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Enhancing creativity and cognitive skills in healthcare curricula: Recommendations from a modified delphi study on virtual reality integration

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A B S T R A C T

The incorporation of Virtual Reality (VR) into healthcare education presents significant opportunities to enhance creativity, critical thinking, and overall learning outcomes, yet comprehensive frameworks to guide its implementation remain sparse. To address this gap, this study employed a three-round modified Delphi process with international healthcare and technology experts, aiming to establish evidence-based guidelines for effectively integrating reusable VR resources into healthcare curricula. In Round 1, nine thematic categories emerged from open-ended questions, encompassing theoretical frameworks, instructional design, resource development, and organizational strategies. In Round 2, 62 statements derived from these themes were refined and rated by experts, focusing on key elements such as managing cognitive load, improving learner engagement, and fostering affective and psychomotor skills. Round 3 validated and prioritized the recommendations, aligning them with models like the Cognitive-Affective Model of Immersive Learning (CAMIL). Key results include practical strategies to enhance learning across cognitive, affective, and psychomotor domains, ensuring that VR resources are co-created with learners, integrate smoothly into existing systems, and leverage immersive learning analytics to continuously assess and optimize their impact. By offering structured guidance on pedagogical approaches, theoretical underpinnings, and resource design, this study provides educators and policymakers with actionable tools for evaluating, scaling, and critically comparing VR applications in healthcare education. Ultimately, these recommendations support VR's transformative role in reimagining healthcare training, encourage the development of creative problem-solving skills among learners, and call for sustained academic inquiry to fully realize VR's benefits in this field.

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1. Introduction

1.1. Emergence of TEL and the need for practical fidelity

Technology Enhanced Learning (TEL) has emerged as a necessary approach to cater the needs of healthcare learners (Antoniou et al., 2014). Over the years, TEL enablers, have a offered unique educational benefits for healthcare training, demonstrating improvements in knowledge retention and skill acquisition (Antoniou et al., 2020; Lewis et al., 2024; Şimşek et al., 2024). Such advancements reflect the increasing significance of TEL as healthcare education moves towards more flexible, efficient, and learner-centred models. Web-based services, for example, National Health System (NHS) e-Learning in UK, providing 24/7 accessible training (*Programmes - elearning for healthcare*, 2023), yet they often lack the practical, hands-on fidelity required for developing complex clinical competencies. While TEL is emerging in Healthcare, the educators mostly have a positive view on the how the technology can be utilised, but also raise concerns on its pedagogically sound implementation in practice (Ryhtä et al., 2020). Digital Pedagogy competences that can be divided in three main categories 1) pedagogical competence, 2) digital competence, and 3) ethical competence (Ryhtä et al., 2020) are an essential catalyst for TEL integration in Healthcare (NHS, 2019; Zhao et al., 2024).

1.2. VR as a bridge to immersive educational experiences

In contrast, immersive technologies—particularly Virtual Reality (VR)—offer opportunities to bridge this gap, enabling realistic, interactive scenarios that simulate clinical practice. These scenarios can enhance cognitive processing, support creative problem-solving, and improve psychomotor skill performance (Dhar et al., 2023; Hoogenes et al., 2018). Immersive resources may involve computer-generated 3D Virtual Reality (VR) environments, experienced in both fully or mobile VR applications, and digital projections that integrate with real-world settings to create Augmented Reality (AR). Both VR and AR are included in the eXtended Reality (XR), broadening the spectrum of immersive educational experiences (Asunis et al., 2023). Notably, VR remains the most employed modality in healthcare education and research compared to AR (AlGerafi et al., 2023). Healthcare education encompasses a wide range of roles from medical practitioners, health informatics specialists, and patient educators and advocates. For all stakeholders students, lecturers, practitioners, and patients, immersive technologies need to be assessed, designed, developed, implemented, and evaluated to be effective (Birkheim et al., 2024; Scorolli et al., 2023). However, while the potential is evident, systematic guidance on how to implement VR into healthcare curricula effectively remains limited.

1.3. Organizational, economic, and theoretical challenges

Challenges persist at both organizational and educator levels. According to a Joint Information Systems Committee (JISC) report (JISC, 2019), immersive technology is not widely used, as the cost of implementing this technology remains one of the major challenges for institutions. The cost of designing and implementing a VR training for healthcare professionals in hospitals was roughly $106,387 (Farra et al., 2019). VR hardware required is still seen as expensive and cost-prohibited in some contexts (Camilleri, 2024). To reduce such a high cost a widespread, streamlined re-usable resources are required. Furthermore, many higher education (HE) institutions reported a lack specialist support, practical guidelines, and robust strategies to harness XR's full educational potential. Nearly all HE institutions indicated that expert-based advice and guidance on VR and AR development would be '*very useful*'. (JISC, 2019). Yet, there is no single source offering comprehensive recommendations—encompassing both organizational strategies and pedagogical frameworks—specifically tailored to healthcare education.

Lie et al. (2023) recent review agreed that research focusing specifically on virtual reality implementation is scarce, with a few current efforts mentioning "paticulalry in the Conclusion section" reccomendations for careful design and evaluation, the training of faculty and students, and the presence of faculty during virtual reality use. The JISC report also highlighted the need for advice on use immersive technologies effectively for learning and teaching, the benefits of use, and guidance around equipment and software. In response to these challenges, JISC has collaborated with Metaverse Learning to provide different experiential content in various industries (*Metaverse Learning for FE*, 2023). This collaboration is an example of an increasing commitment by various companies to develop globally accessible educational platforms integrating VR technologies (e.g. Anatomy Next, Oxford Medical Simulation, Proprio, and Virti), enabling students to analyze, diagnose, and treat virtual patients in diverse clinical scenarios. Such platforms, evidenced by research outputs from organizations like Fundamental Surgery (*Accreditation - Fundamental Surgery*, 2019), offer varied clinical practice environments and ensure adaptability to the learners' actions, mirroring real-life dynamics. This approach demonstrates a significant shift towards personalized, immersive learning experiences in healthcare education.

Experiential learning theory and Constructivist learning theory together with problem-based collaborative learning approaches have been identified to enhance the application of VR (Mallek et al., 2024). Furthermore, pedagogical frameworks for VR-based simulations have been proposed such as the VR-SIMI (Birkheim et al., 2024). However, the integration of academic rigor in these immersive reality technologies is often insufficiently transparent. Recent researches highlighted facilitators and barriers for adopting VR into healthcare education, exploring evaluation methodologies and research outcomes measurements (Abbas et al., 2024). Literature also highlights a need for more systematic, theoretically grounded approaches to development and implementation and pedagogical integration (Jensen & Konradsen, 2018; Mallek et al., 2024; Mergen et al., 2024; Radianti et al., 2020). "Future of Surgery: Technology Enhanced Surgical Training" report, underlining the importance of academically rigor, and industry-aligned development in advancing immersive surgical training technologies (FOS:TEST Commission, 2022) . Without expert-backed theoretical underpinnings and standardized models, the full transformative potential of VR cannot be realized.

