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Effectiveness of Virtual Reality dan Digital Simulation in Medical Education: A Scoping Review Clinical Competency Development

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Abstrak—Background : The digital transformation in medical education is driving the use of technologies such as Virtual Reality (VR) and digital simulations as tools for learning clinical skills. These technologies help students learn in a safe environment. In addition to clinical skills learning, technology is also being used in other competency learning, such as cognitive and affective aspects. However, a comprehensive evaluation of the effectiveness, barriers to implementation, and long-term impacts of these technologies is needed. This study aims to examine the scientific evidence regarding the influence of VR and digital simulations on medical students' mastery of competencies such as clinical skills, cognitive aspects, and affective aspects.

Methods: This study used a scoping review approach by searching for articles from several databases such as PubMed, SpringerLink, and Google Scholar. Article selection was based on predetermined inclusion and exclusion criteria, with study quality assessed using the JBI and MERSQI instruments.

Results : Seven articles were eligible for review. Results showed that using VR increased the chance of passing exams by up to 85% compared to conventional learning methods. VR is used in various fields such as anatomy learning, Problem-Based Learning (PBL), clinical skills training, and OSCEs. Furthermore, VR contributes to the development of student empathy through immersive simulations.

Conclusion: Virtual Reality technology and digital simulation have a positive impact on medical students' achievement. Despite its many benefits, the implementation of this technology still requires careful planning and further research on its cost-effectiveness and long-term impact.

Keywords— *virtual reality; digital simulation; medical education; clinical skills.*

I. INTRODUCTION

Medical education is currently facing a digital transformation. One of the emerging innovations is the use of Virtual Reality (VR) based on Head-Mounted Display (HMD) and digital simulations that are able to replicate clinical scenarios realistically. This technology provides an embodied learning experience, where medical students can interact directly in a three-dimensional environment to hone their skills without harming real patients.[1] However, the shift from conventional methods to digital platforms such as Metaverse requires in-depth evaluation of its effectiveness in improving students' overall competencies.[2]

The use of VR in medical education is crucial for improving assessment standardization and learning efficiency. Conventional methods still have limitations in visualizing three-dimensional anatomical structures and providing consistent clinical case presentations for all students. [3]Furthermore,

digital technology has the potential to support transformative learning, including the development of empathy and critical reflection on social health issues. However, challenges such as high investment costs, limited infrastructure, and the risk of emerging novelty effects must be considered before wide-scale implementation is undertaken.[2][3]

To date, despite numerous small-scale studies, gaps remain in the generalizability of results and the validity of VR-based assessment instruments. Most literature focuses on short-term satisfaction and academic achievement, while evaluation of long term clinical behavior changes is still very limited. Therefore, this scoping review aims to map the scientific evidence regarding the influence of VR and digital simulations on clinical skills, procedures, and OSCE performance in medical students. Through this review, it is hoped that recommendations for appropriate implementation strategies for medical educational institutions can be formulated, particularly in integrating technology as a strong complement to learning methods. conventional teaching.[4][5][6]

II. METHOD

This study used a scoping review method to seek information on the use of virtual reality and digital simulation in developing medical students' skills. The literature search was conducted in several electronic databases, namely PubMed, Spinner Link, and Google Scholar, using keywords such as ("virtual reality" OR "digital simulation") AND ("medical education" OR "clinical skills"). "*digital simulation*") AND ("*medical education*" OR "*clinical skills*").

Article screening was conducted systematically using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines.

The screening was then conducted based on inclusion and exclusion criteria. The inclusion criteria for this study were (1) Articles discussing virtual reality or digital simulation for medical students (2) Articles discussing virtual reality or digital simulation as a method for learning clinical skills (3) Articles published within the last 5 years. Furthermore, the exclusion criteria for this study were articles discussing the author's theories and opinions without any research data. The study selection process began with an article screening stage, where titles and abstracts were read to determine the exclusion of articles that were not relevant to this study. Subsequently, the remaining articles were thoroughly reviewed through full-text assessment. Articles that meet the inclusion criteria are then entered into the data extraction table.

After conducting the article search, seven primary articles were selected for review. These articles were screened through a selection process using appropriate instruments to ensure the

quality of each article. Study quality was assessed using the Joanna Briggs Institute (JBI) for systematic reviews and the Medical Education Research Study Quality Instrument (MERSQI) for assessing the quality of medical education research. The effectiveness of the intervention was measured quantitatively using the Odds Ratio (OR) and p-value to determine the level of validity of the results, and qualitatively using the Kirkpatrick Model to measure academic achievement and student response to the technology used.

