

Preparing for the Unpredictable: Integrating Simulation-Based and Digital Twin-Driven Learning Systems for Healthcare Professionals in Emergency and High-Risk Clinical Care Scenarios

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ABSTRACT

Healthcare professionals working in high-risk and emergency care settings are expected to make quick, high-stakes decisions, yet many existing training approaches struggle to fully prepare them for the complexity, uncertainty, and dynamic nature of real clinical environments. Traditional simulation-based training and digital twin technologies remain largely disconnected from healthcare training systems. This disconnect represents a critical gap in the preparation of a workforce expected to operate in increasingly complex, data-driven healthcare systems. This study examines how simulation-based and digital twin-driven learning systems can be combined to enhance the training of healthcare professionals in high-risk and emergency care scenarios, using a critical integrative review approach to synthesise diverse evidence. The findings reveal that simulation-based learning is widely effective in developing technical and non-technical skills, confidence, and experiential knowledge, but is limited by its lack of adaptability and real-time responsiveness. In contrast, digital twin technologies offer dynamic, data-driven, and predictive capabilities that support personalised and adaptive learning, yet remain underdeveloped in training applications. From this synthesis, four key themes emerged: including the need for dynamic and adaptive learning environments; the role of real-time feedback and predictive insights; the importance of continuous and personalised learning; and the influence of contextual factors such as infrastructure, data governance, and digital competence. Building on these insights, the study develops a novel conceptual framework that positions simulation and digital twins as complementary components of an integrated learning system. In this model, simulation provides experiential grounding, while digital twins enhance adaptability, intelligence, and real-time responsiveness. Together, they enable a shift from static training models to continuous, data-driven, and context-aware learning environments. Therefore, this study concludes that integrating simulation-based and digital twin-driven learning systems has the potential to transform healthcare training by making it more realistic, adaptive, and aligned with clinical practice. However, realising this potential will require empirical validation, investment in infrastructure and workforce capabilities, and careful attention to ethical and data governance considerations.

Keywords- Virtual Reality (VR), Digital Simulation, Real-Time Simulation, Predictive Analytics, Personalized Training Environments, Digital Twin Technology, Technological Innovation, Practical Implementation.

I. INTRODUCTION

Healthcare professionals working in high-risk and emergency care settings are often required to make quick, life-saving decisions in situations that are complex, unpredictable, and emotionally demanding. In these environments, there is very little room for error, and the ability to think clearly, adapt quickly, and act confidently is essential. On account of this, how healthcare professionals are trained becomes critically important. Training is not just about learning procedures, it is about preparing people to respond effectively in real-world situations where outcomes can change rapidly (Matthieu et al., 2024). Over the years, simulation-based learning has become a widely accepted and valuable approach to healthcare training. It allows professionals to practice clinical scenarios in a safe and controlled environment, helping them develop both technical and non-technical skills such as communication, teamwork, and decision-making (Guisse and Wiig, 2016; Birkheim et al., 2023). Studies have shown that simulation can improve confidence and provide realistic insights into clinical practice, making it especially useful for preparing professionals for challenging situations (Einloft et al., 2024).

However, despite these strengths, simulation-based training has its limitations. Many simulation scenarios are pre-designed and relatively fixed, which means they cannot always reflect how quickly and unpredictably real clinical situations evolve. In practice, patient conditions can change moment by moment, requiring continuous reassessment and adaptation. Simulation, in its traditional form, does not always capture this level of complexity. As a result, there can be a gap between what healthcare professionals experience in training and what they encounter in real-life clinical settings. Some evidence also suggests that while simulation improves performance, it may not fully address the emotional and cognitive pressures experienced in real crises (Beneria et al., 2020; Snogren et al., 2024).