1.4. Addressing gaps and defining research questions

A critical issue is the disconnect between VR innovations and the healthcare professionals who will ultimately use them. Halbig et al. (2022), noted that "*the actual needs and concerns of the people who work in the healthcare sector are often disregarded in the development of VR applications*". User-centred and co-creation approaches involving all stakeholders are essential to ensure VR solutions meet actual educational requirements (Mergen et al., 2024). Although previous works have explored user-centred design (Matsangidou et al., 2023), participatory methods (Pears et al., 2024), and best practices for VR development (Antoniou et al., 2023), the field still lacks a unified, evidence-based blueprint for producing re-usable VR resources that reduce costs, streamline implementation, and target the cognitive, affective, and psychomotor domains of learning. Moreover, with an expanding range of VR-based e-learning products available, there is a pressing need to validate their effectiveness and ensure that they meet learners' expectations. Involving end-users in resource design and evaluation is paramount (Mathew et al., 2021), while broad areas of measurement of user experience of immersive technology in simulation such as self-reported measure on user; depth of immersion; fidelity of experience; psychological safety of a scenario; and aspects of reflection have been proposed (Jacobs et al., 2023). Nonetheless, many gaps remain: current literature and practice often focus on isolated case studies or single applications rather than developing overarching frameworks that can be widely adopted. There is also limited discussion on how models like Cognitive Load Theory or the Cognitive-Affective Model of Immersive Learning (CAMIL) (Makransky & Petersen, 2021) could guide VR resource design, or how procedural, declarative, and conditional knowledge acquisition can be optimized within these virtual environments.

Incorporating innovative strategies such as simulation-based learning, critical thinking enhancement and spatial awareness and practical skill development have been proposed as best practices for integrating digital transformation in nursing curricula (Tiago & Mitchell, 2024). Four steps proposed for incorporation of immersive resources into the curriculum: preparatory work to of readiness and need assessment including stakeholders; curriculum design and development with stakeholders; implementation by enhancing educators professional development and learner orientation, conducting pilots before at large implementation; and evaluation and continuous improvement (Lewis et al., 2024; Motola et al., 2013). However linkages with educational theories, scientific evidence, finances, technical limitations, and didactic aspects poses challenges in VR implementation integration in healthcare education (Mergen et al., 2024).

To address these challenges, this paper aimed to formulate a series of expert-guided recommendations through a modified Delphi study to address the integration challenges of VR technologies in healthcare education. This approach enables systematic consensus-building among international experts, ensuring that the resulting recommendations are both theoretically sound and practically applicable. Specifically, the study aims to answer the following research questions:

1. What essential theoretical and practical considerations should guide the design of reusable VR resources in healthcare education?
2. How can VR applications optimize learning across cognitive, affective, and psychomotor domains, thereby fostering creativity and critical thinking skills?
3. Which strategies can facilitate the scalable and accessible integration of VR resources into existing healthcare curricula?
4. How can co-creation and user-centred design approaches enhance adoption, acceptance, and effectiveness of VR in healthcare education?

After leveraging the collective expertise of professionals in healthcare and technology, this study seeks to establish consensus guidelines that provide structured models, frameworks, and implementation strategies for VR. These guidelines are designed to be academically supported and practically applicable; in doing so, it lays the foundation for a more coherent and impactful integration of VR, driving forward research, practice, and policy to fully realize immersive technology's potential in shaping the future of healthcare education.

2. Method

A three-round modified Delphi technique was employed to achieve expert consensus on the integration of Virtual Reality (VR) resources into healthcare curricula. This was chosen for its adaptability to rapidly evolving technologies and practices. The Delphi method permits a panel of experts to form consensus by adaptive facilitation of decision-making and prioritisation, ultimately achieving the desired guidelines (Diamond et al., 2014). This approach diverges from traditional Delphi methods by strategically recruiting identified experts rather than anonymous participants, while keeping the anonymity between participants, ensuring highly relevant and informed feedback. A key criticism of the Delphi method is that it may artificially force consensus among participants (Keeney et al., 2001; Walker & Selfe, 1996). This limitation arises because panellists have limited opportunities to fully explain and justify their perspectives. To address this concern, the study employed open-ended questions rather than predetermined response options, helping to minimize both publication bias and individual researcher bias (Sinha et al., 2011) in the first round, followed by commenting opportunities in the two next rounds. Our modified Delphi techniques, including data processing, were modeled from those recommended by Witkin and Altschuld (Witkin & Altschuld, 1995). This strategy helped address known gaps in applying theoretical models, frameworks, and pedagogical strategies to VR resource development, as the literature often provides limited or non-specific guidance (Jensen & Konradsen, 2018; Mergen et al., 2024; Radianti et al., 2020).

2.1. Participants

To enhance the results of the Delphi study a diverse group of healthcare and technology professionals were included in the study (Mosadeghrad, 2013). Inclusion criteria for the study were sociometric (i.e., social status/role level), extended domain experience (i.e., years of experience), and education/career metrics (i.e., research outputs, academic qualifications) (Ericsson, 2000, 2006; Ericsson & Lehmann, 1996; Ericsson & Ward, 2007). Participatns identified trough bibliometric analysis of Web of Science and invited through personlised emails. Professionals with fewer than 6 years of experience and/or were in early-career roles were excluded from the study, ensuring that participants had substantial practical and theoretical knowledge. This approach aimed to incorporate a rich variety of perspectives, reflecting multiple healthcare roles, and thus strengthening the applicability of the final recommendations

2.2. Materials

The study utilized JISC online surveys for data collection, ensuring a standardized approach for participant responses. The materials for the survey included open-ended questions designed to cover a broad range of topics. The survey was structured to facilitate both qualitative and quantitative data collection, involving a Likert scale for ranking consensus in later rounds. NVivo was used to code the themes of the data.

2.3. Procedure

The Delphi study was conducted online over a two-month period and comprised of three rounds. Each round had a duration of 2 weeks for completion, followed by a short time for data analysis before the process was repeated.

Round 1 initiated the process intending to gather a broad range of insights from the expert panel. In this Round, participants responded to three open-ended questions. The questions initially designed by one researcher tailored to the identified literature gap and the study's research questions, followed an iterative refinement with 2 additional researchers, being experts on the topic and the methodology. These questions aimed to cover a wide spectrum of topics, including sociodemographic factors like roles, job titles, and years of experience, but also topics related practical and experience-driven information (see Table 1). Thematic analysis on the participants responses in round one was conducted (Brady, 2015; Phillips et al., 2014). NVivo software was used to ensure systematic coding. This analysis generated 63 key items, which we iteratively grouped into 9 categories for round 2. These categories—supported by the literature (Jensen & Konradsen, 2018; Mergen et al., 2024; Radianti et al., 2020).

In **Round 2,** the sixty-two statements, distilled from the Round 1 themes, were presented as Likert-scale items for rating, accompanied by open-ended comment sections. This structured approach enabled quantitative assessment of consensus. Participants were asked to consider the relevance and clarity of each statement. The rationale behind each item and its alignment with theoretical models or practical frameworks was informed by the initial thematic analysis. This round's focus was to determine which statements achieved strong consensus and which required refinement.

Round 3 focused on finalizing the recommendations based on the expert consensus. Based on the results of Round 2, a revised set of recommendations was presented for final validation. Participants voted on whether to include each recommendation, include it after minor modifications, or exclude it. This voting ensured that only those recommendations reflecting broad expert consensus and theoretical soundness were retained. The comments provided throughout Rounds 2 and 3 clarified how certain recommendations emerged directly from initial participant insights, linking them to recognized theories and models. Alongside providing feedback on the grammar, syntax, and context of the recommendations, they were asked to vote on each recommendation, with options including 'include', 'include after modification', or 'do not include'.

