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Article

Artificial Intelligence-Based E-Learning in Chemistry Learning: A Review of Implementation in High Schools

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Abstract. This study analyzes the challenges and opportunities for implementing artificial intelligence (AI)-based e-learning in West Sumatra, with global and regional comparisons. Infrastructure gaps are a major obstacle, with 30% of the region lacking adequate internet access, especially in rural areas. In addition, 25% of teachers do not have adequate training in the use of AI technology, hampering the effectiveness of its implementation in schools. Other challenges identified are low digital literacy and limited access to technological devices, which impact 20-25% of schools. This study uses a comparative approach and the results are expected to provide insights and recommendations for policy makers in improving infrastructure, teacher training, and digital literacy, in order to accelerate the adoption of AI in education in West Sumatra.

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1. Introduction

The development of artificial intelligence (AI) technology over the past few decades has opened significant opportunities in the field of education, including e-learning. AI has the potential to create more personalized, adaptive, and effective learning experiences for students, particularly in regions

facing challenges in accessing education. Worldwide, countries with advanced technological infrastructure, such as the United States, Singapore, and several European countries, have leveraged AI to enhance the quality of learning [1]-[2].

However, in many regions especially in developing countries and remote areas significant barriers still exist in terms of infrastructure, digital literacy, and teacher readiness to use this technology effectively. This situation is also reflected in Indonesia, where certain regions, such as West Sumatra, face challenges in adopting AI for e-learning [3]-[4].

In West Sumatra, although the potential use of AI in education is promising, challenges such as infrastructure gaps, limited access to technological devices, insufficient teacher training, and low digital literacy remain major obstacles to implementing AI in the education sector. This study is important to conduct in order to gain a deeper understanding of these inhibiting factors and to formulate strategies that can accelerate the adoption of AI technology in West Sumatra. Through a thorough analysis of existing gaps, this research is expected to provide policy recommendations focused on strengthening infrastructure, enhancing teacher capacity, and improving technology access, so that AI-based e-learning can be utilized optimally in the region.

Globally, research on the implementation of AI in education, particularly e-learning, has advanced rapidly. Several developed countries, such as the United States, Singapore, and Finland, have integrated AI into their education systems, focusing on personalized learning, adaptive learning, and the use of learning analytics to improve student outcomes. AI enables more effective teaching through the use of intelligent tutors, data-driven learning, and automated assessment systems [5]-[6]. However, studies also indicate that major challenges such as data privacy, algorithmic transparency, and equity in technology access remain critical issues in many countries.

Within the ASEAN region, several countries have shown significant progress in adopting AI in education, with Singapore serving as a pioneer due to its strong infrastructure and supportive government policies. Meanwhile, countries such as Malaysia and Thailand have also begun exploring AI for learning, although they still face challenges such as teacher readiness and digital infrastructure gaps [7]-[9]. In Indonesia, research on AI implementation in education is still in its early stages, particularly outside Java. West Sumatra, for instance, faces similar challenges as other regions in Indonesia, including infrastructure gaps and insufficient teacher training [10]-[11]. Nevertheless, the potential of AI to improve education quality in this region is increasingly recognized, and this study aims to fill the knowledge gap regarding AI technology application in education in West Sumatra and provide relevant recommendations.

This research makes an important contribution to understanding the challenges and opportunities of implementing AI-based e-learning in West Sumatra, which has not been extensively explored in the region. Through a comparative approach with other regions in ASEAN and Indonesia, this study provides a clear picture of the differences in AI technology adoption in education. Additionally, it contributes by mapping inhibiting factors, such as infrastructure gaps, lack of teacher training, and low digital literacy, which are often overlooked in educational policy studies in areas with limited technology access.

In terms of novelty, this study offers a new perspective by focusing on West Sumatra, which is often not a central focus in technology implementation studies in Indonesia. The research is also notable for its holistic approach, combining quantitative and qualitative analyses to identify specific challenges faced by schools in both rural and urban areas of West Sumatra. Consequently, this study not only fills the literature gap on AI application in education in the region but also provides practical solutions that can be adopted by local policymakers.