III. RESULTS AND DISCUSSION

A total of 7 articles have passed the selection stage based on the inclusion and exclusion criteria. entered into a data extraction table. This table is used to summarize the main information from each article.

TABLE I. DATA EXTRACTION RESULTS

No	Authors and Year of Publication	Article Title	Research Method	Research Focus
1.	Zhao <i>et al.</i> , 2021	<i>The comparison of teaching efficiency between virtual reality and traditional education in medical education: a systematic review and meta-analysis</i>	<i>Systematic review and meta-analysis</i>	Comparison of the effectiveness of VR-based learning versus traditional medical education
2	Gencer <i>et al.</i> , 2025	<i>Problem-based Learning in the Metaverse Environment: Evaluation of Virtual Reality Applications in Medical Education</i>	Quantitative comparatif (Wilcoxon and Mann-Whitney)	Evaluation of VR- and metaverse-based Problem-Based Learning (PBL) compared with face-to-face PBL in medical education
3.	Minouei <i>et al.</i> , 2024	<i>Effectiveness of virtual reality on medical students' academic achievement in anatomy: systematic review</i>	<i>Systematic review (model Kirkpatrick)</i>	Effectiveness of VR-based learning models on medical students' anatomy learning outcomes and academic performance.
4.	Mühling <i>et al.</i> , 2025	<i>Comparing Virtual Reality-Based and Traditional Physical Objective Structured Clinical Examination (OSCE) Stations for Clinical Competency Assessments: Randomized Controlled Trial</i>	<i>Randomized Controlled Trial (RCT)</i>	Comparison between VR-based OSCE and conventional OSCE in assessing clinical competence
5.	Lin <i>et al.</i> , 2024	<i>Can virtual reality technology be used for empathy education in medical students: a randomized case-control study</i>	<i>Randomized case-control study</i>	Impact of VR technology on the improvement of empathy, attitudes, and understanding of depression among medical students.
6.	Suri <i>et al.</i> , 2022	<i>Systematic literature review: The use of virtual reality as a learning media</i>	<i>Systematic literature review (SLR)</i>	Utilization of VR as a learning medium, including its benefits, effectiveness, and limitations
7.	Neher <i>et al.</i> , 2025	<i>Virtual reality for assessment in undergraduate nursing and medical education – a systematic review</i>	<i>Systematic review</i>	Use of immersive VR as a competency assessment tool for nursing and medical students

Based on a review of the collected literature, the results of the meta-analysis showed that students who used virtual reality (VR) had an 85% higher chance of passing the exam compared to traditional methods, with an Odds Ratio (OR) of 1.85. In the context of clinical skills, VR-based OSCEs have been shown to be equivalent or even more effective than traditional OSCEs in improving student learning outcomes.[4] In addition, the integration of VR in anatomy learning consistently improves academic achievement due to its ability to visualize complex three-dimensional structures.[3] At a more advanced level of learning, this technology also facilitates the development of empathy and critical reflection through simulations of complex social situations, such as the experiences of patients with disabilities or mental disorders.[1]

VR technology has demonstrated significant effectiveness in medical education. Despite its great potential, related research still faces challenges, such as the limited number of participants (between 12 and 123), which limits the broad applicability of the results.[7] Furthermore, most research still focuses on the first and second levels of Kirkpatrick's model, namely reactions and learning processes, so further study is needed regarding the level of clinical behavior and patient health outcomes. In terms of application, this digital technology is not intended to completely replace traditional methods, but rather as an effective supplement or supporting method.[3]

The success of VR implementation depends on organized learning design, instructor guidance, and post-simulation discussions to avoid risks such as social distancing or stereotyping of certain groups. In Indonesia, the use of this technology requires consideration of differences in digital access, facility availability, and the relatively high initial cost. Therefore, a phased implementation approach that includes checking facilities, training lecturers, and conducting small trials are highly recommended to ensure the continuity of the program in medical education institutions.

a. Application in preclinical education

Based on findings from a scoping review, the use of virtual reality (VR) and digital simulation in medical education has undergone significant development and encompasses various learning stages, both in the preclinical and clinical phases. VR technology allows for interactive, three-dimensional visualization of anatomical structures, allowing students to better understand the spatial relationships between organs compared to two-dimensional media such as atlases or conventional radiological images. A systematic review by Minouei et al. (2024) showed that the majority of studies reported improvements in medical students' understanding and

academic outcomes when using VR as an aid in anatomy learning, particularly at the level of reaction and learning according to the Kirkpatrick evaluation model.[3]

