersion in problem solving. Whereas classical PBL focuses on cognitive inquiry by applying real-life problems and discussion, and reflection, PIE contextualizes them in digitally simulated contexts in which learners can experiment and manipulate elaborate situations. In PBL, the process of reflection is usually done through group discussion and tutor feedback whereas in PIE it is intensified by use of digital debriefing, performance replays, and analytics that enable learners to monitor and assess their problem-solving activities. Furthermore, the cooperation in PBL is usually in real life group environment, whereas PIE allows synchronous and asynchronous cooperation in XR-mediated space, increasing the possibility of international and cross-context communication. The role of tutor also change-s of facilitator of inquiry in PBL to learning orchestrator in PIE; the tutor will be in control of cognitive scaffolding and technological interaction. Quintessentially, PIE keeps the pedagogical strengths of PBL, namely: authentically oriented problems, learner autonomy, collaboration, and reflection, but builds on them with immersive experiences that offer greater contextual realism, adaptive feedback, and performance-based learning that are consistent with Industry 4.0 competencies.

2.3 6C Skill (Collaboration, Communication, Critical Thinking, Creativity, Character, and Computational Thinking)

The requirements of the 21st century have resulted in the development of the 6C Skills model that includes collaboration, communication, critical thinking, creativity, character, and computational thinking. These are

considered as the necessary competency levels of equipping the learner to succeed in a more complex, technology-enhanced, and globalized world (Huisman & Stensaker, 2022). Teamwork has been extensively known to be based on collaboration in both academic and professional practices. It does focus on teamwork, collective responsibility, and the possibility to cooperate in multifunctional teams (OECD, 2018). Communication is a closely related concept, and it encompasses not only the language fluency but also the skills to communicate ideas in a persuasive manner with modalities and across cultures, a skill set that is considered important in knowledge economies (Trilling & Fadel, 2009).

The 6C skills represents a holistic model for 21st-century learning. Within this study, each competency is operationalized through measurable indicators to ensure construct validity: (1) Collaboration consists of active team participation, task responsibility, collective problem solving and adaptability and flexibility in XR/PIE settings indicators; (2) Communication consists of clarity in expressing ideas, active listening skills, communication-based collaboration and effective communication indicators; (3) Critical thinking skill consist of problem statement, evidence (selecting and using information to investigate a point of view or conclusion), influence of context and assumptions, student position (perspective, hypothesis), conclusions and related results (implications and consequences) indicators; (4) Creative thinking skill consists of acquiring competence, taking risks, solving problems, embracing contradictions, thinking innovatively, connecting, synthesizing, and transforming indicators; (5) Character consists of responsibility, integrity, resilience, empathy and respect indicators; (6) Computational thinking skill consists of decomposition, pattern recognition, abstraction, algorithmic thinking, automation, creating data, collecting data, manipulating data, visualizing and analysing indicators.
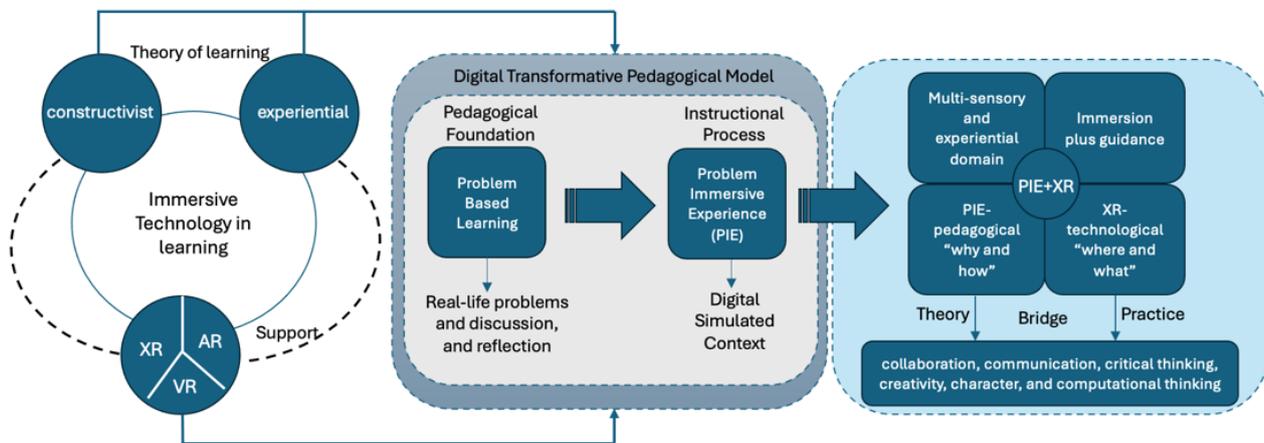

Fig. 1 *Conceptual framework*

3. Methods

3.1 Research Type and Procedures

The study is based on a quasi-experimental control and experimental design to determine the effect of XR-enhanced PIE pedagogy on the 6C competencies (collaboration, communication, critical thinking, creativity, character, and computational thinking) in learners. The needs assessment of students, lecturers and industry and literature reviews were carried out to develop proper solutions. Then, the interaction XR-based learning model and simulation scenarios have been created in accordance with the higher education curriculum. VR/AR as XR-based learning media were created and complemented with Problem-Immersive Experience-Based Learning approach to enhance the 6C skills of students. Experts then validated the model to establish the strengths and weaknesses of the model. Then refined and validated model was applied to the students to provide the evaluation of the model in terms of its effectiveness in improving 6C skills of the students. This was followed by a phase of monitoring to determine the effectiveness of learning, technical complications and responses of students and lecturers. The evaluation phase was based on the results of this monitoring and was used to analyse the impact of XR-based learning.