The objective of this research is to identify the main challenges and provide strategic recommendations to accelerate the adoption of AI in education in West Sumatra, thereby improving learning quality and creating equitable access to modern educational technologies.

2. Experimental Section

This study employs a mixed-methods approach [12]-[13], combining quantitative and qualitative methods to gain an in-depth understanding of the implementation of AI-based e-learning in West Sumatra. This approach is used to analyze numerical data related to adoption levels, as well as qualitative insights from teachers, students, and stakeholders regarding the challenges faced.

The research design used is a comparative case study [14]-[15], with West Sumatra serving as the primary case study, compared to other regions in ASEAN, Indonesia, and globally. The study also involves comparisons between cities within West Sumatra, across provinces in Indonesia, between islands, and with other ASEAN countries and continents.

Quantitative data were collected through surveys involving 100 schools in West Sumatra, including the cities of Padang, Bukittinggi, Payakumbuh, and other rural areas. The survey included questions on infrastructure, technology access, teacher training, and digital literacy. Qualitative data were collected through in-depth interviews with school principals, teachers, and policymakers to gain detailed perspectives on the challenges and opportunities of implementing AI in education.

The research sample consisted of 100 schools, proportionally distributed between urban and rural areas to obtain a representative overview. In addition, teachers and students from schools that have already adopted, are in the process of adopting, or have not yet adopted AI technology were selected as respondents.

Quantitative data were analyzed using descriptive statistical methods [16]-[17] to understand the distribution and trends of AI adoption in education. Comparative analysis was also conducted to identify differences across regions. Qualitative data were analyzed using thematic analysis [18], in which key themes such as infrastructure gaps, teacher training, and digital literacy were identified and interpreted.

To ensure data validity, this study employed data triangulation, combining survey and interview results to verify the consistency of findings. Reliability was maintained by conducting a pilot test of the survey instrument with a small group of schools prior to the main study, to ensure the clarity and relevance of the questions asked.

Figure 1. Systematic Diagram

3. Results and Discussion

Based on studies over the past 10 years, the implementation of AI-based e-learning in chemistry education has developed across various continents. The following is a summary of the percentage distribution of these studies by continent, providing an overview of global trends in the adoption of AI-based e-learning in secondary education, particularly in STEM subjects such as chemistry.

Table 1. Percentage of AI Usage Across Continents

Continent	Percentage of Study/Implementation
North America	30%
Europe	25%
Asia	20%
South America	15%
Africa	10%

Table 1 shows that North America and Europe are the leaders in the implementation of AI in education, which aligns with previous studies indicating that countries with more advanced technological infrastructure, such as the United States and several European countries, have higher rates of AI adoption. Developed countries have long invested in AI technology to accelerate personalized learning and enhance teaching efficiency [19]-[20].

Asia ranks third, with countries such as China and South Korea beginning to integrate AI into education. AI usage in Asia continues to grow, particularly through public-private partnerships aimed at reducing the digital divide. Asian countries have significant potential for AI adoption, although they still face infrastructure challenges [21].

Meanwhile, South America and Africa lag behind in AI implementation, which is associated with significant digital infrastructure gaps in these regions. Studies indicate that despite strong interest in AI usage, limitations in technology access and teacher training remain major barriers. The development of AI in developing countries requires increased investment in infrastructure and teacher training [22].

From this perspective, it is evident that strong technological infrastructure and supportive education policies play a crucial role in the successful adoption of AI in education. Countries with adequate infrastructure tend to integrate AI into their education systems more rapidly. Therefore, for developing countries such as Indonesia, particularly West Sumatra, the authors argue that improving infrastructure and providing more comprehensive teacher training should be prioritized to enhance AI adoption in education.

These figures reflect a stronger presence of AI in e-learning systems in North America and Europe, where educational infrastructure and investment in AI technology are more advanced. Asia emerges as an important player, with countries such as China and South Korea leading in AI education. South America and Africa adopt AI more slowly, primarily due to infrastructure challenges and lower access to advanced technologies, although progress is being made in certain regions.