At the same time, healthcare is undergoing a major transformation driven by digital technologies, data, and artificial intelligence. One of the most promising developments in this space is digital twin technology, which creates real-time virtual models of patients, systems, or processes. These models can use data from multiple sources to simulate, predict, and monitor changes, allowing for more personalised and proactive decision-making (Liu et al., 2017; Meijer et al., 2023; Vallée, 2023). In simple terms, digital twins make it possible to not only see what is happening, but also to anticipate what might happen next. Despite this potential, digital twin technology is still largely underutilised in healthcare training. Much of the current

research focuses on conceptual models, system design, or clinical applications, rather than on how these technologies can be used to train healthcare professionals (Machado and Berssaneti, 2023; Bansah, 2024; Rathod & Mamatha, 2024). This creates a disconnect between technological innovation and educational practice. On one hand, simulation is widely used but often static; on the other, digital twins are dynamic and predictive but not yet fully integrated into training environments (Lakhan et al., 2023; Harode et al., 2023; Latif et al., 2023).

Another important challenge is the digital readiness of the healthcare workforce. As healthcare becomes more technology-driven, professionals are expected to engage with complex digital systems. However, many still lack sufficient training in digital tools and data-driven decision-making, which can limit the effectiveness of new technologies in practice (Navarro-Martínez et al., 2023). This highlights the need for training approaches that not only incorporate advanced technologies but also support professionals in developing the skills required to use them effectively. Although there is growing interest in simulation, digital twins, artificial intelligence, and immersive technologies, these areas are often explored separately rather than as part of an integrated system. There is limited research that critically examines how simulation-based learning and digital twin-driven systems can be combined to create more adaptive, responsive, and realistic training environments (Lektauers et al., 2022; Falayi et al., 2024). As a result, there is a lack of clear guidance on how to design, implement, and evaluate such integrated approaches.

This study addresses this gap by conducting a critical integrative review of the existing literature. The aim is to explore how simulation-based and digital twin-driven learning systems can be brought together to enhance the training of healthcare professionals, particularly in high-risk and emergency care settings. Thus, this study seeks to develop a clearer understanding of current knowledge, identify key gaps, and propose a conceptual framework to guide future research and practice.

II. LITERATURE REVIEW

At the heart of this review are two key ideas: simulation-based learning and digital twin technology. Both are trying to address the same underlying challenge, how to better prepare healthcare professionals for complex, high-risk situations, but they approach it in different ways. Understanding how they relate to each other helps to clarify where the field is now and where it could go next.

