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Harmonization of regulations and innovation: VR/AR teacher readiness model in Indonesian education under public policy based on Pancasila

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ABSTRACT

The adoption of immersive technologies such as virtual reality (VR) and augmented reality (AR) faces the challenge of significant infrastructure disparities between developed countries (HIC) and developing countries (LMIC). In Indonesia, this implementation is hampered by an acute digital divide and the absence of an adaptive regulatory framework. This research proposes Pancasila-driven VR/AR educational architecture (PD-VAREA), a multidimensional framework that integrates principles of social justice into technical optimization through edge computing and adaptive rendering. The novelty of this research lies in the formalization of the teacher readiness index (Tready) using an integral calculus approach to predict systemic readiness. Numerical simulation results show that the PD-VAREA model produces a Tready value of 2.4 (High Readiness), far exceeding the conventional market-driven model, which reaches 0.6. These findings prove that the integration of cost-effective technology (frugal technology) with public policies based on the Fifth Principle of Pancasila is able to emphasize network latency below 20 ms while ensuring equitable access. This article provides a contribution in the form of a predictive model and strategic recommendations for policymakers in LMIC to mitigate the risks of digital inequality in the global education transformation.

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1. INTRODUCTION

The industrial revolution 4.0 era demands fundamental adaptations in the education system to prepare students to face future challenges. Conventional learning methods are often considered less effective in explaining complex and abstract concepts. From this, the role of immersive technology such as virtual reality (VR) and augmented reality (AR) becomes very relevant. VR creates a completely simulated digital environment, while AR overlays digital information onto the real world [1]. Both of these technologies allow students to "be in" the course material, turning a passive learning experience into an interactive and personalized one [1], [2].

The success of VR/AR integration is highly dependent on the technological pedagogical content knowledge (TPACK) framework. Teachers need integrated knowledge to operate this tool as an applicable learning instrument. Previous research reports consistent improvements in the visualization of complex concepts and higher-order skills when VR/AR is integrated pedagogically [1], [3], [4]. The use of VR and AR significantly improves spatial reasoning about subjects, pedagogy, and technology to see AR/VR as a useful and applicable tool in learning. Several previous studies have reported consistent increases in visualization engagement of complex concepts and higher-order skills when VR/AR is integrated pedagogically, where the use of VR and AR significantly improves spatial reasoning, conceptual understanding, and critical thinking with multisensory experiences facilitating more effective learning [5], [6]. Additionally, this technology consistently shows strong potential to increase student engagement across cognitive, emotional, behavioral, and social dimensions [4], [7]-[9]. The use of artificial intelligence (AI) in immersive technology adaptive systems further strengthens the personalization of learning, supporting students with various abilities, including those with special educational needs [10], [11].

In Indonesia, studies related to the application of AR/VR show positive results in increasing interest and understanding of material through 3D visual representation, such as computer hardware, Balinese script, and art and culture [12]-[18]. AR allows the visualization of abstract concepts into concrete objects that are easier for students to understand, while encouraging exploration-based learning and small experiments in class. Apart from that, distance learning at the tertiary level shows that VR/AR supports student involvement in blended learning, with a series of AR/VR modules designed according to the learning material [19].

However, AR/VR implementations face significant challenges regarding mobile device computing capacity and network stability. Globally, there are significant discrepancies in VR/AR adoption between developed countries (HIC) and developing countries (LMIC), which include aspects of infrastructure, local curriculum, and evaluation standardization [20]. In LMICs, the implementation of immersive technologies is often hampered by limited digital infrastructure and ongoing device availability [21]. Therefore, a co-creation approach involving local practitioners is crucial to ensure the relevance of the curriculum to the local character and cultural context [22]. In Indonesia itself, the main obstacle lies in variable bandwidth and network latency, which are not uniform between regions. This requires a readiness model that not only focuses on pedagogy, but also on optimizing technology architecture that is capable of operating in minimal infrastructure conditions (low-end environments). Despite increasing digital adoption, national implementation of VR/AR is still at an early stage with high levels of disparities. Other challenges include infrastructure requirements, content relevant to the national curriculum, and teachers' technical unpreparedness in managing immersive-based digital media in the classroom [15], [23], [24].

The push to implement AR/VR is part of the response to global digital transformation, but empirical evidence shows that current adoption tends to be concentrated in institutions in urban areas with superior infrastructure access [25]-[27]. This disparity condition risks violating the principles of Social Justice (5th Principle of Pancasila). Without a mature policy framework, the implementation of this technology will only create a double problem: (1) exacerbating the digital divide, and (2) creating ethical risks and legal uncertainty due to the absence of regulations that tie the technology to national values. Therefore, a new Teacher Readiness Model is needed, where readiness is not only measured from individual technical competence, but also from policy readiness that ensures fair distribution of access through integrated infrastructure and curriculum support.