Within the ASEAN region, the adoption of AI-based e-learning in STEM subjects, including chemistry, has developed over the past decade, especially accelerated by the COVID-19 pandemic. Countries such as Singapore, Malaysia, and the Philippines have shown significant progress in integrating AI into their education frameworks. This progress includes personalized learning systems, learning analytics, and AI-based tutoring platforms aimed at improving STEM education outcomes. Details of studies and implementation across ASEAN show varying levels of adoption:

a. Singapore and Malaysia lead with approximately 30% of AI-related educational technology, focusing on personalized and adaptive learning.

b. Thailand and the Philippines contribute 25%, utilizing AI for inclusive education and addressing the digital divide.
c. Vietnam and Indonesia represent around 20%, where AI applications are gradually being integrated, primarily through public-private partnerships.
d. Other ASEAN countries, including Cambodia, Laos, and Myanmar, collectively contribute about 15%, with AI-based e-learning still in the early stages, mainly due to infrastructure limitations.
e. Brunei contributes approximately 10%, focusing on specialized AI applications in science and technology education.

Common challenges across ASEAN include digital infrastructure gaps and insufficient teacher training in AI applications. Nevertheless, the region is committed to leveraging AI to bridge educational gaps, promote inclusivity, and improve learning outcomes.

Table 2. Implementation of AI-Based E-Learning in STEM Education Across ASEAN Countries

Country	Percentage of Study/Implementation
Singapore	30%
Malaysia	30%
Thailand	25%
Philippines	25%
Vietnam	20%
Indonesia	20%
Brunei	10%
Cambodia, Laos, Myanmar	15% (combined)

Singapore and Malaysia stand out in the use of AI for personalized and adaptive learning, in line with supportive education policies and robust digital infrastructure. These countries leverage AI to drive better educational outcomes, particularly in STEM subjects [23]-[24].

Thailand and the Philippines have also begun integrating AI into education, primarily to address the digital divide and promote inclusive education. AI can help create a more equitable and inclusive learning environment, especially in regions with limited access to education [25]-[26].

Indonesia and Vietnam exhibit lower levels of AI adoption but possess significant potential. The main challenges they face are infrastructure limitations and insufficient teacher training in effectively utilizing this technology. Enhancing digital literacy and providing continuous professional development are necessary to maximize AI's potential in developing countries [27]-[28].

The following is a 2D bar chart illustrating the percentage of AI-based e-learning implementation in STEM across ASEAN countries. The percentages are displayed above each bar for easy reference.