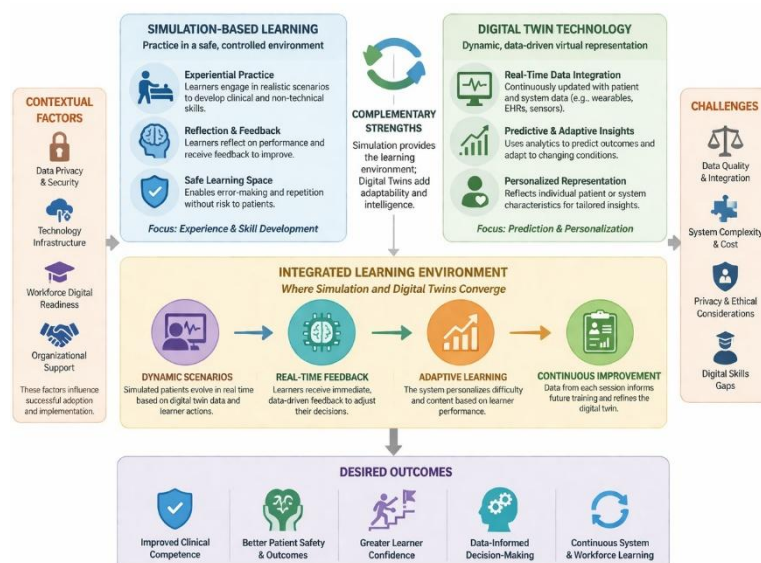


Fig. 1: Conceptual Framework

Simulation-based learning is grounded in the idea that people learn best when they can practice in a safe, controlled environment before facing real-life situations. In healthcare, this includes activities such as mannequin-based simulations, role-playing, and virtual scenarios that mimic clinical situations. Studies such as Guise and Wiig (2016) show that simulation allows professionals to gain realistic insight into new ways of working, such as telecare, while building confidence and practical skills. Similarly, Birkheim et al. (2023) and Einloft et al. (2024) highlight how immersive simulation, particularly through virtual reality, can enhance engagement and improve both technical and non-technical skills, especially in high-risk settings like emergency care. What makes simulation particularly valuable is its focus on experience and reflection. Learners are able to make decisions, observe outcomes, and refine their actions without risking patient safety. However, despite these strengths, simulation is often limited by its static nature. Many scenarios are pre-designed and do not fully adapt to the learner's actions or reflect the dynamic complexity of real patients. As noted in studies like Snogren et al. (2024), simulation and digital training can improve task performance, but they do not always lead to deeper changes in knowledge or attitudes. This suggests that while simulation is effective for skill development, it may not fully capture the evolving and unpredictable nature of real clinical environments.

This is where digital twins become particularly relevant. A digital twin can be understood as a dynamic virtual representation of a real-world entity, such as a patient or healthcare system, that is continuously updated using real-time data. Unlike traditional simulation, which is often fixed, digital twins are designed to adapt, evolve, and even predict future outcomes. For example, Liu et al. (2017) describe how

digital twin systems can integrate data from wearable devices and healthcare records to support real-time monitoring and personalised care. Similarly, Meijer et al. (2023) and Vallée (2023) emphasise the potential of digital twins to enable predictive analytics, personalised treatment planning, and improved clinical decision-making.

In simple terms, while simulation focuses on practice and experience, digital twins focus on prediction and personalisation. Simulation asks, "What would you do in this situation?" whereas digital twins extend this by asking, "What is likely to happen next, and how can we respond more effectively?" This shift reflects a broader movement in healthcare towards more data-driven and proactive approaches to care (Goni et al., 2024; Olorunfemi et al., 2024). Early conceptual work, such as Lektuers et al. (2022), begins to explore this possibility by combining digital twin frameworks with simulation environments, although empirical evidence remains limited. Another important concept that emerges from the literature is continuous feedback and adaptation. Traditional simulation often provides feedback after the session has ended, but digital twin integration could enable real-time feedback, allowing learners to adjust their actions as situations unfold. This aligns with broader discussions in the literature about the role of AI and data-driven systems in supporting clinical decision-making and learning (Giordano et al., 2021; Falayi et al., 2023). Over time, such systems could become increasingly personalised, adapting to the learner's level of experience and providing more targeted training.

III. RELATED STUDIES

Across the literature, a clear but nuanced picture emerges: simulation-based learning and digital twin technologies are both seen as valuable for

improving healthcare training and practice, yet they are evolving along different paths and are rarely meaningfully integrated. What is particularly striking is that, although both aim to improve decision-making and patient outcomes in complex clinical environments, they are often discussed in isolation rather than as complementary systems. Simulation-based learning has consistently been shown to provide a safe and realistic environment for healthcare professionals to develop skills, especially in high-risk or unfamiliar contexts. For example, Guise and Wiig (2016) demonstrate how simulation helped practitioners gain practical insight into telecare, allowing them to rehearse new modes of patient interaction without real-world consequences. This aligns with later studies, such as Birkheim et al. (2023) and Einloft et al. (2024), which highlight the value of immersive and VR-based simulations in enhancing engagement, realism, and skill acquisition, particularly in emergency care settings. Similarly, Power et al. (2023) found that even brief, structured training interventions can lead to measurable improvements in communication and knowledge. Taken together, these studies strongly agree that simulation is effective for building confidence, technical competence, and non-technical skills such as teamwork and communication.

However, this positive picture becomes more complex when examining deeper or longer-term outcomes. Some studies suggest that improvements in performance do not always translate into improved psychological resilience or sustained behavioural change. For instance, Beneria et al. (2020) found that healthcare professionals who had undergone simulation-based teamwork training reported higher levels of anxiety and depression during the COVID-19 pandemic, despite experiencing slightly lower stress levels. This finding challenges the assumption that better training automatically leads to better coping under pressure. In a similar vein, Snogren et al. (2024) observed that while digital training made it easier for professionals to perform practical tasks, it did not significantly alter their knowledge or attitudes. These findings suggest that simulation, while effective for “learning by doing,” may have limitations in shaping deeper cognitive or emotional outcomes, highlighting a gap between skill acquisition and broader professional development.