In addition to anatomy, VR and digital simulations are also used in problem-based learning (PBL) methods and to hone non-cognitive skills. Research evaluating PBL utilizing the metaverse shows that students feel more satisfied compared to conventional PBL experiences, especially in terms of learning engagement, flexibility in space and time, and the development of clinical reasoning and communication skills. The virtual environment allows students to actively interact with clinical scenarios without physical limitations, thus aligning with the characteristics of a generation of medical students who are increasingly familiar with digital technology.[5] In addition, VR also functions in empathy education, particularly in understanding the conditions of patients experiencing mental disorders such as depression. By undergoing immersive patient experience simulations, medical students can develop a cognitive perspective on the patient's psychological condition that is difficult to master using only conventional learning methods.[8]

b. Application in clinical education

In clinical education, VR and digital simulation technologies are widely used for clinical skills training and competency assessment. One notable example is the use of VR in Objective Structured Clinical Examination (OSCE). Randomized controlled trials have shown that VR-based OSCEs, particularly in emergency scenarios, can be technically implemented and managed effectively, and have comparable difficulty and assessment validity to conventional OSCEs using standardized patients. VR technology has even demonstrated good ability to differentiate item quality, effectively recognizing differences in student ability levels.[4] Furthermore, a systematic review of the use of VR as an assessment tool has shown that VR has the potential to reduce examiner workload, increase objectivity in assessment, and enable more standardized performance-based evaluations, particularly in competencies such as patient care, communication, and clinical decision-making.[6]

c. Effectiveness and Comparison with Conventional Methods

The results of the literature review indicate that the effectiveness of VR and digital simulations is generally comparable to or even superior to conventional learning methods, especially in terms of cognitive learning and practical skills. A meta-analysis comparing VR-based learning with

conventional education shows that students engaged in learning using VR have significantly higher pass rates and exam performance. This indicates that learning through VR can improve understanding and application of material better than passive lecture and demonstration methods.[2]

However, several studies have also noted that there is not always a significant difference between the use of VR and conventional methods, particularly in anatomy learning. In this case, VR is considered most effective when used as a complementary method supporting cadaveric dissection or face-to-face learning, rather than as the sole alternative. This suggests that the effectiveness of VR is highly dependent on instructional design, curriculum integration, and user readiness to utilize the technology to its full potential.[3] In the context of clinical assessment, VR-based OSCEs have demonstrated comparable effectiveness to traditional OSCEs, with the added benefits of resource efficiency and potential long-term cost savings despite requiring a substantial initial investment.[4]

d. Advantages and Disadvantages

This review reveals the numerous benefits of using VR and digital simulation in medical education. One of the key advantages of this technology is its ability to provide immersive, interactive, and safe learning experiences for students. With VR, complex and high-stakes clinical simulations, such as medical emergencies, can be simulated without endangering real-world patients. Furthermore, VR Supports standardization of learning and assessment, reducing the variability often associated with conventional human based methods. From an institutional perspective, this technology has the potential to increase long-term efficiency by reducing the need for standardized patients, single-use medical equipment, and large physical spaces.

However, there are several drawbacks that should also be considered. The costs for the initial development and implementation of VR tend to be high, especially related to hardware, software development, and teacher training. Furthermore, not all users can immediately adapt to VR technology, so it takes time to adjust and get used to it. Several studies have also shown side effects such as dizziness, nausea, and visual discomfort (cybersickness), which can interfere with the learning experience for some students. Another limitation is that VR's capabilities cannot yet fully replace real human interaction, especially in developing complex emotional aspects and interpersonal communication.[3]

IV. CONCLUSION

Based on the results of this scoping review, it can be concluded that the use of Virtual Reality (VR) and digital

simulation has been widely used in medical education, particularly in anatomy learning, clinical skills training and assessment such as OSCEs, problem-based learning (PBL), and also in the development of empathy and communication, has a real positive impact on improving academic achievement and clinical skills of students. The main advantage of this technology lies in its ability to create a safe learning environment for practicing complex clinical procedures and displaying anatomy in three-dimensional detail. However, widespread implementation still faces challenges such as high initial costs, infrastructure readiness, user adaptation, and the risk of side effects such as cybersickness. Thus, VR and digital simulation are promising innovations in improving the quality of medical education, although careful planning and further research are needed regarding the long-term impact and cost-effectiveness.

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