3.2 Research Sampling

Purposive sampling method was used together with cluster random sampling. The initial stage applied the purposive sampling method to identify vocational institutions that would be of interest to the study area,

Universitas Negeri Padang, Department of Mechanical Engineering year 2 taking electrical and electronic fundamental course. The sample was defined at the level of the institution at the class or the study group (cluster) after the choice of the institution. Out of every institution, those classes that passed the inclusion criteria were sampled and randomly divided into two categories the experimental group which would receive Extended Reality (XR)-based learning intervention combined with Problem-Immersive Experience (PIE) and a control group which would maintain the use of the traditional learning method. The overall number of students obtained was 80 of whom 40 students belonged to the experimental group and 40 students belonged to the control group. The combination of purposive and cluster random sampling was selected to guarantee the occurrence of various vocational settings and reduce the selection bias, thus, to enable the research findings to be more valid and to make the extrapolation to similar vocational learning settings. The estimation of the minimum sample size needed to have a medium effect size (Cohen d = 0.5), alpha = 0.05, and power (1- 0.8) was carried out with G Power 3.1. The outcome is that there were at least 64 participants, thus, 80 students (40 experimental and 40 control) were included to give sufficient statistical power to identify significant group differences.

3.3 Internal Validity Control

To maintain internal validity, this study employed several control strategies, as follows: (1) The use of a pretest-post-test design with a control group ensured that differences in outcomes could be more accurately attributed to the XR-PIE intervention rather than to external factors; (2) Cluster randomization or matching based on baseline scores was employed to reduce selection bias between groups; (3) Standardized instruction and curriculum were applied to both groups, ensuring that differences stemmed solely from the intervention method, not variations in materials or instructors; (4) Partial blinding of the outcome raters ensured that the 6C competency evaluation was not influenced by knowledge of the participant group; (5) Control for history, maturation, and instrument effects was maintained by a uniform intervention schedule across groups, the use of validated instruments, and rater training to ensure measurement consistency; (6) Fidelity monitoring was conducted through classroom observations, XR log recordings, and instructor reports to ensure the intervention was proceeding as planned; (7) In a bid to eliminate the influence of instructors, the two groups were instructed by the same rank and teaching experience instructors. A collaborative educational exercise was held to normalize the delivery of instructions, assessment processes and XR device use. The same instructional designer oversaw the rotation of every instructor between control and experimental sessions in different weeks.; (8) The number of preventive measures was taken to reduce the possibility of contamination between the control and the experimental group. The two classes were taught differently in different classes and time. Each of the groups had separate instructors and facilitators who were not supposed to interchange instructional methods and materials. Students were asked not to disseminate learning activities and experience throughout the study period, and all sessions were observed to facilitate procedural fidelity. These measures worked well to minimize the chances of information crossover and integrity of the experimental comparison.

3.4 Research Instrument

This study used several quantitative instruments to assess the influence of the integration of Extended Reality (XR) and Problem-Immersive Experience (PIE) on the 6C competencies of vocational students.

Table 1 *Summary of Instruments*

Instruments	6C Competencies Measured	Form	Scale
Pretest and Post-test	Critical Thinking, Computational Thinking	Multiple-choice	0 – 100
Performance Rubric	Critical Thinking, Computational Thinking, Communication, Collaboration, Creativity, Character	Rubric, case-based problems	4-point rating scale
PIE and XR Validity Questionnaires	Expert judgemental validity questionnaires	Likert-scale survey items	1 (Strongly Disagree) – 5 (Strongly Agree)

3.5 Pilot Study

A pilot study was done before the actual research was done, and it focused on the possibility of the intervention design, research instruments, and technical preparedness to apply XR and Problem-Immersive Experience (PIE) in the format of vocational education. In the pilot study, there was a purposive selection of 15 vocational engineering students in a small class. The session started with an orientation to present the participants to the use of XR tools and PIE procedures and train the instructors on XR-based learning scenarios in a few moments. Instrument trials followed (pre-test/ post-test of the 6C competencies (collaboration, communication, critical thinking, creativity, character and computational thinking), performance rubric and learning perception questionnaire) to ascertain reliability, validity and readability of the items. Students went through a single PIE XR-based learning cycle during the pilot intervention phase. To evaluate the implementation of the intervention, the degree of engagement in the process, and possible technical difficulties, this process was observed in classrooms, video-recorded the XR activities, and made notes as an instructor. A formative evaluation was done after the intervention by conducting short interviews with students and instructors to determine what students and instructors learned, technical challenges (e.g., motion sickness, device restraints), and the practicability of the assessment tool. Findings of the pilot study were used to modify the study design, such as instruments, changes to the intervention duration, improvements in training of instructors, and XR risk mitigation protocol.

The internal consistency reliability was checked by Cronbach 0.82-93 subscale reliability that was high in range. Rating consistency was established through the calculation of inter-rater reliability which was the intraclass correlation coefficient (ICC = 0.89).

Table 2 *Instrument reliability*

Instruments	Cronbach's Alpha Coefficients
Critical Thinking	0.824
Computational Thinking	0.864
Communication	0.931
Collaboration	0.910
Creativity	0.853
Character	0.884

3.6 Data Analysis Technique and Hypotheses Development

A detailed statistical analysis plan (model analysis), consistent with the research instrument, is given below. The analysis will be based on the intention-to-treat principle (all participants will be taken into consideration based on their initial assignment). The significance level α was determined as 0.05 (two-tailed). In all hypothesis tests, report p-values and 95 percent confidence intervals. They will use statistical software like SPSS and Smart PLS.