In contrast, the literature on digital twin technology presents a more forward-looking perspective. Many studies, such as Liu et al. (2017) and Hassani et al. (2022), describe digital twins as systems capable of continuously integrating real-world data to create dynamic virtual representations of patients or healthcare processes. This enables real-time monitoring, predictive analytics, and highly personalised care. Reviews by Meijer et al. (2023), Vallée (2023), and Goni et al. (2024) consistently emphasise the transformative potential of digital twins to shift healthcare from a reactive model to a predictive and preventive one. In simple terms, while simulation helps professionals

practice what might happen, digital twins aim to anticipate what will happen.

Despite this shared optimism, there is also strong agreement that digital twin applications in healthcare are still in an early stage of development. Much of the existing work remains conceptual, focusing on frameworks, architectures, or proof-of-concept studies rather than real-world implementation. For example, Hussain et al. (2021) demonstrate the feasibility of a digital twin for stroke prediction using EEG data, but this remains a controlled, experimental application. Across the literature, recurring challenges include data integration, model accuracy, privacy and security concerns, and the lack of standardised validation processes (Akash and Ferdous, 2022; Iliuta et al., 2024). Machado and Berssaneti (2023) further note that the field is still emerging, with limited evidence of fully developed, large-scale digital twin systems in clinical practice. This creates a clear tension: while digital twins are widely promoted as transformative, their practical impact is not yet firmly established.

Perhaps the most important insight for this review is the limited intersection between simulation-based learning and digital twin technologies. While simulation research is primarily concerned with education and human performance, digital twin research focuses on data, systems, and predictive modelling. Only a small number of studies begin to explore how these approaches might be combined. For instance, Lekturers et al. (2022) propose a framework that integrates digital twins with simulation environments for training purposes, and Vallée (2023) suggests that digital twins could enhance simulation by enabling more adaptive and personalised scenarios.

At the same time, several studies highlight an often-overlooked barrier: the readiness of the healthcare workforce to engage with these technologies. Navarro-Martínez et al. (2023) found that many healthcare professionals, particularly nurses, receive limited training in digital skills, sometimes needing to fund their own learning. This suggests a gap between technological advancement and user preparedness. Giordano et al. (2021) similarly argue that the rise of AI and data-driven systems will require significant changes in healthcare education, including a better understanding of how these technologies work and their limitations. Without this foundational knowledge, even the most advanced systems may fail to achieve their intended impact.

In summary, the literature points to a field in transition. Simulation-based learning is well established and effective for developing practical skills, but its impact on long-term outcomes and real-world performance remains uncertain. Digital twin technology, on the other hand, offers powerful possibilities for predictive and personalised healthcare but is still developing and lacks robust validation. Crucially, the integration of these two approaches, combining the experiential strengths of simulation with the adaptive,

data-driven capabilities of digital twins, remains underexplored.

IV. METHODOLOGY

This study adopts a critical integrative review approach, which is especially useful for topics that are still developing and where evidence comes from many different types of research. Rather than focusing only on one kind of study, this approach allows for the inclusion of quantitative studies, qualitative research, conceptual papers, and technological frameworks. Thus, it brings together different kinds of knowledge and then carefully examines how they connect, where they agree, and where they fall short. This is particularly important for this review, as research on simulation-based learning and digital twin technologies in healthcare is still fragmented and evolving. In this study, the approach made it possible to explore how simulation-based learning and digital twin technologies are being used in healthcare training, especially in high-risk and emergency care, and to understand why these two areas have not yet been fully integrated.

To gather relevant literature, a structured search was conducted across several major academic databases, including PubMed, Scopus, Web of Science, IEEE Xplore, and Google Scholar. A combination of keywords was used to capture both educational and technological perspectives, such as “simulation-based learning,” “healthcare simulation,” “digital twin,” “digital twin healthcare,” “virtual simulation,” and “emergency care training.” These terms were used in different combinations to ensure that the search was broad enough to include diverse perspectives, while still remaining focused on the core topic. Only studies published in English were considered.