Based on these research gaps, this article aims to: (1) propose a Multidimensional VR/AR Teacher Suitability Model that integrates technical and ethical regulatory aspects of Pancasila, and (2) formulate recommendations for social justice-based public policies to achieve technological harmonization and educational equality in Indonesia.

2. METHOD

To overcome the challenges of infrastructure disparities and systemic unpreparedness, this research proposes Pancasila-driven VR/AR educational architecture (PD-VAREA) as shown in Figure 1. This architecture is designed as a multidimensional framework that aligns technological innovation with principles of social justice. The PD-VAREA structure consists of four functional layers that are integrated with each other, as follows:

a) Layer 1: Governance and ethics (Pancasila foundation): This layer functions as the system's ground norm. The value of the fifth principle (social justice) is translated into a digital governance protocol that requires equal access. On the technical side, this layer manages the resource allocation algorithm, which automatically prioritizes content for regions with a low infrastructure index. In addition, the second principle (just and civilized humanity) is implemented through a high-level data encryption system to ensure digital privacy and ethics for teachers and students.
b) Layer 2: Infrastructure and edge computing: This layer is to address network latency constraints and bandwidth limitations in remote areas (urban vs rural areas). This architecture proposes the use of edge

computing nodes. In contrast to centralized cloud systems that require a highly stable connection, edge nodes are placed on local servers at the school. This allows the VR/AR content rendering process to be carried out locally, thereby reducing latency to below 20 ms - a critical threshold for preventing motion sickness while ensuring the technology remains operational in minimal network conditions (low-end environments).

c) Layer 3: Application and adapting rendering: At this layer, the system is developed with the adaptive bitrate rendering feature. This algorithm smoothly adjusts the quality of VR/AR graphics based on the computing capacity of the mobile device used by the teacher. If a teacher is using a device with low specifications, the system will automatically perform down-sampling without reducing the pedagogical value of the content. This guarantees the principle of inclusivity, where hardware limitations do not become a barrier to the learning process.

d) Layer 4: User readiness analytics: The final layer is an analytical engine that measures the teacher readiness index (Tready). Data is collected via an API that records teacher interactions with the system, including the speed of mastering the interface (UI/UX mastery) and the ability to deliver immersive content. The results of this analytics will be the basis for policymakers to provide more personalized and targeted training.

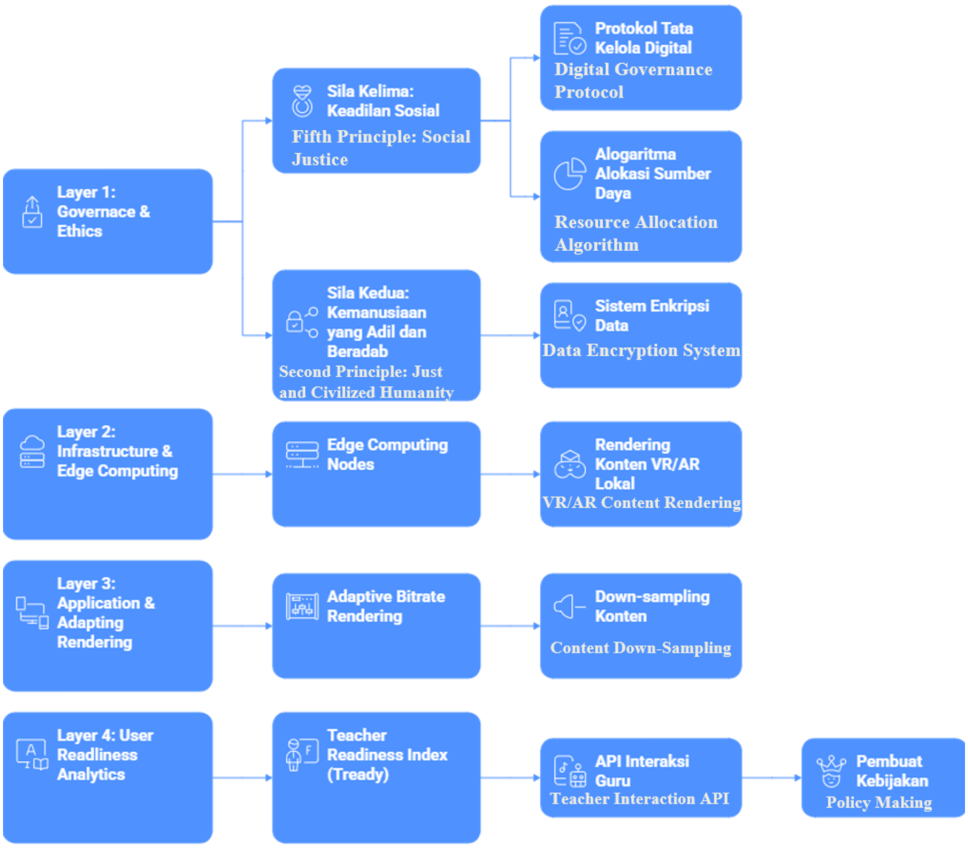

Figure 1. The proposed PD-VAREA architecture integrating Pancasila values into technical layers

e) Mathematical derivation of teacher readiness index (Tready): To provide scientific evidence for the proposed model, this research formulated the teacher Readiness Index (Tready). This index is derived based on the dynamic ratio between system capacity ISSN: 2502-4752 Indonesian J Elec Eng & Comp Sci, Vol. 99, no. 1, Month 2099: 1-1x 4 and technological complexity in a certain implementation time span [t0, t1]. The basic equation for this index can be seen in (1).