2.4. Data analysis

Qualitative Analysis: The open-ended responses from Round 1 underwent thematic analysis, a process where we identified, analysed, and reported patterns within the data. This method was chosen to explore the nuances and complexities in the experts' feedback, focusing on interpreting the underlying ideas and viewpoints rather than merely aggregating data. The aim was to uncover and articulate the foundational themes from these insights, thereby renovating them into meaningful statements that reflect the experts' perspectives on the use of these technologies in healthcare education.

Quantitative Analysis: A quantitative format was created in Round 2 with the use of Likert scale responses. The rating scale

Table 1
Round 1 exploratory questions and aspects addressed.

Aspect Addressed	Questions
Sociodemographic	Role, Job Title, Years of experience
Practical and experience-driven information	List of pedagogical recommendations for the use of VR in educational practice for the successful formation and implementation
Contextual evidence	Scenarios of how VR resources can be used in Health Sciences/ Medical Education
Research/information	Educational theories or frameworks to be applied in aiding the creation and use of VR, in Health Sciences / Medical education

ranged from 1 (strongly agree) to 5 (strongly disagree), with an additional option for 'unsure', to capture a complete range of opinions. To determine consensus among the experts regarding each item, we combined two primary metrics for each statement: (i)*Strength Score*: This was a weighted measure, the calculation follows a formula where each likert response category is multiplied by its corresponding frequency, and these products are then added together. A lower strength score indicated stronger agreement among participants, signifying that the item was viewed favourably or deemed important by the majority. *(ii)Participant Endorsement*: This metric represented the percentage of participants who agreed (rated 1 or 2) with each statement. It provided a straightforward criterion of how many experts felt positively about each item. This method aligns with the statistical approaches seen in Delphi studies, such as those documented in BMC Medical Research Methodology, which include median, range, mean, standard deviation, and weighted Kappa values to assess agreement and consensus (Holey et al., 2007).

High consensus was indicated by a strength score of 70 or lower and a participant endorsement of 60 % or higher. Medium consensus was marked by a strength score of 78 or lower, participant endorsement of 50 % or higher, and at least 25 % of participants strongly agreeing with the item. In cases where the strength score was higher than 78 or the participant endorsement was lower than 50 %, the item was considered to have no consensus.

Round 3 involved revisiting the refined statements, where participants voted on the inclusion of each recommendation. Consensus was set a priori at 75 % agreement with the following options (include', 'include after modification', 'do not include'), consistent with previous Delphi studies reported in the literature (Keeney et al., 2006).

2.5. Ethics

Participation in the study was voluntary. Participants were assured of anonymity and given the choice to be recognized as collaborators towards the final outputs, with their names and roles included in certain documents. The study was granted approval from the Faculty of Medicine and Health Sciences Research Ethics Committee (Ref: FMHS 186–0221) of the University of Nottingham.

3. Results

3.1. Participants

In the initial Round, 75 participants, encompassed professionals from healthcare, research, and academia. Roles included healthcare professionals ($n = 23$, 30 %), lecturers/professors ($n = 30$, 40 %), researchers ($n = 15$, 20 %), with $n = 7$, 10 % being learning technologists/software developers. The years of experience in their current professions had an average of approximately 12 years, with maximum at 37 years- highlighting a mix of both founded and seasoned experts in their respective fields.

The second Round reduced participants to 31, from the initial pool of invited experts, a 44 % response rate, which aligns with typical response rates in similar Delphi studies. Demographics in terms of age and gender, were not specified. This Round continued to feature experts from fields such as medical simulation, clinical teachings and practice, software development, and pedagogy.

In the final third Round, the number of participants was 27. The mean years of experience among these participants was 12.1 (SD = 7.5). Among them, 15 experts had a decade or more of experience. This Round's professional makeup included highly experienced individuals, e.g., Professors of medical simulation; a lead body in national programs for innovative simulation educators; and a software research developer specializing in healthcare material development for pedagogy, including VR.

3.2. Round 1

In Round one, participants generated 225 responses to three open-ended questions. These inquiries related to gathering pedagogical recommendations in education, detailing use cases in health sciences and medical education, and eliciting educational theories to enhance e-learning resource development in these areas. The thematic analysis of the data collected revealed several distinct categories:

1. **Technology Use and Limitations:** This area addresses the essential aspects of immersive technology in healthcare education, focusing on the balance between cutting-edge technological advances and their practical limitations. It highlights the critical need for uniformity in development approaches and the challenge of ensuring high-quality, realistic experiences. This theme also tackles the obstacles associated with resource allocation, affordability, and diversity in development practices across different institutions.
2. **Safety and Compatibility:** This theme underscores the importance of safeguarding the well-being of users in virtual settings. It involves continuous monitoring and assessment of both mental and physical health risks associated with VR usage. It contemplates the development of environments within VR that are secure and psychologically beneficial, potentially offering more efficient and less expensive alternatives to conventional training methods.
3. **Organizational Strategies:** Here, the focus is on the strategic planning and implementation of VR in educational settings. It encompasses the need for clear leadership, effective project management, and comprehensive staff training. This theme also deals with the adaptability of organizations to new technologies, emphasizing the need for an evolving approach to technological integration in educational environments.
4. **Educational Theories and Frameworks:** This theme explores the array of pedagogical theories, models, and frameworks that support the use of VR in healthcare education. It encompasses discussions on how these conceptual underpinnings can inform the design and application of VR content, aiming to enhance the acquisition of practical skills and theoretical knowledge. This theme

emphasizes the significance of using these theories and frameworks as a foundation for developing and evaluating effective VR-based learning experiences.

5. **Teaching Methods:** This area explores the diverse instructional approaches utilized in VR-based education. It highlights the need for immersive, interactive learning experiences that can supplement or enhance traditional educational methods. The focus is on the variety of pedagogical strategies that can be employed to maximize the educational benefits of such technology.
6. **Instructional Design:** This theme is concerned with the design principles and methodologies behind creating e-learning content for education. It emphasizes the importance of creating content that is centred around the learner's needs, advocating for designs that are engaging, adaptable, and conducive to skill development. The theme also underscores the integration of educational and cognitive theories to ensure that VR content meets academic standards.
7. **Interactive Methodologies:** This theme has foundations in the interactive nature of VR and its capacity to provide engaging, hands-on learning experiences. It stresses the importance of active participation and reflection in the learning process, utilizing VR to create scenarios that closely mimic real-life situations. This approach aims to enhance learning through experiential and discovery-based methods.
8. **Specific Scenarios:** This area covers the application of immersive technology in specific healthcare training scenarios. It discusses how VR can be tailored to various specialized fields within healthcare, providing students and professionals with contextual and practical experiences. The theme underscores VR's versatility in offering training specific to certain healthcare disciplines and procedures.
9. **Fields of Application:** This theme looks at the broader range of applicability in healthcare education. It highlights how tools can be integrated into various facets of healthcare training, from patient care to team collaboration. The focus is on the expansive potential of VR to transform different aspects of healthcare education, aligning with contemporary teaching models and pedagogical needs.

This analysis suggested a multi-faceted approach from the participants, and approximately 6–8 statements per theme were emerged to further probe consensus from this broad collective in round 2, organised under 4 broader categories: Guidelines for development, Theories and Models, Pedagogical Strategies, Area of Usage.

Table 2
Round 2 recommended statements, in which high, or medium consensus reached.