Clear inclusion and exclusion criteria were applied to keep the review focused. Studies were included if they related to healthcare professionals or systems, and if they addressed simulation-based learning, digital twin technologies, or closely related approaches such as virtual reality or AI-driven systems. Both empirical studies and theoretical or conceptual papers were considered, as long as they contributed meaningfully to understanding training, decision-making, or clinical application. Studies were excluded if they were not related to healthcare or focused purely on technical development without any link to practice or training, or if they lacked sufficient analytical depth.

The study selection process was carried out in stages. First, titles and abstracts were reviewed to remove clearly irrelevant articles. Then, full texts were examined more carefully to ensure they met the inclusion criteria. Because this is an integrative review, the aim was not to narrow the selection too strictly, but rather to include a broad and meaningful range of studies. This helped ensure that both well-established research, such as simulation-based training, and

emerging work, such as digital twin frameworks, were adequately represented.

In terms of quality evaluation, a flexible approach was used. Instead of applying a single rigid checklist, each study was assessed based on its overall credibility, clarity, and contribution to the topic. For empirical studies, attention was given to the appropriateness of the methods and the strength of the findings. For conceptual and technical papers, the focus was on the clarity of the framework, the logic of the arguments, and the potential relevance to healthcare training and practice.

The analysis of the selected studies followed a thematic and critical process. Each paper was read carefully and compared with others to identify recurring ideas, differences in findings, and underlying assumptions. Rather than simply listing results, the analysis focused on drawing connections across studies and developing broader themes. Finally, the review moved beyond description to develop a more integrated and critical perspective. This involved reflecting on why certain gaps persist, particularly the disconnect between established training methods and emerging digital technologies. It also involved identifying opportunities for future research, especially in combining simulation-based learning with digital twin systems to create more adaptive and data-driven training environments. As this study is based entirely on previously published literature, no formal ethical approval was required. However, care was taken to ensure that all sources were interpreted accurately and represented fairly.

V. RESULTS

When all the studies are carefully compared, the evidence reveals a mix of strengths and emerging possibilities, especially when looking at simulation-based learning and digital twin technologies side by side. One of the strongest and most consistent findings across the literature is that simulation-based learning is effective for developing practical skills and confidence. Studies such as Guise and Wiig (2016), Birkheim et al. (2023), and Einloft et al. (2024) all point in the same direction: simulation gives healthcare professionals a safe space to practice, make mistakes, and improve without risking patient safety. These improvements do not always translate into long-term outcomes. For example, while simulation improves performance during training, studies like Snogren et al. (2024) show that it may not significantly change knowledge or attitudes. Even more interestingly, Beneria et al. (2020) found that those who had undergone simulation training experienced higher levels of anxiety and depression during the COVID-19 pandemic, although their stress levels were slightly lower.

A second major finding relates to the growing role of digital and immersive technologies in training. Studies on virtual reality and digital learning

environments, such as those by Power et al. (2023) and Einloft et al. (2024), show that these tools can make learning more engaging and accessible. Moreover, unlike simulation, which is supported by many practical studies, digital twin research is largely conceptual and future-oriented. Studies such as Liu et al. (2017), Meijer et al. (2023), and Vallée (2023) consistently describe digital twins as powerful tools for real-time monitoring, prediction, and personalised care. There is strong agreement that digital twins could transform healthcare by allowing professionals to anticipate patient outcomes and make more informed decisions. For example, studies like Hussain et al. (2021) show early proof-of-concept applications where digital twin models support diagnosis and prediction.

However, despite this optimism, the literature also clearly shows that digital twin applications are still in an early stage of development. Many studies focus on frameworks, models, or small-scale experiments rather than real-world implementation. Common challenges include difficulties with data integration, concerns about privacy and security, and the need for accurate and reliable models (Akash and Ferdous, 2022; Iliuta et al., 2024). As Machado and Berssaneti (2023) note, the field is still maturing, with limited large-scale applications currently in practice. This creates a noticeable gap between what digital twins promise and what has actually been achieved so far. Another important finding is the lack of integration between simulation-based learning and digital twin technologies. Although both are widely discussed, very few studies actually combine them in a meaningful way. Simulation studies tend to focus on education and training, while digital twin research focuses on data, prediction, and system optimisation. Some early work, such as Lektuers et al. (2022), suggests that combining these approaches could create more advanced training environments, but this idea is still mostly theoretical.