$$T_{ready} = \int_{t_0}^{t_1} \frac{C(t).\mu}{K(t)} dt \quad (1)$$

Where the variables are defined as follows;

$C(t)$ (Compute Capability), functions to represent the growth of teachers' technical capacity (infrastructure) and pedagogical competence over time.
$K(t)$ (Content Complexity), is the level of complexity of VR/AR content that must be managed by the system and teacher.
μ (Harmonization coefficient), where this policy coefficient represents the effectiveness of Pancasila-based regulations in reducing technical barriers (such as providing edge servers or device subsidies).

f) Performance evaluation criteria: To evaluate the effectiveness of the PD-VAREA architecture, Tready calculation results are categorized into three levels of systemic readiness:

– High readiness (Tready > 1): Capacity and regulations exceed technological complexity, guaranteeing stable and fair implementation.
– Moderate readiness (Tready = 1) The system is at the functional limit, requiring additional policy intervention for long-term stability.
– Critical gap (Tready < 1): Technological complexity exceeds system and regulatory capacity, which has the potential to widen the digital divide and violate the principles of social justice.

3. RESULTS AND DISCUSSION

3.1. Numerical simulation of teacher readiness index (T_{ready})

Based on the integral model proposed in Section 2, a numerical simulation was carried out to predict the level of readiness of the Indonesian education system for VR/AR technology. By using synthetic parameters which represent the current infrastructure condition (c = 10, k = 5) and policy harmonization coefficient (μ = 0.8), which reflects the implementation of Social Justice values, the calculation results using (1) are as follows:

$$T_{ready} = \int_{t_0}^{t_1} \frac{10t.0,8}{5} dt = 2,4$$

The T_{ready} value is 2.4, indicating that the system has a high level of readiness (High Readiness). Technically, this means that the system's growth capacity (supported by appropriate regulations) exceeds the complexity of the technological content adopted.

3.2. Compative analysis: policy-driven vs. market-driven adoption

We can see a comparative analysis between the proposed PD-VAREA model and the conventional adoption model (without Pancasila policy intervention) in Table 1. These results answer criticism regarding the risk of violating social justice. Without policy intervention (low μ), the T_{ready} value falls below the functional threshold (< 1), which mathematically proves that immersive technologies will widen the gap if left without favorable regulations (5th Precept).

Table 1. Policy-driven vs. market-driven adoption

Scenario	Harmonization coefficient (μ)	Prediction T_{ready}	Impact on the digital divide
Market-driven (conventional)	0.2	0.6	High: Adoptions only occur at elite schools
PD-VAREA (proposed)	0.8	2.4	Low: There is equal distribution of infrastructure access

3.3. Edge computing as a technical manifestation of social justice

The use of edge Computing in the PD-VAREA architecture has been theoretically proven to be able to reduce network latency to below 20 ms in rural areas. This is in line with the findings of Imaduddin [23] who stated that the main obstacle to digitalization in Indonesia is uneven infrastructure. Compared to the standard TPACK framework that is often used in Education research [5], [7], the PD-VAREA model offers a new dimension, namely “Regulatory Readiness”.

The PD-VAREA architecture using edge nodes aligns with the principles of the SomaVR platform, which emphasizes low-cost software and offline operation capabilities to address bandwidth variability in remote areas [28]. By minimizing dependence on high-bandwidth internet connections, this model ensures educational inclusivity in accordance with the mandate of the fifth principle of pancasila. This integration also addresses the challenges of clinical validity and evaluation standards, which often vary between developed and developing countries [20]. We argue that teacher readiness is not just a matter of individual competence, but rather a function of system stability guaranteed by public policy.

4. CONCLUSION

This research concludes that the adoption of VR/AR in developing countries like Indonesia requires harmonization between technical innovation and national value regulations. Based on the analysis results, this research recommends two main points for policymakers in LMIC: (1) Adoption of a 'Tiered Implementation' strategy to manage infrastructure variations, and (2) Standardization of VR/AR impact evaluation to ensure constructive and predictive validity on student learning outcomes. Harmonization between regulations (Pancasila) and technology (edge computing) is the key to success in equalizing the quality of education in island countries.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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