Table 3 *Data analysis technique*

Hypotheses	Data Analysis Technique
There was a significant difference in students' Critical Thinking, Computational Thinking, Communication before and after implementing XR integration and Problem-Immersive Experience.	Paired sample t-test
There was a significant difference in the improvement of 6C competencies between students who learned with XR integration and Problem-Immersive Experience and students who learned with conventional methods.	Independent sample t-test
There was a significant difference in student engagement in XR integration and Problem-Immersive Experience-based learning based on gender.	ANCOVA
The implementation of XR integration and Problem-Immersive Experience significantly increased the likelihood of students achieving 6C competencies above the minimum standard.	Regression analysis
PIE and XR are valid and can be implemented in learning	KMO

Before the inferential testing, the assumptions of normality (Shapiro Wilk) and homogeneity of variances (Levene test) and independence of observations were checked. In the case of within group differences, paired sample t-tests were applied; in the case of between group comparison; independent sample t-tests and two ways

ANOVA were utilized. Also, the magnitude of treatment effects was determined using Cohen d used to compute the mean differences and partial etas used to compute the ANOVA results. The small, medium, and large benchmarks provided by Cohen (1988) were used to interpret the effect sizes (0.2, 0.5, and 0.8). Reliability diagnostics, correlation studies and regression modelling were conducted to investigate the relationships between subcomponents of 6C competencies and engagement measures. The statistical significance was fixed at $p < 0.05$.

3.7 Ethical Consideration

This study involved a low-risk and did not include any sensitive or personally identifiable data. Therefore, formal ethical approval was not required in accordance with the institutional research policy of Lembaga Penelitian dan Pengabdian Masyarakat Universitas Negeri Padang. All information was gathered in the form of anonymity and well secured in password databases available to the research team only. Data analysis also involved the removal of personal identifiers because of the confidentiality and the adherence to the data protection rules. Considering the application of XR technology, certain health and safety measures were applied. The participants were oriented on how to use headsets, and the sessions were not drawn too long to minimize the chances of cybersickness, eye strain, or fatigue. XR space was built in such a way to reduce disorientation, and participants were allowed to pause the activity as soon as they felt uncomfortable. Furthermore, no biometric or personal movement data were recorded after the duration of the study to secure privacy and safety of data. In general, the study was conducted in accordance with the principles of beneficence, non-maleficence, autonomy, and justice, which ensured the complete safety and protection of the participants of the research.

4. Results and Discussions

To support the educational requirements of the 21st century and the necessity of new digital modes of learning, the current work presents the concept of a Problem-Immersive Experience (PIE) learning framework mediated using Augmented Reality (AR) and Virtual Reality (VR). The model will incorporate the notion of problem-based learning with immersive technologies, thus allowing learners to experience the principles of problem-solving, excursive exploration, and knowledge building in groups. As seen in the syntax, the PIE framework offers a detailed learning journey that helps students orientate problems, engage in deep exploration, collaborative analysis, solution generation, and reflection, and introduce the nurture of the six competencies (6Cs). This strategy will not only promote cognitive activities but also promote transformational learning experiences that will equip students to succeed in digitally motivated and challenging real-world situations.

Table 4 *Problem Immersive Experience (PIE) procedures*

Syntax	Objective	Activities
Problem Orientation	Stimulate curiosity and introduce real-world problems relevant to the subject.	The instructor presents an authentic problem scenario (e.g., machine failure, product design challenge, or scientific phenomenon) using Augmented Reality (AR) to visualize 3D objects as triggers.
		Students discuss the context, identify initial issues, and connect them to learning goals.
Problem Definition & Hypothesis	Define the core problem, formulate guiding questions, and propose initial hypotheses.	The instructor sets boundaries regarding resources, time, and XR tools.
		Students, working in groups, identify the main problem, formulate research questions, and propose possible solutions.
Immersive Exploration	Provide experiential learning opportunities through immersive environments.	Virtual Reality (VR): Students enter interactive simulations
		AR: Overlays additional information (e.g., instructions, animations, technical data) onto real-world objects.
		Each group member plays a specific role (navigator, recorder, analyst, communicator).
Collaborative Analysis		The instructor provides scaffolding through critical questions and formative feedback.