Finally, the literature repeatedly highlights the importance of human and organisational factors, especially in relation to digital readiness (Okolo et al., 2024). Studies like Navarro-Martínez et al. (2023) show that many healthcare professionals do not receive enough training in digital technologies, which may limit their ability to use advanced systems effectively. Similarly, Giordano et al. (2021) emphasise that as healthcare becomes more data-driven, professionals will need new skills and knowledge to understand and work with technologies like AI and digital twins. This suggests that even the most advanced tools will not have a meaningful impact unless healthcare systems invest in training, support, and infrastructure.

VI. DISCUSSION

This review shows that strong pieces of the puzzle already exist, but they are not yet fully working together. Starting with simulation-based learning, the

evidence consistently shows that it is a valuable and reliable foundation for training, as it helps healthcare professionals build confidence, practice skills, and prepare for high-risk situations in a safe way (Guise and Wiig, 2016; Birkheim et al., 2023; Einloft et al., 2024). This aligns with the first part of the conceptual framework, where simulation creates the learning environment, a space where people can actively engage, make decisions, and learn from experience. In many ways, simulation is already doing what it is meant to do, and doing it well.

However, the findings also highlight its limitations. Simulation is often pre-designed and static, meaning it cannot fully respond to the complexity and unpredictability of real clinical situations. This helps explain why improvements are often seen in immediate performance, but not always in deeper learning or long-term results (Snogren et al., 2024). In some cases, the impact may even be mixed; for example, Beneria et al. (2020) found that simulation-trained professionals reported higher levels of anxiety and depression during the COVID-19 pandemic, despite slightly lower stress levels. This suggests that while simulation strengthens performance, it does not always address the emotional and cognitive demands of real-world crises.

This is where digital twin technology becomes particularly important. The literature shows that digital twins introduce real-time data integration, predictive capabilities, and personalization; and offer a more dynamic approach to understanding clinical situations (Liu et al., 2017; Meijer et al., 2023; Vallée, 2023). Within the conceptual framework, this represents the layer that adds intelligence and adaptability to the learning environment. Rather than relying on fixed scenarios, digital twins allow situations to evolve based on data and user interaction, shifting the focus from simply practicing tasks to anticipating outcomes (Goni et al., 2024).

When these two approaches are considered together, their complementary nature becomes clear. The framework suggests that simulation and digital twins are not separate solutions, but interdependent systems. Simulation provides the structure and experiential learning, while digital twins enhance this by introducing responsiveness and data-driven insights. Early conceptual work supports this idea; for instance, Lektuers et al. (2022) propose integrating digital twin frameworks with simulation environments to create more advanced training systems, although empirical validation is still limited.

The themes identified in the results, such as dynamic scenarios, real-time feedback, adaptive learning, and continuous improvement, fit naturally within this integrated model. For example, instead of following a fixed script, a simulated patient could change in real time based on the learner's actions, supported by predictive models and real clinical data. This would make training more reflective of real-life

practice, where uncertainty and rapid change are common. Similarly, feedback could shift from being delivered after a session to being provided continuously during the learning process, supporting immediate reflection and adjustment (Giordano et al., 2021).

Another important insight is the role of continuous improvement within the framework. Traditional training often ends when the session is over, but an integrated system allows data from each interaction to inform future learning. Over time, this creates a feedback loop where both the learner and the system improve together. This aligns with broader discussions in the literature about the potential of data-driven systems to enhance clinical decision-making and personalise healthcare delivery (Vallée, 2023; Goni et al., 2024). At the same time, the framework also helps make sense of the challenges identified in the literature. Issues such as data quality, system complexity, and privacy concerns are not just technical barriers, they are central to whether integration can succeed (Akash and Ferdous, 2022; Iliuta et al., 2024). In addition, contextual factors such as infrastructure, organisational support, and workforce readiness play a critical role. For example, Navarro-Martínez et al. (2023) highlight that many healthcare professionals lack sufficient digital training, which can limit their ability to effectively use advanced technologies. This suggests that successful integration depends not only on innovation, but also on people, systems, and environments being ready to support it.