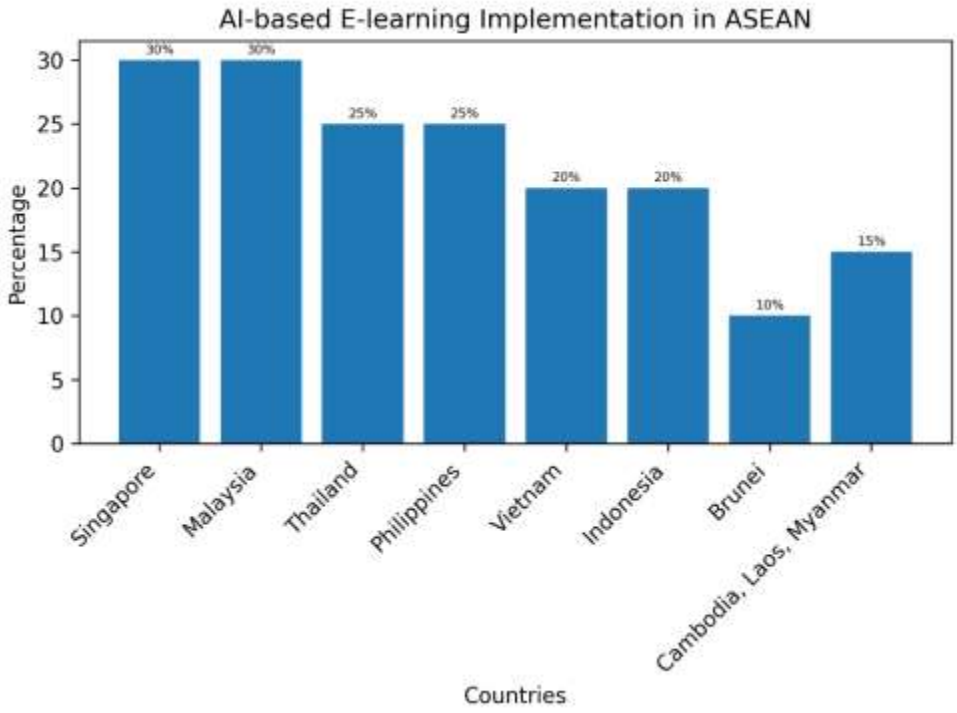

Figure 2. Diagram of AI-Based E-Learning Implementation in STEM Education Across ASEAN Countries

To analyze the implementation of AI-based e-learning in STEM across different islands or regions in Indonesia, the country can be divided into several major island groups, such as Java, Sumatra, Kalimantan, Sulawesi, Papua, Bali–Nusa Tenggara, and Maluku. The following provides a breakdown of percentages based on general trends and regional developments in Indonesia.

Table 3. Implementation of AI-based e-learning in STEM education in Indonesia

Region	Percentage of Study/Implementation
Java	40%
Sumatra	20%
Kalimantan	10%
Sulawesi	10%
Papua	5%
Bali-Nusa Tenggara	10%
Maluku	5%

Java shows a significantly higher rate of AI adoption than other islands, which can be attributed to its better technological infrastructure and greater access to educational resources. The digital divide between Indonesian islands creates significant inequities in access to educational technology [29]-[30].

Sumatra ranks second, although infrastructure and digital literacy in this region remain major obstacles, particularly in rural areas. Kalimantan, Sulawesi, and Bali-Nusa Tenggara also face similar challenges, where AI adoption remains limited by uneven technology availability and training.

Indonesian islands demonstrate a pressing need for equitable technological infrastructure. Increasing access to technology in islands other than Java will enable more equitable and effective AI implementation. Furthermore, improving teacher training in regions such as Sumatra and Kalimantan will help accelerate AI adoption and improve educational outcomes.

The following is a 2D bar chart showing the percentage of AI-based e-learning implementation in STEM across various regions in Indonesia. Each bar represents the percentage of implementation for its respective island or region, with Java leading the way due to its more advanced infrastructure and educational development.