| Syntax	Objective	Activities
	Interpret findings and develop potential solutions collaboratively.	Groups analyse XR data, test ideas, and connect findings with theoretical knowledge. They create flowcharts or proposed procedures.
Prototype Development & Iteration	Develop and refine a practical solution or prototype.	Students design and develop prototypes (digital or physical). Documentation of design changes and rationales is required.
Presentation & Peer Review	Communicate findings and solutions while engaging in critical peer evaluation.	Groups present their solutions. Peer groups provide constructive criticism and alternative perspectives.
Reflection & Conclusion	Deepen understanding and assess personal and group learning progress.	Students reflect individually and collectively on their learning experiences and competencies developed. The instructor synthesizes key concepts and real-world implications.
Assessment	Measuring the achievement of 21st century competencies (6C).	Formative: Conducted during exploration, group discussions, and XR interactions. Summative: Based on prototypes, presentations, reflective reports, and a 6C rubric (critical thinking, creativity, collaboration, communication, citizenship, and character).
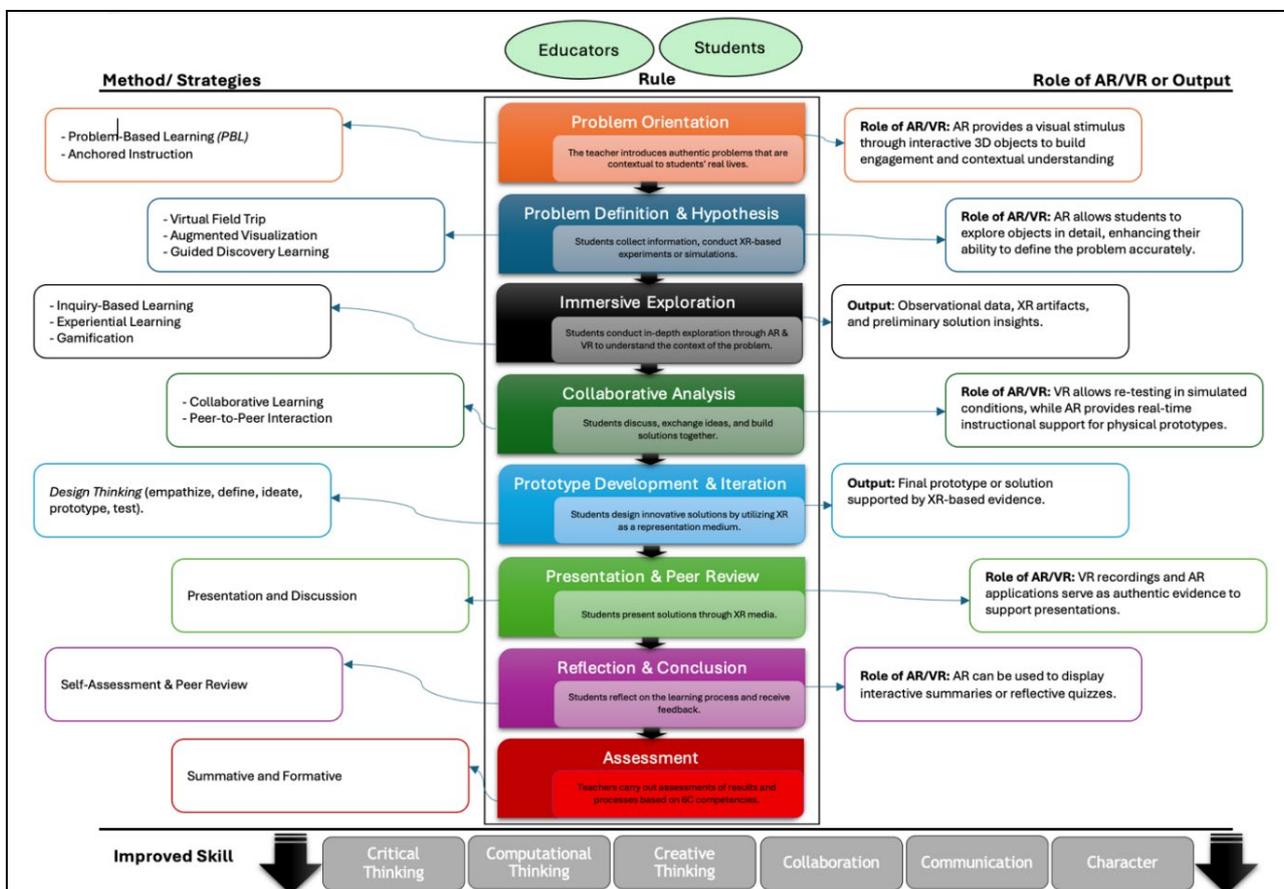
Fig. 2 *Problem Immersive Experience (PIE) syntax*

The syntax of Problem-Immersive Experience (PIE) learning with augmented reality (AR) and virtual reality (VR) is demonstrated in the image above. It involves starting with the Problem Orientation stage where AR will trigger the interest of students through visualization of 3D objects about real life problems. Then, during the Problem Definition phase, students will create problems and hypotheses to study the specifics of an object or a phenomenon with the help of AR. The Immersive Exploration stage offers an immersive learning experience in VR, enabling students to simulate, observe, or troubleshoot, with the AR overlaying further information. Next, the

Collaborative Analysis stage helps students to analyse the data presented by XR explorations, experiment with ideas, and find solutions, VR serves as a test space, and AR is used as a kind of additional teaching.

During the Prototype Development phase, students create solutions or prototypes which are tested and iterated in VR, and AR is used to visualize and interact with physical prototypes. The resulting solutions are tabled at the Presentation and Peer Review stage, through footage of VR or AR demonstrations, followed by peer feedback. The second one is Reflection & Conclusion, where the students compare their learning experiences with the 21st-century skill sets (6Cs) they have acquired, with AR helping them to summarize or complete reflective quizzes. Lastly, the Assessment level is implemented by applying a 6C rubric and XR-based learning artifacts as evidence of accomplishment. Overall, this syntax shows how AR and VR can be incorporated in PIE to make learning more authentic, immersive, collaborative, and effective in developing 21st-century competencies.

Table 5 *Variable feasibility analysis results*

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.834	Meritorious sampling adequacy
Bartlett's Test of Sphericity	Approx. Chi-Square	148.886	
	df	28	Significant
	Sig.	0.009	

Notes:
KMO = Kaiser-Meyer-Olkin; this denotes a percentage of the variance among variables that could be common variance.
Interpretation: 0.90-1.00 = Marvelous; 0.80-0.89 = Meritorious; 0.70-0.79 = Middling; 0.60-0.69 = Mediocre; less than 0.60 = Not suitable to be included in the factor analysis.
Bartlett Test of Sphericity: 2 = Chi-square statistic (unitless) df = Degrees of freedom, Sig. (p) = Probability value. p 0.05 denotes that there is enough correlation among items to work with factor analysis.
The higher is the KMO, the stronger the shared variance; the significant is the Bartletts test, the more suitable is the extraction of factors.