This also helps explain the gap between the promise of digital twin technology and its current level of implementation. While many studies highlight its transformative potential, most applications remain at the conceptual or early development stage (Machado & Berssaneti, 2023; Olugbade, et al., 2023; Olugbade, et al., 2024). The framework suggests that this is because integration requires more than just new tools, it requires a shift towards adaptive, data-driven learning systems, as well as changes in education, policy, and clinical practice. Another key point is the central role of the healthcare professional within this system. The framework is not just about technology, it is about supporting human learning and decision-making. As Giordano et al. (2021) emphasise, healthcare professionals need to understand how data-driven systems work, including their limitations, in order to use them safely and effectively. Without this understanding, even advanced systems may not lead to better outcomes (Okolo et al., 2024). In summary, the discussion highlights that the future of healthcare training lies not in choosing between simulation and digital twins, but in bringing them together in a meaningful and practical way. Simulation helps healthcare professionals learn how to act, while digital twins help them understand what is likely to happen next. When these are combined, training can better reflect the complexity of real clinical practice, especially in high-risk and emergency care

settings where preparation, adaptability, and informed decision-making are essential.

VII. INDUSTRY IMPLICATIONS

When we step back and look at what all of this means for the healthcare industry, one thing becomes very clear: training can no longer stay the way it is. The demands on healthcare professionals, especially in high-risk and emergency care, are increasing, and traditional training methods are starting to show their limits. What this review suggests is not just a small improvement, but a shift in how training is designed, delivered, and supported. First, there is a strong case for moving beyond standalone simulation towards more integrated, technology-enhanced training systems. Simulation has already proven its value, but on its own, it is often too fixed and limited. As such, organisations have the opportunity to create training environments that are more dynamic, personalised, and reflective of real clinical complexity. In practical terms, this could mean training systems where patient scenarios evolve in real time, where decisions have consequences that unfold, and where learners receive immediate, data-driven feedback.

For healthcare organisations, this shift has important implications for investment and infrastructure. It is no longer just about buying simulation equipment or running occasional training sessions. Instead, there is a need to invest in integrated digital ecosystems, systems that combine simulation tools, data platforms, artificial intelligence, and real-time analytics. While this may seem like a significant investment upfront, the long-term benefits could include better-prepared staff, fewer clinical errors, and ultimately improved patient outcomes. Similarly, healthcare professionals need to feel confident using these systems and understand how they work. This means organisations must prioritise digital skills training alongside clinical training. It also means rethinking education and professional development to include areas like data literacy, AI awareness, and digital decision-making. Without this, even the most advanced systems may go underused or be used incorrectly.

There is also an important implication for how training is delivered over time. Traditionally, training has often been seen as something that happens occasionally, during workshops, courses, or scheduled simulation sessions. However, integrated systems open the door to continuous learning. Training can become an ongoing process, where healthcare professionals learn, receive feedback, and improve as part of their everyday work. This is particularly valuable in fast-changing high-risk environments like emergency care, where new challenges constantly arise. However, the industry also needs to approach this transition carefully. The review highlights real concerns around data privacy, system reliability, and ethical use of technology. Healthcare data is highly sensitive, and digital twin systems rely heavily

on large amounts of it. This means organisations must put strong safeguards in place to protect patient information and ensure that systems are accurate and trustworthy. In addition, there needs to be clear guidance and regulation around how these technologies are used in both training and clinical decision-making.

VIII. NOVEL CONTRIBUTION

What this study really brings to the table is a new way of looking at two important but often separate ideas, simulation-based learning and digital twin technology; and showing how they can work together. One of the main contributions is the development of a clear and simple conceptual framework that explains this integration. Instead of seeing simulation as just a training tool and digital twins as just a technological innovation, the framework brings them together into a layered learning system. In this system, simulation provides the experience and practice environment, while digital twins add real-time data, prediction, and adaptability. This combined view helps move the conversation forward from “what each tool does” to “how they can enhance each other.”