Categories	Statement	% Pct. Endorsed	% Pct. Strong Agree	Strength Score	Consensus	Mean	Mode
Theories and Models	Cognitive load theory	70.37 %	48.15 %	57	*High*	2.11	1
	Cognitive affective model of immersive learning	70.37 %	44.44 %	58	*High*	2.15	1
	Cognitive learning theory	66.67 %	40.74 %	57	*High*	2.11	1
	Discovery-Based Learning / Enquiry-Based Learning	66.67 %	36.67 %	66	*High*	2.20	1
	procedural step-by-step acquisition	63.33 %	23.33 %	70	*High*	2.33	2
	Sociocultural learning	52.17 %	26.09 %	59	*Medium*	2.57	2
	Co-design/co-creation	53.33 %	26.67 %	78	*Medium*	2.60	2
Guidelines for Development	Evaluating learning activities with learners and other stakeholders	66.67 %	40.00 %	64	*High*	2.13	1
	Increasing understanding through making mistakes	73.33 %	36.67 %	64	*High*	2.13	2
	Recorded metrics to save and analysis for user performance	63.33 %	36.67 %	68	*High*	2.27	1
	Real-Time/Live Feedback	63.33 %	40.00 %	68	*High*	2.27	1
	Integration to existing systems	73.33 %	30.00 %	67	*High*	2.23	2
	Accommodate ease of use and access	70.00 %	40.00 %	67	*High*	2.23	1
	Make equipment available 24/7	60.00 %	33.33 %	71	*Medium*	2.37	1
	Implement demonstrations from educators to students	53.33 %	26.67 %	71	*Medium*	2.37	3
Pedagogical Strategies	Use for training of cognitive knowledge and kinaesthetic skills	70.00 %	33.33 %	63	*High*	2.10	2
	Training of team cooperative procedures including multi-personnel management of patients	66.67 %	33.33 %	65	*High*	2.17	1
	Providing clarity about learning objectives before VR usage	66.67 %	26.67 %	68	*High*	2.27	2
	Training of medical procedures for remote learners, joined by a VR group	60.00 %	30.00 %	70	*High*	2.33	2
	Encourage reflection of scenarios after usage	66.67 %	33.33 %	72	*Medium*	2.40	1
	Perform Pre-briefing and de-briefing of VR scenarios	60.00 %	33.33 %	73	*Medium*	2.43	1
Areas of usage	Decision-making in high-risk scenarios	73.33 %	46.67 %	65	*High*	2.17	1
	3D Anatomy- Complex Structures	70.00 %	36.67 %	68	*High*	2.27	1
	Procedural Learning in Site Planning of Difficult Procedures	63.33 %	36.67 %	69	*High*	2.30	1
	360-degree VR videos of a specific method/ procedure/technique	66.67 %	36.67 %	66	*High*	2.20	1
	Operating Theatre orientation/ Surgical Workflow	63.33 %	33.33 %	71	*Medium*	2.37	1
	Clinical Safety Procedures	63.33 %	30.00 %	72	*Medium*	2.40	2

3.3. Round 2

The findings highlighted 19 out of 62 statements which garnered high consensus, reflecting strong agreement, eight with medium consensus, while 34 statements rated as low consesus, indicating diverse viewpoints and areas needing further exploration (see Supplement File).

In response to theory/model category, five statements reached high, and two medium consensus. Overall, participants' open-ended responses suggested that recommendations should include more details on the application of relevant theories, models, or approaches (Table 2). Within Guidelines for Development category 6 statements reached high consensus and 2 medium consensus, with 3 high consensus statements receiving comment for further exploration (Table 2). The categoy of the Pedagogical Strategies towards immersive reality education in healthcare had 4 statements with high consensus and 2 with medium consensus, with one of the statements around reflection on scenarios after usage of VR to further need clarification based on participants open-ended suggestions (Table 2). The category of Areas of Usage of the VR through practical application had 4 high consensus statements and 2 medium ones. The statement on decision making in high-risk scenarios was suggested to be turned into a more generic recommendation by participants through the open-ended responses (Table 2).

3.4. Round 3

The final recommendations were identified and included in the guidelines report. Table 3 presents and summarises the recommendations. The resulting Round 3 statements represent a synergy of expert knowledge and theoretical principles, providing robust, practical guidelines for the application and development of VRresources in healthcare curricula.

4. Discussion

4.1. Contextualizing vr recommendations within learning theories

As an output of the Delphi study, we gather expert opinions and recommendations for the development of immersive e-resources. The study resulted in a consensus among experts, which identified several practical recommendations (Fig. 1). A significant body of literature describes the generic necessities for re-usability of healthcare education resources, the development of immersive resources and evaluation of their effectiveness in practice. However, before this work, no systematic effort has been put, so far, against the challenge of providing concrete recommendations for the characteristics and the theoretical underpinnings, the development, the

Table 3
Round 3 recommendation statements in which consensus reached.

Recommendation	Include[+] (%)	Do not include (%)
Cognitive Load Theory should be used as one primary theory within the final set of recommendation guidelines for use of virtual reality (VR) reusable e-resources in healthcare curricula, in terms of pedagogical aspects.	100.00	0.00
The volume of information experienced by Learners should be measured, during design of a Learning Resource. The weight and impact of each element should be considered for the intrinsic and extrinsic load of the Learners.	96.15	3.85
Recognised measures of Cognitive Load should be used during testing with samples of Learners, to identify areas of cognitive overload and/or inefficient data presentation.	96.00	4.00
Co-creation of Immersive Reality resources should be used as one primary method within the final set of recommendation guidelines for use of virtual reality (VR) reusable e-resources in healthcare curricula, in terms of pedagogical aspects.	92.59	7.41
Expert knowledge should be included as feedback. When expert knowledge is provided to a Learner, this provides effective scaffolding of the learner's cognitive schema towards more complex comprehension of the system.	91.67	8.33
Real time feedback during a learning scenario should be used to provide the learner with immediate association between their input to the system and the consequence of the input to the system. If not present, their understanding of their effect may not be as complete due to convolution with further events.	90.91	9.09
Accurate decision-making requires high-levels of understanding. Where possible, explanations of events/actions/behaviours and any consequences should be included- to improve the Learners ability to accurately decide on healthcare delivery actions.	88.00	12.00
Self-regulation should be encouraged through natural reflective opportunities in an immersive environment. It should aim to scaffold a learner's ability to receive positive feedback, attempt continuation of tasks, and regulate feelings and actions.	86.36	13.64
Cognitive Affective Model of Immersive Learning should be used as one primary theory within the final set of recommendation guidelines for use of virtual reality (VR) reusable e-resources in healthcare curricula, in terms of pedagogical aspects.	85.19	14.81
A design structure is important for an efficacious outcome- such as Analysis, Design, Development, Implementation, and Evaluation. This can guide and optimize co-creation of Learning Resources.	84.00	16.00
Negative effects from high cognitive demand on Learners' understandings of information, or their learning experience, should be rectified before continuation.	83.33	16.67
The agency of Learners (Learners having control over their actions) should be measured during development. They should have the ability to exert control and freedom over parameters that have been identified in the virtual environment.	78.26	21.74
A learning resource should allow Learners to challenge their comprehension of the system, and support failure.	76.19	23.81
Newly created learning resources should be integrated into existing systems where possible, to ease the transition to new resources for the learners.	76.00	24.00

[+] Include or include with modifications.