As indicated in Table 5, the Kaiser-Meyer-Olkin (KMO) measure of 0.834, which is above the 0.600 threshold, showed that all variables can be analysed further. The Bartlett Test of Sphericity was also tested to assess correlation among the variables with significance value of 0.009 < 0.050 which means the factor analysis can be done. The number of factors created is determined by extracting of the factor with the principal component analysis method. From this process there are 2 main outputs which include Communalities, which show how many the component is contributing to the Internal Factor measured through the Extraction value in percentage & Total variance explained which shows how many factors are formed. After analysing the other eight phases, it appears that a single factor emerges, signifying a novel construct, which brings together these eight phases into one learning model. The communalities result which is shown below also allows a better understanding of each component's contribution to this factor.

Table 6 *Variable feasibility analysis results*

	Initial	Extraction	Interpretation
Syntax_1	1.000	.665	Moderate loading
Syntax_2	1.000	.734	Strong loading
Syntax_3	1.000	.881	Strong loading
Syntax_4	1.000	.669	Moderate loading
Syntax_5	1.000	.815	Strong loading
Syntax_6	1.000	.643	Moderate loading
Syntax_7	1.000	.674	Moderate loading
Syntax_8	1.000	.821	Strong loading

Extraction Method: Principal Component Analysis
Effect indicators: ≥ 0.70 = strong factor loading (high contribution), 0.50 – 0.69 = moderate factor loading (acceptable), < 0.50 = weak loading (should be consideration)

Referring to Table 6, it is shown that syntax 1 accounts for 66.5% of the variance in the developed model, syntax 2 contributes 73.4%, syntax 3 contributes 88.1%, syntax 4 explains 66.9%, syntax 5 explains 81.5%, syntax 6 contributes the highest with 64.3%, syntax 7 explains 67.4%, and syntax 8 explains 82.1% of the model. These findings, derived from the total variance explained analysis, indicate the proportion of variance each phase contributes and serve as the basis for determining the number of factors generated through the factor analysis.

Table 7 *Total factor score*

Component	Initial Eigenvalues			Effect Indicators	Interpretation
	Total	% of Variance	Cumulative %		
1	5.904	73.778	73.778	Eigenvalue > 1	Retained Factor
2	.818	10.225	84.003	Eigenvalue < 1	Not Retained
3	.560	7.000	91.003	Eigenvalue < 1	Not Retained
4	.398	4.975	95.978	Eigenvalue < 1	Not Retained
5	.322	4.022	100.000	Eigenvalue < 1	Not Retained

Extraction Method: Principal Component Analysis.

According to Table 7, the analysis shows that no one factor was extracted with an eigenvalue greater than 1. This factor recorded an eigenvalue of 5.904 and was able to account for 73.778% of the overall model, The cumulative variance above 70% suggests that the extracted factor sufficiently represents the shared variance among observed variables. Based on the Total Variance Explained, it can be concluded that a learning model consisting of eight phases was successfully established. Since only a single component was generated, factor rotation was not performed, serving as evidence of the model's construct validity.

Table 8 *Total components matrix*

	Components			
	1	2	3	4
Syntax_1	.721	.060	-.270	-.262
Syntax_2	.652	.456	.178	.264
Syntax_3	-.215	.063	.368	.834
Syntax_4	-.693	.433	.020	-.026
Syntax_5	-.571	.574	-.058	-.396
Syntax_6	-.200	-.322	-.677	.204
Syntax_7	.114	-.119	.699	-.399
Syntax_8	.310	.805	-.246	.123

Extraction Method: Principal Component Analysis.
a. 4 components extracted.

Referring to Table 8, the component matrix indicates that a single factor group accommodates all the analysed components. This finding suggests that every phase is confirmed as valid in constructing the problem-immersive experience learning model. A clearer overview of how these phases combine into a single model can be observed in Figure 3, which presents the Scree Plot.
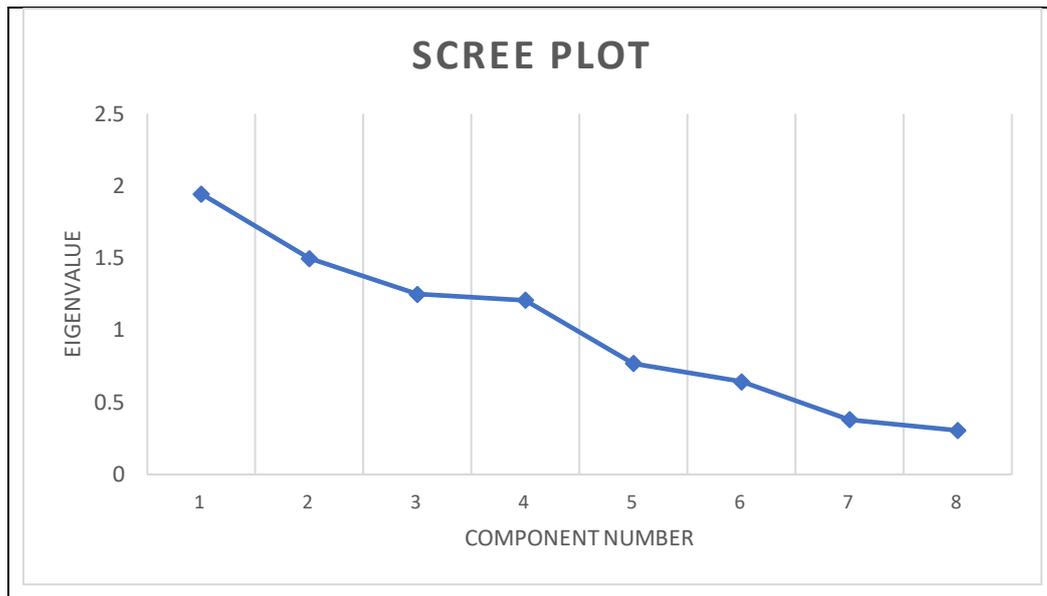
Fig. 3 *Scree plot of the formation of phases into a model*

Based on Figure 3, the analysis reveals that out of the eight components examined, no one component possesses an eigenvalue greater than 1. This indicates that all eight components converge into a single factor. When linked to the syntax development in testing this learning model, it can be concluded that the eight phases collectively form a unified model. Therefore, the learning model is considered valid according to the results of factor analysis.