There is also a shift in perspective from static training to adaptive learning. Much of the existing studies focus on simulation as something that is planned in advance and delivered in a fixed way. This study challenges that idea by showing how digital twins can make training more responsive and personalised. Thus, instead of everyone going through the same scenario, training can adjust to the learner’s actions, level of experience, and even predicted outcomes. This introduces the idea of intelligent training environments, which is still underexplored in current healthcare education research.

Another novel aspect is the emphasis on human and contextual factors, not just technology. Rather than focusing only on what these systems can do, the study also considers what is needed to make them work in real healthcare settings, such as digital skills, organisational readiness, and infrastructure. This adds a more realistic and practical dimension to the discussion, which is often missing in technology-driven research. Finally, this study contributes by reframing the future of healthcare training. Instead of viewing training as a separate activity that happens occasionally, it presents the idea of continuous, data-driven learning embedded within clinical practice. This is a subtle but important shift. It suggests that training and practice do not have to be separate, they can become part of the same system, constantly informing and improving each other.

IX. LIMITATIONS AND FUTURE DIRECTIONS

Like any study, this study has its limitations, and being open about them helps put the findings into

the right perspective. First, much of the literature on digital twins in healthcare is still at an early stage and focus on proposed models, frameworks, or proof-of-concept systems rather than fully implemented solutions in real clinical settings. This makes it difficult to fully assess how effective these technologies are in practice, especially when combined with simulation-based training. As such, we are often looking at what *could* work, rather than what has already been widely proven to work. There is also a limited number of studies that directly explore the integration of simulation and digital twin systems for healthcare training. Most of the evidence comes from looking at these areas separately and then bringing them together through interpretation. While this is a strength of the integrative approach, it also means that the proposed conceptual framework has not yet been extensively tested in real-world settings. Contextually, the studies included in this review come from different countries, healthcare systems, and technological environments. What works well in one setting may not be easily transferable to another, especially in regions with limited resources or digital infrastructure. This means that the findings may not fully reflect the realities of all healthcare settings, particularly in low-resource settings.

Looking ahead, future studies could explore how digital twin data can be used to personalise training experiences, adjust difficulty levels, and provide real-time feedback in ways that truly support individual learners. Second, more attention should be given to long-term outcomes. Many existing studies focus on immediate learning gains, but we need to understand whether integrated training approaches lead to sustained improvements in skills, decision-making, and real-world clinical practice over time. There is also a need to better understand the human side of adoption. This includes exploring healthcare professionals’ attitudes towards these technologies, their readiness to use them, and the kinds of training and support they need. Without this understanding, even well-designed systems may face resistance or underuse. Finally, more work is needed to explore scalable and context-sensitive implementation strategies. This includes finding ways to adapt these technologies to different healthcare settings, including low- and middle-income environments, where resources may be more limited but the need for effective training is just as critical.

X. CONCLUSION AND RECOMMENDATIONS

Healthcare training is evolving, and it needs to evolve faster, especially for high-risk and emergency care where decisions are critical and mistakes can have serious consequences. Therefore, this study concludes that the real value lies in bringing these technologies together. When simulation and digital twins are integrated, training can become more realistic, more

adaptive, and more closely aligned with real clinical practice. Instead of simply practicing scenarios, healthcare professionals can begin to engage with evolving situations, anticipate outcomes, and make better-informed decisions.

Based on these insights, this study recommends that healthcare organisations should begin to move towards integrated training systems rather than relying on simulation or digital tools in isolation. This does not have to happen all at once, it can start with small pilot projects that gradually bring simulation and data-driven technologies together. Second, there is a strong need to invest in digital infrastructure and workforce development. Technology alone is not enough. Healthcare professionals need the skills and confidence to use these systems effectively. This means embedding digital literacy, data awareness, and basic understanding of AI and predictive tools into training programs. Third, training should be rethought as a continuous and evolving process, rather than a one-time event. Integrated systems make it possible to provide ongoing feedback and personalised learning, helping professionals improve over time as part of their everyday work. Finally, developers, educators, and healthcare organisations should work more closely together to ensure that these systems are practical, user-friendly, and aligned with real clinical needs. Collaboration is essential to bridge the gap between technical innovation and real-world application.

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