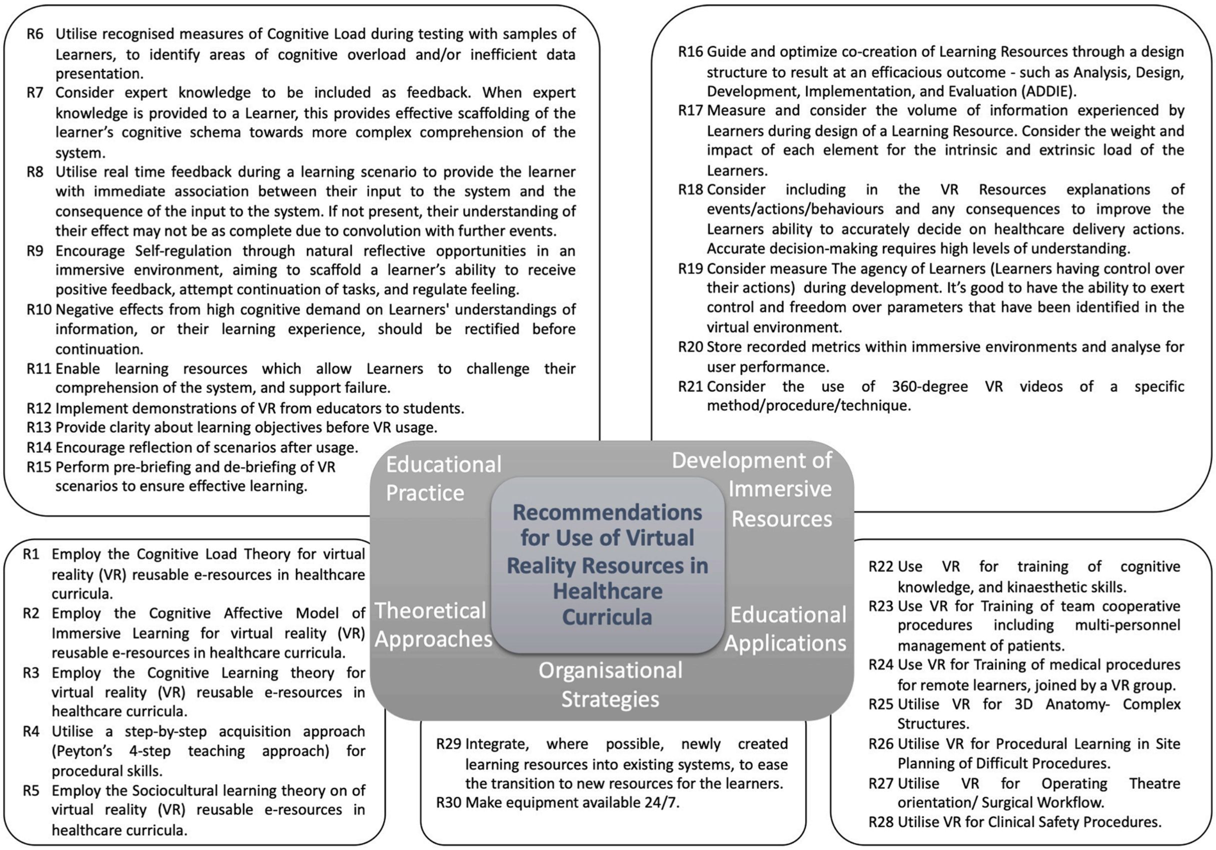

Fig. 1. Overview of Recommendations (R) for use of Virtual Reality resources in Healthcare Curricula.

practical applications and the implementation in practice of re-usable VR e-resources into Healthcare education.

4.2. Linking development strategies with pedagogical frameworks

Radianti et al. (2020) noted the scarcity of explicit learning theories in VR design, and our findings confirm that addressing theoretical gaps is essential. The Cognitive Affective Model of Immersive Learning (CAMIL) (R2) focuses on the efficacy of immersive VR usage in learning. Here, the instructional method becomes the focus when facilitated by the virtual medium. The CAMIL was advanced from growing evidence of systematic differences between VR and other forms of media for educational delivery (Klingenberg et al., 2020; Mayer, 2014; Meyer et al., 2019). This evidence highlights interaction effects between media and method of delivery improved knowledge transfer, retention, and self-efficacy. The model has predictive power for how the relationships between six key affective and cognitive factors can influence and relate to different learning outcomes. The six factors are formed from presence and agency named: 1) interest, 2) intrinsic motivation, 3) self-efficacy, 4) embodiment, 5) cognitive load, and 6) self-regulation. These form the desired types of knowledge necessary for skill progression. In the proposed recommendations emphasis is given in the Cognitive Load Theory (R1) and the volume of information experienced by learners, which should be considered towards the intrinsic and extrinsic load of the learners (R17). In contrast, measures of cognitive load should ensure that there is no cognitive overload, inefficient data presentation (R6), or adverse effects (R10).

Furthermore, participants suggested a step-by-step approach for procedural skills (R4). Peyton's Four-Step approach (Demonstration, Deconstruction, Comprehension, Performance) has been found to be an effective teaching approach for the acquisition of procedural skills in health professions education (Giacomino et al., 2020). Recent studies also supported its effectiveness in utilising VR (Yoganathan et al., 2018). Participants suggested implementing demonstrations of VR from educators to students (R12) (Demonstration step), while demonstration and description for each of the procedural tasks should be followed by the educator or the VR resource having explanations of events/actions/behaviours. Consequences should also be shown to improve the Learners ability to accurately decide on healthcare delivery actions fostering accurate decision-making (R18) (Deconstruction step). In the Comprehension step, the trainee articulates the procedural steps to the demonstrator, demonstrating understanding and readiness to handle potential errors (R11). During the Performance step, the student performs the procedural tasks, while the educator or the VR resource proceeds feedback (R8, R7) and possibly encourages reflection on the VR scenarios after usage (R14).

Cognitive Learning Theory (CLT) (R3) explains how internal and external factors influence mental processes to supplement learning. On the other hand, Social Cognitive Theory (SCT) and Cognitive Behavioural Theory (CBT) as part of cognitive learning have been utilised in healthcare education with few examples identified utilising VR (Nijman et al., 2020). Interestingly, our participants responded to the umbrella term of CLT, most probably emphasising the generic factors that influence learning rather than the specifics of the theory itself. Our study findings resonate with Scavarelli et al. (2021), who highlighted the pivotal role of Social Cognitive Theory (SCT) in enriching VR/AR educational practices. We underscore the value of SCT in framing VR/AR as tools that not only replicate traditional learning environments in a digital context but also define social relationships among learners, educators, and the technology itself. This approach set the bases of how virtual and real-world spaces intersect, enhancing both individual and collaborative learning experiences towards the suggested working framework of how to facilitate VR-based collaborative learning (Spike & Xie, 2025). By integrating SCT principles, our recommendations advocate for VR/AR resources that support self-guided learning (R9) while also facilitating meaningful social connections (R23, R24), thereby reinforcing the interconnectedness of technology, pedagogy, and social engagement in the digital age of education (Mallek et al., 2024).

While Vygotsky's Sociocultural Theory of Cognitive Development is among the well-applied theories in healthcare and medical education (Badyal & Singh, 2017; Torre et al., 2006), applying this method in VR, implies social interactions in students' experiences. These social interactions involve both verbal (R23) and kinaesthetic activities (R24), focusing on observation and imitation. Currently, few examples are addressing this theory within the VR environment or as part of the learning process (Loke, 2015), but its importance and usefulness have been suggested (Liaw et al., 2018). In the Sociocultural Theory the learner is involved in community practice, learning through the relationship between people and environment (Badyal & Singh, 2017). Co-creation (R16) allows for learning through this relationship, and enable learners to be part of the process and own their learning experiences, following *Community of Practice theory* (Wenger et al., 2002).