Table 9 *Paired sample t-test*

Observations	Groups	N (Number of participants)	Paired Sample T-test			
			Mean Differences	t-value	Df (degree of freedom)	P-Value
Pretest-Posttest analysis of Critical Thinking	Experimental	40	29.4	19.565	39	0.001
	Control	40	6.8	1.520	39	0.491
Pretest-Posttest analysis of Computational Thinking	Experimental	40	24.73	19.041	39	0.000
	Control	40	1.25	0.674	39	0.504

Paired samples t-test was conducted to analysis the pretest and the post-test are different in terms of critical and computational thinking for both experimental and control groups. The results of the experimental group indicated a critical thinking mean increase of 29.4 points which was significant t(39) = 19.565, p = 0.001. According to this finding, teaching students through the integration of XR and Problem-Immersive Experience-based learning significantly promotes students' ability to analyse, evaluate and solve problems. On the other hand, the control group's pre-test and post-test mean increase of 6.8 points was not significant, t(39) = 1.52, p = 0.491, indicating that traditional learning methods are not effective in enhancing one's critical thinking skills.

Likewise, for computational thinking, the experimental group has an average difference of 24.73 points with t(39) = 19.041, p = 0.000 level of significance. This result implies that students learned to decompose, abstract, and reason algorithmically better through reinventing, problem-based approaches. At the same time, the control group had a mean increase of 1.25 points which was not significant, t(39) = 0.674, p = 0.504, further showing how little traditional methods increase computational thinking. In short, these findings provide strong evidence that learning with XR integration and Problem-Immersive fosters better critical thinking and computational thinking than traditional pedagogies. The study finds that when the teaching design is immersive and uses technology, it strengthens 21st-century skills in the students.

Based on results from the paired samples t-test, the experimental group who experienced XR integration and Problem-Immersive Experience-based learning had critical thinking and computational thinking scores which

improved significantly, whereas the control group demonstrated no meaningful improvements. The result shows that immersive learning designs have an important role in equipping higher-order thinking skills in 21st-century competencies. The significant improvement in thinking ability in the experimental group found technology-enhanced active learning significantly promotes critical thinking, reasoning and problem-solving (Song & Kim, 2023). Likewise, XR environments improve cognition, allowing students to apply evaluative judgment in more authentic and interactive contexts (Abdul Hanid et al., 2022). The slight enhancement seen in the control group further supports that standard forms of teaching, relying mostly on talk, do not help complex reasoning. The substantial growth in computational thinking also corroborates with a study by Fernández-Cerero et al. (2025) who argued that problem-based and technology-rich settings can nurture computational thinking effectively. The immersive and problem-solving scenarios help students put in practice decomposition, pattern recognition as well as algorithm design, competencies that are essential for computational literacy. The new findings add to this knowledge by showing that XR and immersive techniques promote computational thinking more than any other teaching techniques, by experimenting (Kang & Lee, 2023).

Table 10 *Independent sample t-test*

Observations	Group		Independent Sample T-test			
			Mean	t-value	df (Degree of freedom)	P-value
Post-test comparison analysis of Critical Thinking	Experimental	40	87.8	23.413	78	0.001
	Control	40	62.1			
Post-test comparison analysis of Computational Thinking	Experimental	40	86.6	32.723	78	0.006
	Control	40	61.3			
Post-test comparison analysis of Communication	Experimental	40	80.9	25.625	78	0.001
	Control	40	58.5			
Post-test comparison analysis Collaboration	Experimental	40	87.4	13.374	78	0.001
	Control	40	60.2			
Post-test comparison analysis of Creativity	Experimental	40	80.9	20.601	78	0.001
	Control	40	60.3			
Post-test comparison analysis of Character	Experimental	40	86.6	27.375	78	0.001
	Control	40	62.6			

The independent samples t-test showed significant post-test differences between the experimental group that received XR integration and Problem-Immersive Experience-based learning and the control group that received conventional instruction for all six domains of 21st-century competencies. Students' Critical Thinking Scores. Experimental group students (M = 87.8) scored significantly higher than control group students [M=62.1, t(78) =23.41, p=0.001] which shows that immersive approaches significantly improve students' capacities for analysis and reasoning. Like this, for Computational Thinking, the experimental group (M = 86.6) outperformed the control group [M=61.3, t(78) =32.72, p=0.006]. Eliciting support for the hypothesis that XR-based pedagogies can enhance learners' problem decomposition and algorithmic skills. The experimental group (M = 80.9) had a statistical advantage over the control group [M=58.5, t(78) =25.63, p=0.001] in Communication reflecting expressive and interactive abilities. Collaboration is another area where the experimental group (M = 87.4) outperformed the control group [M=60.2, t(78) =13.37, p=0.001] highlighting the ability of XR to enhance partnered learning experiences. Also, for Creativity, the experimental group (M = 80.9) had a significantly higher score than the control group [M=60.3, t(78) =20.60, p=0.001]. So, immersive learning environments foster creativity. Finally, for character, the experimental group (M = 86.6) scored significantly higher than the control group [M=62.6, t(39) =27.38, p=0.001]. Immersive pedagogical practices strengthen values of responsibility, perseverance, integrity, etc. The findings confirm that XR integration and Problem Immersive Experience can significantly improve the students' achievement on all six dimensions of the 21st century competencies. Thus, the findings provide strong evidence of the efficacy of digital transformative pedagogy.