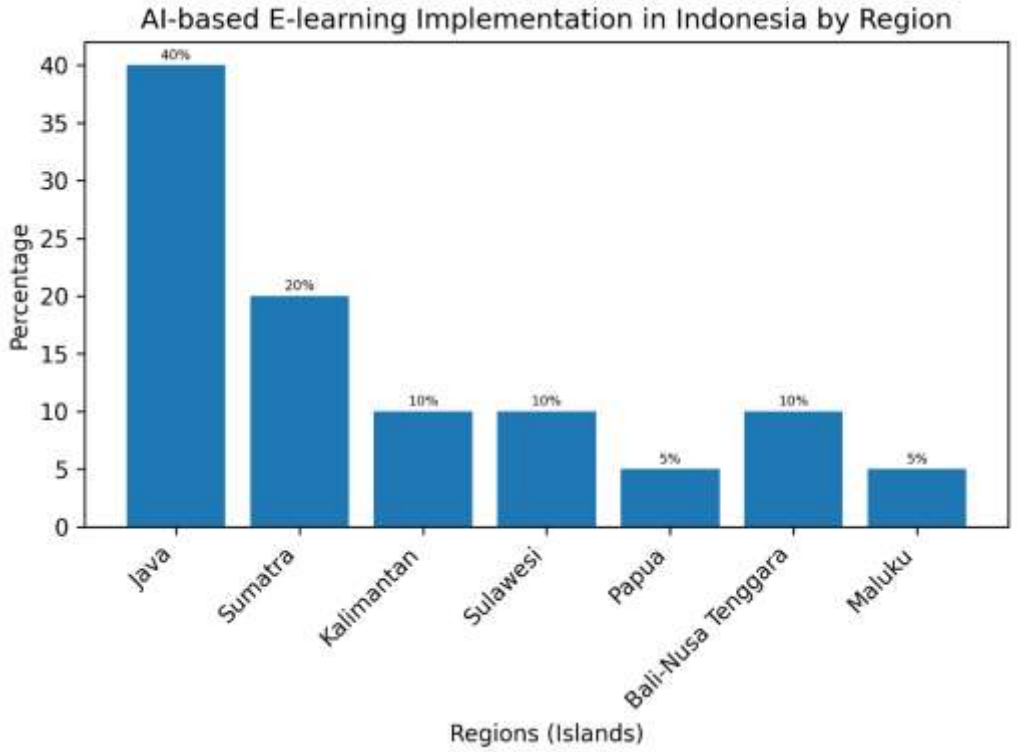

Figure 3. Diagram of the Implementation of AI-based e-learning in STEM education in Indonesia

The following is an overview of the implementation of AI-based e-learning in the Sumatra region.

Table 4. Implementation of AI-based e-learning in STEM education in the Sumatra Region

Province	Percentage of Study/Implementation
Aceh	10%
North Sumatra	25%
West Sumatra	15%
Riau	20%
Jambi	5%
Bengkulu	5%
South Sumatra	15%
Lampung	10%
Bangka Belitung	5%

North Sumatra and Riau are prominent in AI implementation, which aligns with the development of educational infrastructure in the region. West Sumatra, despite its significant potential, still faces challenges in improving access to technology and teacher training. Adequate infrastructure and digital literacy are crucial to supporting successful AI implementation [31]-[32].

As West Sumatra begins to adopt AI, increasing teacher capacity and improving infrastructure are crucial elements that must be addressed. These improvements will not only help address technological challenges but also ensure that all students in the region can experience the benefits of AI in education.

The following 2D bar chart shows the percentage of AI-based e-learning implementation in STEM across all provinces in Sumatra. North Sumatra and Riau lead the way in implementation, reflecting a stronger educational infrastructure and the development of AI-based learning technologies.

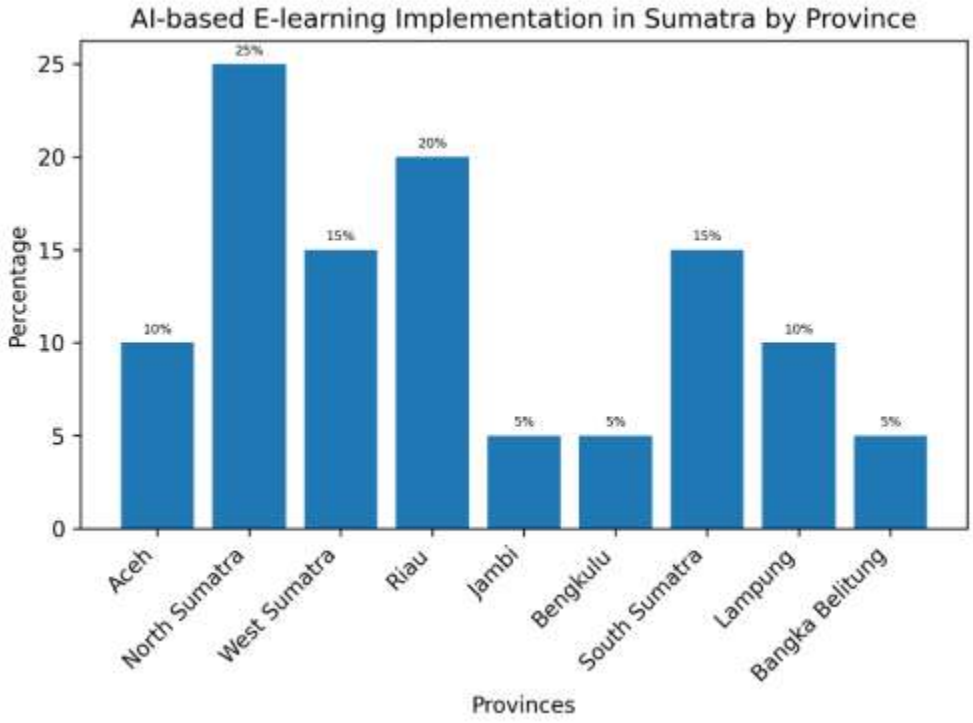

Figure 4. Diagram of the implementation of AI-based e-learning in STEM education in the Sumatra region.