4.3. Development of immersive resources and educational application

Jensen and Konradsen (2018) noted that VR instructors may have limited options regarding the instructional material available to them, which may not always align with their specific needs or the desired learning outcomes. Recommendation 16 suggested that the co-creation of VR resources should be guided and optimised for an efficacious outcome through a design structure is essential such as Analysis, Design, Development, Implementation, and Evaluation, which are the stages suggested by the *ADDIE model* (Branch, 2010). The vital role of stakeholders and their central place in the development is reflected in *the Community of Practice theory* (Wenger et al., 2002), further enhanced by R19 in which the Agency of Learners during development should be considered and enhanced as it gives them the freedom to both drive creative change and develop their skills (Petersen et al., 2022; Piccione et al., 2019) and tailors the resource to learners needs (Wharrad et al., 2021).

Practical R18 recommends incorporating detailed descriptions of events, actions, behaviors, and outcomes to enhance learners' comprehension and decision-making in healthcare delivery. This approach serves as a foundation for applying various decision-making theories in clinical settings, including descriptive, normative and prescriptive theories (Watkins, 2020). Additionally, R20 emphasizes the importance of designing metrics to record user performance early in the development phase. This strategy enables the collection of valuable learning analytics within the VR environment, guiding learners to pinpoint and improve upon their areas of

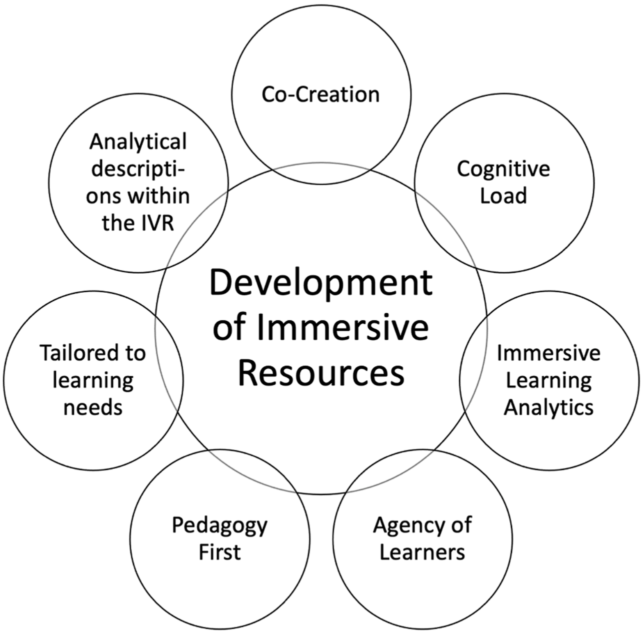

Fig. 2. Recommendation constructs for development of immersive resources.

weakness (Konstantinidis et al., 2020).

Recommendation 17 suggests that the creators should measure and consider the volume of information experienced by learners during design of a learning resource and their impact on the learners' intrinsic and extrinsic load. According to Cognitive Load Theory (R1) (Andersen et al., 2016; Frederiksen et al., 2020; Sweller, 1988), the main premise is that working memory and information processing is limited. Learning and skills acquisition can be hindered if a user's total cognitive load is not enough for the demands of the learning system. The limits in working memory and processing of information are exceeded when the learner fails to integrate multiple complex sources of information (Kirschner et al., 2018). Users' cognitive load needed consideration in the learning environment to gain a positive experience and increase the likelihood of practice success (Wen et al., 2024).

Immersive resources that can be repurposed have emerged and proliferated for over a decade. In that landscape of multiple emerging VR resource instantiation pools, there is a need for a theoretical base to support their pedagogical value (Antoniou et al., 2023; Pears et al., 2022). The need to tailor immersive resources to real educational needs having the pedagogy first is considered in R21, which iterates the use of 360-degree video in specific cases, where needed, to reach an impactful educational outcome, an area where existing resources are lacking (Alammary et al., 2023). This can be also elicited from the recommended educational applications (R22-R28), which reflect a variety of topics and skills pushing towards the more challenging for an immersive resource's educational experiences, such as team cooperative procedures (R23, R24). Fig. 2 summarises the recommendation constructs for Development of Immersive Resources.

4.4. *Practical recommendations and organisational strategies*

As elaborated by Sousa (2016), the three domains of learning encompass cognitive, affective, and psychomotor learning experiences, emphasizing the importance of integrating theoretical and practical elements in healthcare professional education. These are still in consensus with modern digital immersive technologies (Barretta et al., 2023; Dengel, 2022; Sousa, 2016). Recent systematic reviews (Foronda et al., 2017; Hamilton et al., 2021; Shorey & Ng, 2021; Yilmaz et al., 2020) have found that virtual reality (VR) applications in education address these domains, with most existing educational interventions targeting the lower levels of the cognitive, affective, and psychomotor domains. This study's practical recommendations aim to enhance learning across all three domains, presenting a mapping of these recommendations with the Learning Domains and the Cognitive, Affective, and Metacognitive Influences on Learning (CAMIL) model in Fig. 3. The model acknowledges a known overlap between the cognitive and affective domains, particularly at the lower levels of achievement (Lynch et al., 2009).

The cognitive domain focuses on intellectual development, mental skills, and knowledge acquisition. Anderson and Krathwohl