Based on study findings, the implementation of XR integration and Problem-Immersive Experience-based learning has a significant effect on all six dimensions of 21st Century competencies (6Cs) namely, critical thinking, computational thinking, communication, collaboration, creativity, and character. Students in the experimental

group scored better than those in the control group. This was true for all the competencies. Immersive pedagogical strategies prepare students for the future. According to Kuleto et al. (2023) and Sharma (2021) studies, the great improvement in critical thinking and computational thinking is in line with the findings of previous studies. This is because the interactive context provided by immersive technology improves problem analysis and reasoning and algorithm thinking. Communication and collaboration skills have also improved. The XR learning environments are conducive to students' peer-to-peer interaction and co-operation engagement, thus facilitating the social learning process (Jang et al., 2021).

Also, the problem-immersive and authentic learning activities trigger divergent thinking and creativity (Ilić et al., 2021). The 21st-century education should not only centre on cognitive skills, but should also foster values like integrity, perseverance and responsibility important for student's holistic development (Jiang et al., 2024). According to this research, there is experimental evidence on a larger array of capabilities from a new experimental design. Historically, the studies focused on one or two dimensions of engagement or skills. The present finds that immersive pedagogical approaches have a universal effect on many abilities at the same time. The findings show that XR and Problem-Immersive learning can be used together as a digital transformative framework to prepare students for 21st-century workforce demands.

Table 11 *ANCOVA analysis result*

Source	Type III Sum of Squares	df (degree of freedom)	Mean Square	F-value	Sig.	Partial η^2
Model	32.415	3	10.805	14.521	0.000	0.547
XR Integration	12.624	1	12.624	16.961	0.000	0.320
Problem-Immersive Experience	10.732	1	10.732	14.421	0.001	0.286
Gender	6.218	1	6.218	8.355	0.007	0.188
Error	26.724	36	0.743			
Corrected Total	59.139	39				

Study of the ANCOVA results for testing the hypothesis about the difference in student engagement in XR integration and Problem-Immersive Experience-based learning with regards to gender. ANCOVA model with the control of pretest scores as covariate showed significant main effects of XR Integration and the model is significant overall, $F(3, 36) = 14.52$, $p = 0.000$, Partial $\eta^2 = 0.547$. This shows that the predictors explained a fair amount of variance in student engagement. The integration of XR has an overall great impact on student engagement ($F = 16.96$, $p = 0.000$, Partial $\eta^2 = 0.320$). The results suggest that XR learning activities significantly promote student engagement. It is likely that the immersive and interactive features of XR learning activities enhance student engagement by stimulating their attention and motivation.

Secondly, the variable for problem-immersive experience also produced a significant effect ($F = 14.42$, $p = 0.001$, Partial $\eta^2 = 0.286$). By participating in authentic problem solving, which involve critical thinking and collaboration, embedding problem-based immersive in learning enhances engagement in students. There was a statistically significant effect of SDQ type ($F = 8.355$, $p = 0.007$, Partial $\eta^2 = 0.188$). It shows that male students and female students engage with XR and problem-immersive learning environments differently. The variations could result from differences in learning preferences, interaction styles or levels of comfort with technology, which should be studied more in future.

The ANCOVA results provide strong evidence to support the research hypothesis. Student engagement is enhanced significantly as a function of XR integration and problem-immersive learning with reference to gender differences. This means that digital transformative pedagogy design should use the technological affordances as well as gender responsive strategy for achieving optimum learning outcomes. The findings of this study are in accordance with various studies. These studies support the uncovered effects of XR Integration and Problem-Immersive Experience on student engagement and recognize gender as a moderator in the current research. Integrating XR positively affects student engagement. In agreement, the XR-based learning environments significantly improve learner immersion, motivation, and participation, compared with conventional learning environments (Pregowska et al., 2023). XR technologies tend to create more engaging experiences due to their multisensory and interactive affordances that create a higher cognitive process (Ota et al., 2024).

The Problem-Immersive Experience is a very relevant finding and accords well with the research work of Strobel & van Barneveld (2009). Their conclusions show that problem-based and immersive learning contexts can enhance student engagement. These methods allow pupils to take an active role or participant rather than become

a passive recipient of knowledge. In total, participation of students strengthens overall learning engagement. The finding that gender differences affect engagement supports earlier work by Dochy et al., (2003). They found that male and female students tend to engage differently with digital and immersive technologies because of their varying prior exposure, confidence levels, and learning preferences. A similar study by Kang & Lee (2023) pointed out that technology enhanced pedagogy to student engagement was moderated by gender. The present findings build upon prior studies by investigating the integration of XR, Problem-Immersive Experience and gender together in one ANCOVA model. Earlier studies were concerned with individual factors. But this study explains how an interplay of immersive technologies and demographic factors together shapes student engagement. Thus, this offers a holistic understanding of digital transformative pedagogy. This result underlines the necessity of inclusive and gender-responsive pedagogical design. Educators must consider several report and account grouping strategies, deliver on different communication types in XR, and design problems that are interesting for as many students as possible.