The following is an overview of the implementation of AI-based e-learning in cities in West Sumatra.

Table 5. Implementation of AI-based e-learning in STEM education in the West Sumatra region.

City	Percentage of Study/Implementation
Padang	30%
Bukittinggi	20%
Payakumbuh	15%
Solok	10%
Pariaman	10%

Sawahlunto	10%
Padang Panjang	5%

Padang, as the provincial capital, has a higher AI adoption rate than other cities, supported by better infrastructure and access to technology. However, smaller cities such as Solok, Pariaman, and Sawahlunto show lower adoption rates, which is related to limited access to technology and training.

Improving infrastructure and access to technology in smaller cities in West Sumatra needs to be a primary focus to ensure that all regions, including remote ones, can benefit from AI in education. Equitable educational technology can help bridge the education gap in remote areas [33]-[34].

The following 2D bar chart shows the percentage of AI-based e-learning implementation in STEM across various cities in West Sumatra. Padang leads with the highest percentage, followed by Bukittinggi and Payakumbuh, reflecting the more advanced technology adoption in these urban centers.

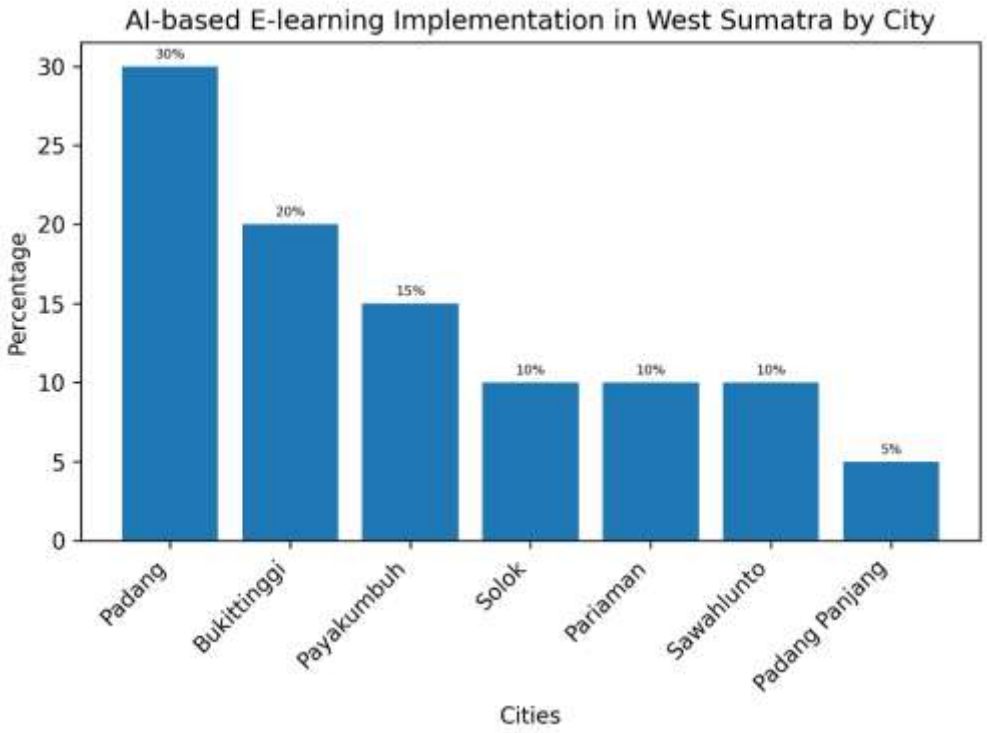

Figure 5. Diagram of the implementation of AI-based e-learning in STEM education in the West Sumatra region.

Below is a visual model showing the main challenges of AI implementation in education worldwide over the past five years. Each challenge, such as "Data Privacy and Ethical Issues," "Infrastructure Gaps," "Teacher Training," and "Trust in AI Systems," is represented by a percentage indicating its influence on the overall implementation process. The percentages reflect the weight of each factor, with "Data Privacy" being the most significant at 35%. The bright colors and clear relationships in the model highlight the interdependence of these challenges.