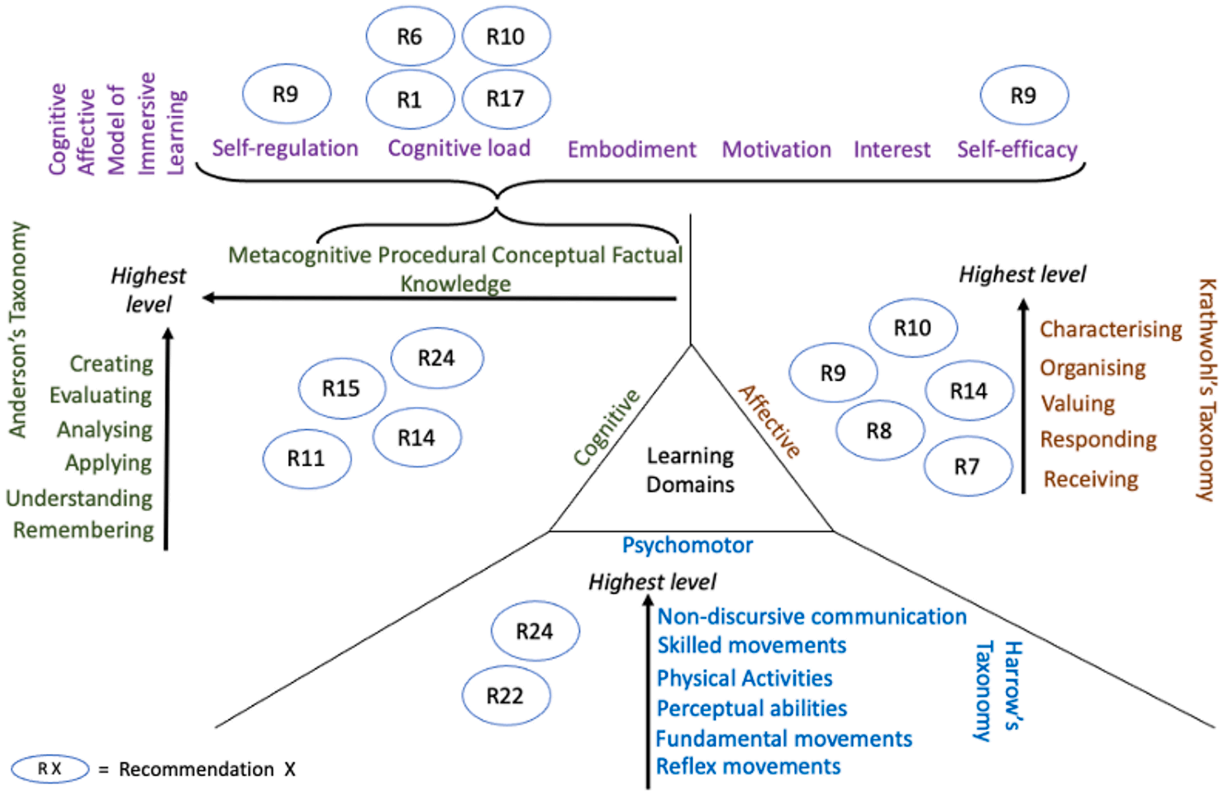

Fig. 3. Recommendations of educational practice and applications mapping in the three learning domains and the CAMIL model.

(2001) revised Bloom's taxonomy, proposing a two-dimensional framework that distinguishes types of knowledge (Factual, Conceptual, Procedural, Metacognitive) from cognitive processes (Remember, Understand, Apply, Analyse, Evaluate, Create) (Krathwohl, 2002). Recent research has shown that cognitive skills assessed are primarily related to the lower levels of Bloom's Taxonomy (Jensen et al., 2019), and limited evidence-based literature precludes definitive conclusions (Jallad & Işık, 2022; Kim & Kim, 2023). Although directly linking Cognitive Load Theory (CLT) with Anderson's revised taxonomy is challenging, there is a consensus that CLT should be considered for each cognitive process. The CAMIL model suggests that six cognitive and affective factors, including interest, intrinsic motivation, self-efficacy, embodiment, cognitive load (R1, R6, R9, R10, R17), and self-regulation (R9), contribute to factual, conceptual, and procedural knowledge, as well as knowledge transfer, partially aligning with Anderson's Taxonomy (Anderson & Krathwohl, 2001).

Additionally, the recommendations promote reflective practices after using VR resources (R14), encouraging learners to draw connections between ideas (Analyse) and recommend pre- and debriefing sessions (R15), guiding learners to support or critique decisions (Evaluate) and support failure (R11). Team cooperation, including multi-personnel patient management (R23), may enable learners to debate opinions and develop arguments and patient pathways for complex scenarios (Create).

The affective domain encompasses feelings, emotions, and attitudes (Krathwohl, 2002; Savickiene, 2010). Despite limmited VR interventions in the literature specifically targeting this domain for learning enhancement (Jensen & Konradsen, 2018; Shorey & Ng, 2021), non-educational research has demonstrated that VR can facilitate affective and behavioural change (Hamilton et al., 2021).

Recommendation R17 aims to foster the initial affective domain (Krathwohl, 2002) by promoting awareness of the environment during VR learning, thus targeting individuals' attitudes. Recommendations 9 and 14 encourage self-regulation through reflective learning, enabling students to receive and understand (R8) the feelings and emotions presented in the VR resource and to value and justify them during the reflection process, ultimately organizing them for effective self-regulation. This approach is partially supported by Recommendation R10, which advises that any adverse effects experienced by learners during VR educational practice should be addressed and resolved before continuing. This implies that learners should be able to "review, conclude, and resolve" their experiences, reaching the characterizing level of the affective domain. The identified recommendations highlight the need for VR educational applications to target the higher levels of the affective domain, aiming to fill the gap in the literature.

The psychomotor domain focused on motor skills and coordination (Harrow, 1972) to enhance hands-on skills of learners. Although few VR interventions target this domain directly, some studies show positive outcomes (Hamilton et al., 2021; Jallad & Işık, 2022; Shorey & Ng, 2021). This includes improvements in decision-making and the transfer of safer practices, which facilitate experiential learning.

Recommendation R22 suggests using VR resources to enhance cognitive as well as kinaesthetic skills, targeting the Perceptual level of Harrow's Taxonomy of Psychomotor Domain (Harrow, 1972). Meanwhile, R24 supports practicing complex procedures requiring precise movements (Physical Activities level). This aids in performing complex tasks (Skilled Movements level) within a VR group setting. This approach may encourage team communication and complement non-verbal cues (Non-discursive Communication level). Consequently, the identified recommendations aim to target the higher levels of the psychomotor domain.

To utilise the VR across cognitive, affective, and psychomotor domains, resource availability of equipment should be considered (R30). Studies that acceptance depends on consistent access and minimal technical issues (Baniasadi et al., 2020; Pears et al., 2023; Schiza et al., 2023). Integrating resources into existing systems (R29) also helps ensure a unified transition, aligning VR design with human perceptual processes (Neves & Yablonski, 2022). Strategic implementation plans should be carefully considered to ensure an effective learning experience (Lewis et al., 2024).

Within the recommendations the acquisition of knowledge spans from procedural knowledge and declarative knowledge to conditional knowledge. Immersive Virtual Reality has a tendency to be more advantageous in terms of knowledge acquisition, when it compared with other type of media (Conrad et al., 2024). Its superiority noted mostly to declarative knowledge, while comparisons with hands-on practice shows moderate results (Conrad et al., 2024). Emphasis should be put though to higher level of engagement which leads to a higher level of cognitive processing and therefore leads to a higher learning outcome (Conrad et al., 2024) in accordance with ICAP Framework (Chi & Wylie, 2014) and the CAMIL model (Makransky & Petersen, 2021).

4.5. Limitations

This work, aimed to find consensus on how to utilize reusable VR resources in educational practice. Sound recommendations that fit well within the wider literature have been proposed. However, several reliable and feasible recommendations did not make the final selection despite their potential value. These excluded suggestions, if applied with careful consideration to context, may also enhance learning within the cognitive, affective, and psychomotor domains. Further analysis to each of the recommendations' areas may also reveal additional or more detailed guidance such as the frustration or anxiety in using VR. The validity of the panellist response, the feedback mechanism, and its influence on consensus and convergence of opinion (Goodman, 1987) might have led to the exclusion or omission of some recommendations, despite the wide application of feedback mechanisms and analysis.

5. Conclusions

The findings of the modified Delphi study affirm the significant potential of VR targeting the higher levels of the cognitive, affective, and psychomotor domains, thereby enhancing the learning experience for healthcare students. While there is currently no universally endorsed framework or educational model for incorporating VR into the curriculum (Marougkas et al., 2023; Radianti et al., 2020), consensus among experts suggests that varied theoretical approaches should be employed to achieve distinct learning outcomes tailored to different contexts. Furthermore, VR resources should be tailored to meet the specific needs of learners, following a co-creation approach, considering the agency of learners and the pedagogical focus of the resources, while maintaining a balance on the cognitive load and facilitating analytical description and the inclusion of immersive learning analytics. These resources should also be integrated into existing learning systems to make them easily accessible to learners. The present work fosters the streamlining of VR resource implementation and transferability across curricula and their subsequent integration in the mainstream of healthcare education. These recommendations provide a unique framework for educators and policy makers for direction, benchmarking, scale-up and critical adoption of best practices of VR application in healthcare education.