Table 12 *Regression analysis*

Predictor	B	SE	Wald (z)	p	Exp(B) (OR)	95% CI for OR
Constant	-1.500	0.600	-2.500	0.012	0.223	0.069 – 0.723
XR Integration	1.250	0.450	2.778	0.005	3.490	1.445 – 8.432
Problem-Immersive Experience	1.100	0.400	2.750	0.006	3.004	1.372 – 6.580

The study's assumption was tested through logistic regression analysis stated as follows: XR Integration and Problem Immersive Experience will significantly increase the probability of students attaining 6C competence above the minimum standard. In the regression model, results indicate that the model fit is statistically significant, $\chi^2(2, N = 40) = 21.45$, $p < 0.001$, Nagelkerke $R^2 = .42$. This means that about 42% of the variance in students' attainment in 6C competencies can be explained by the predictors. The result discovered that the integration of XR influences positively and is statistically significant for the achievement of students' 6C competencies (B = 1.25, SE = 0.45, p = 0.005). When researchers looked at the data, they found these numbers to be very interesting. The odds ratio (OR = 3.49, 95% CI [1.45, 8.43]) indicated students with XR-based learning were around 3.5 times more likely to exceed the minimum competency standard than students without XR-based learning. This shows that XR is effective in immersive promoting critical and collaborative problem-solving skills, which are important aspects of the 6C framework.

The analyses revealed that the problem-immersive experience significantly predicted students' competency achievement, (B = 1.10, SE =.40, p = 0.006). The odds ratio (OR = 3.00, 95% CI [1.37, 6.58]) suggested that pupils working on immersive, problem-orientated tasks were three times more likely to achieve above the minimum 6C standard than their conventional counterparts. It shows that students are really given the chance to practice their creativity, communication, and collaboration in real-world tasks. Based on these findings, both XR integration and Problem–Immersive Experience raise the probability of students achieving higher 6C competency levels. The evidence shows that reasoned digital pedagogical innovations prepare innovators and learners to become viable and competitive in a global economy. Several diagnostic tests were conducted to give the logistic regression model its strength. The goodness of fit test was Hosmer-Lemeshow test which was applied to assess the ability of the predicted probabilities to match the observed results. The non-significant result of the test (p = 0.71) indicates that the model fits the data well and that the predicted values were not significantly different to actual classifications. these diagnostics validate the fact that the regression model is both significant and can predict well 6C achievement probabilities depending on the variables of XR integration and Problem-Immersive Experience (PIE) factors.

These findings align with previous studies on digital teaching and 21st-century learning. The immersive XR environments produce greater results in higher-order thinking and collaboration than non-immersive settings. Likewise, the engagement level presents an effective contribution of XR (Fernández-Cerero et al., 2025). Moreover, it presents a good contribution to competency development, especially in critical thinking and problem-solving. These studies agree with the current finding that XR makes it 3.5 times more likely to exceed competency standards. Problem-based immersive tasks develop transferable skills such as creativity, collaboration, and communication (Aslan, 2021). Moreover, the problem-centred immersive learning environments significantly enhanced student performance in complex competencies (Kyaw et al., 2019). This finding confirms the outcome in this study where the odds of attaining 6C competencies are three times higher. Combining digital pedagogy with

the 21st Century skills is an epitome of Banic & Gamboa (2019), stating that a teaching design that promotes innovation, particularly one based on authenticity and technology, is necessary to develop the 6C (critical, creative, collaborative, communicative, citizenship, and character) framework. Using the method of logistic regression, the researchers presented quantitative evidence that shows both XR integration and Problem-Immersive Experience enhance the chances of exceeding minimum 6C competency standards. For a dispute resolution to be effective in customer satisfaction and the sustainability of a supply chain the customers are the main components that affect the day-to-day operation of the organization.

5. Conclusion

This study suggests XR integration with problem-immersive pedagogies is a transformative educational pathway for vocational education. The study found that entering an XR-support immersive learning environment may provide significant improvement in the development of 21st-century 6C competencies: critical thinking, creativity, and collaboration, in particular. Communication, citizenship, and character may also be fostered through the authentic interactive environment. This method creates a gap between instruction and industry, and vocational students are facilitated with sustainable skills that are relevant to the requirements of Industry 4.0 and Sustainable Development Goals (SDGs). This research has three key takeaways. First, to teachers, XR-based immersive learning must not be implemented as a technological supplement but rather a tool of transformation as a pedagogical approach that can be used to facilitate experiential, reflective, and performance-based learning. Second, as an instructional designer, the results imply that the scaffolded form of reflection and adaptive feedback should be implemented within the XR learning context to maximize the learning outcomes and avoid cognitive overload. Third, the paper highlights the significance of institutional investment in digital infrastructure and faculty development to policymakers and makes sure that XR technologies become embedded in the Technical and Vocational Education and Training (TVET) curricula on a sustainable basis. In practice, to implement these findings, the TVET institutions can design systematic XR implementation roadmaps, such as educator capacity-building programs, industry co-development of content, and monitoring systems on the long-term effectiveness of their learners in the labour market. Further studies are needed including longitudinal and cross-institutional studies to confirm these findings and examine the opportunities to scale XRPIE models to various professional fields. The implications of this study are multifaceted. Teachers need to enhance their professional development to accomplish effective integration of XR in education. This urges institutions to invest in curriculum innovation and the digital infrastructure. The findings at the policy level reveal that pedagogical transformation through XR can make a significant contribution towards achieving global goals for education and employment and enhance the readiness of vocational learners to thrive in dynamic technology-driven labour markets.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** *Rizky Ema Wulansari, Oriza Candra, Agariadne Dwinggo Samalai;* **data collection:** *Rahmadona Safitri, Rizki Hardian Sakti;* **analysis and interpretation of results:** *Oriza Candra, Agariadne Dwinggo Samala;* **draft manuscript preparation:** *Rizky Ema Wulansari, Rizki Hardian Sakti, Chau Trung Tini. All authors reviewed the results and approved the final version of the manuscript.*

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