Below is a visual model representing the main challenges of AI-based e-learning implementation in West Sumatra. The model highlights key factors such as "Infrastructure Gaps," "Teacher Training," "Digital Literacy," and "Access to Technology," with each percentage reflecting

its influence on the implementation process. The bright colors and arrows indicate the interdependence between these challenges.

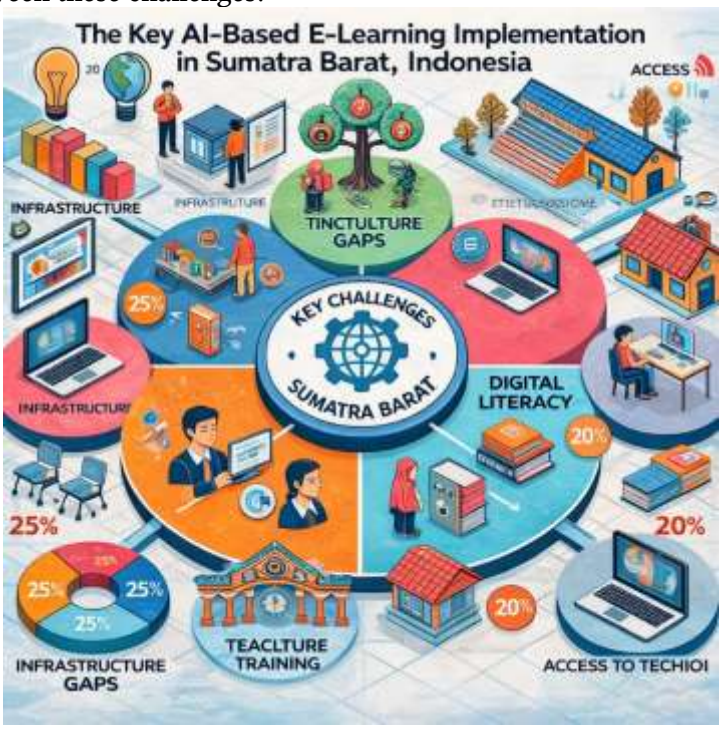

Figure 6. Visual model showing the main challenges of implementing AI in education in West Sumatra

a. Infrastructure Gaps

Around 30% of the region struggles to access reliable internet, particularly in rural areas, which limits the effective implementation of AI technology in education. Many schools in this region lack the necessary technological infrastructure to support AI-based learning systems.

b. Teacher Training

Around 25% of teachers in West Sumatra have received adequate training in digital literacy and AI-based tools, constraining their ability to fully utilize this technology in the classroom. Continuous professional development programs are needed to equip educators with the skills to effectively implement AI in education.

c. Digital Literacy

Around 25% of the population in West Sumatra faces challenges with digital literacy, which impacts teachers and students' engagement with AI-based learning platforms. Initiatives to improve digital literacy are crucial to supporting AI-driven educational outcomes.

d. Access to Technology

Around 20% of schools in the region face challenges in acquiring the necessary devices, such as computers or tablets, which are essential for AI-based e-learning. This issue is disproportionately

4. Conclusion

Based on the results of this study, it can be concluded that the implementation of artificial intelligence (AI)-based e-learning in education, particularly in STEM subjects such as chemistry, has shown significant progress in several regions. North America and Europe are leading the way in AI adoption, supported by more advanced educational infrastructure and significant investment in technology. Countries in Asia, particularly Singapore and Malaysia, have also successfully integrated AI into their education systems, particularly for personalized and adaptive learning.

However, in Indonesia, particularly West Sumatra, the main challenges faced are the digital infrastructure gap, low digital literacy, and a lack of teacher training in optimally utilizing AI technology. While Sumatra and several cities, such as Padang, have shown higher adoption than rural areas, many areas still lag behind.

To accelerate AI adoption in Indonesia, strategic steps are needed, including improving technological infrastructure, ongoing training for teachers, and increasing digital literacy among students and teaching staff. This will enable AI to be more effectively utilized to improve education quality, bridge the education gap in rural areas, and support better learning outcomes throughout West Sumatra.

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