CRediT authorship contribution statement

Matthew Pears: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Panagiotis Antoniou:** Writing – review & editing, Investigation, Formal analysis, Data curation, Conceptualization. **Eirini Schiza:** Writing – review & editing, Validation, Investigation, Formal analysis, Data curation. **Maria Matsangidou:** Writing – review & editing, Validation, Investigation, Formal analysis, Data curation. **Constantinos S. Pattichis:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Panagiotis D. Bamidis:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Stathis. Th. Konstantinidis:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Conflicts of Interest

The authors declare no competing financial interests.

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Informed consent

All participants in this study provided written informed consent.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tsc.2025.101810.

Data availability

Processed Data available as supplement; raw data available on request.

References

Abbas, J. R., Gantwerker, E., Volk, M., Payton, T., McGrath, B. A., Tolley, N., et al. (2024). Describing, evaluating, and exploring barriers to adoption of virtual reality: An international modified Delphi consensus study involving clinicians, educators, and industry professionals. *Journal of Medical Extended Reality, 1*(1), 202–214. https://doi.org/10.1089/jmxr.2024.0022

Accreditation - Fundamental Surgery. (2019). Retrieved January 22, 2024 from https://fundamentalsurgery.com/accreditation/.

Alammary, M. A., Halliday, L., & Konstantinidis, S. T. (2023). 360-Degree virtual reality utilising head-mounted devices in undergraduate nursing and midwifery education: A scoping review. *Virtual Worlds, 2*(4), 396–421. https://doi.org/10.3390/virtualworlds2040023

AlGerafi, M. A. M., Zhou, Y., Oubibi, M., & Wijaya, T. T. (2023). Unlocking the potential: A comprehensive evaluation of augmented reality and virtual reality in education. *Electronics, 12*(18), 3953. https://www.mdpi.com/2079-9292/12/18/3953.

Andersen, S. A. W., Mikkelsen, P. T., Konge, L., Cayé-Thomasen, P., & Sørensen, M. S. (2016). Cognitive load in distributed and massed practice in virtual reality mastoidectomy simulation. *The Laryngoscope, 126*, E74–E79. https://doi.org/10.1002/lary.25449

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of bloom's taxonomy of educational objectives*. Addison Wesley Longman.

Antoniou, P., Arfaras, G., Pandria, N., Ntakakis, G., Bambatsikos, E., & Athanasiou, A. (2020). Real-time affective measurements in medical education, using virtual and mixed reality. In C. Frasson, P. Bamidis, & P. Vlamos (Eds.), *rain function assessment in learning. bfal 2020* Vol. 12462. Springer. https://doi.org/10.1007/978-3-030-60735-7_9.

Antoniou, P. E., Athanasopoulou, C. A., Dafli, E., & Bamidis, P. D. (2014). Exploring design requirements for repurposing dental virtual patients from the web to second life: A focus group study. *Journal of Medical Internet Research, 16*(6). https://doi.org/10.2196/JMIR.3343

Antoniou, P. E., Pears, M., Schiza, E. C., Frangoudes, F., Pattichis, C. S., Wharrad, H., et al. (2023). Eliciting Co-creation best practices of virtual reality reusable e-resources. *Virtual Worlds, 2*(1), 75–89. https://doi.org/10.3390/virtualworlds2010005

Asunis, L., Cirina, A., Stacchio, L., & Marfia, G. (2023). HOCTOPUS: An open-source cross-reality tool to augment live-streaming remote classes. In *2023 IEEE International symposium on mixed and augmented reality adjunct (ISMAR-Adjunct)*. https://doi.org/10.1109/ISMAR-Adjunct60411.2023.00014

Badyal, D. K., & Singh, T. (2017). Learning theories: The basics to learn in medical education. *International Journal of Applied and Basic Medical Research, 7*(Suppl 1), S1. https://doi.org/10.4103/IJABMR.IJABMR_385_17
Baniasadi, T., Ayyoubzadeh, S. M., & Mohammadzadeh, N. (2020). Challenges and practical considerations in applying virtual reality in medical education and treatment. *Oman Medical Journal, 35*(3), e125. https://doi.org/10.5001/omj.2020.43
Barretta, R., Mystakidis, S., & Lympouridis, V. (2023). Immersive learning. *Encyclopedia, 3*(2), 396–405. https://doi.org/10.3390/ENCYCLOPEDIA3020026
Birkheim, S. L., Calogiuri, G., & Martinsen, R. (2024). Advancing immersive virtual reality-based simulation practices: Developing an evidence-based and theory-driven pedagogical framework for VR-based simulations of non-technical skills among healthcare professionals. *Interactive Learning Environments, 32*(7), 3579–3591. https://doi.org/10.1080/10494820.2023.2186896
Brady, S. R. (2015). Utilizing and adapting the Delphi method for use in qualitative research. *International Journal of Qualitative Methods, 14*(5), Article 1609406915621381. https://doi.org/10.1177/1609406915621381
Branch, R. M. (2010). *Instructional design: The addie approach*. Springer US. https://doi.org/10.1007/978-0-387-09506-6
Camilleri, M. A. (2024). Metaverse applications in education: A systematic review and a cost-benefit analysis. *Interactive Technology and Smart Education, 21*(2), 245–269. https://doi.org/10.1108/ITSE-01-2023-0017
Chi, M. T. H., & Wylie, R. (2014). The ICAP Framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist, 49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823
Conrad, M., Kablitz, D., & Schumann, S. (2024). Learning effectiveness of immersive virtual reality in education and training: A systematic review of findings. *Computers & Education: X Reality, 4*, Article 100053. https://doi.org/10.1016/j.cexr.2024.100053
Dengel, A. (2022, 30 May-4 June 2022). What is immersive learning? 2022 8th international conference of the immersive learning research network (iLRN), Vienna, Austria. https://doi.org/10.23919/iLRN55037.2022.9815941.
Dhar, E., Upadhyay, U., Huang, Y., Uddin, M., Manias, G., Kyriazis, D., et al. (2023). A scoping review to assess the effects of virtual reality in medical education and clinical care. *Digital Health, 9*. https://doi.org/10.1177/20552076231158022, 20552076231158022.
Diamond, I. R., Grant, R. C., Feldman, B. M., Pencharz, P. B., Ling, S. C., Moore, A. M., et al. (2014). Defining consensus: A systematic review recommends methodologic criteria for reporting of Delphi studies. *Journal of Clinical Epidemiology, 67*(4), 401–409. https://doi.org/10.1016/j.jclinepi.2013.12.002
Ericsson, K. A. (2000). Expertise in interpreting. *Interpreting. International Journal of Research and Practice in Interpreting, 5*(2), 187–220. https://doi.org/10.1075/INTP.5.2.08ERI
Ericsson, K. A. (2006). The influence of experience and deliberate practice on the development of superior expert performance. In *The Cambridge Handbook of Expertise and Expert Performance* (pp. 683–704). https://doi.org/10.1017/CBO9780511816796.038
Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual Review of Psychology, 47*, 273–305. https://doi.org/10.1146/ANNUREV.PSYCH.47.1.273
Ericsson, K. A., & Ward, P. (2007). Capturing the naturally occurring superior performance of experts in the laboratory: Toward a science of expert and exceptional performance. *Current Directions In Psychological Science, 16*(6), 346–350. https://doi.org/10.1111/J.1467-8721.2007.00533.X
Farra, S. L., Gneuhs, M., Hodgson, E., Kawosa, B., Miller, E. T., Simon, A., et al. (2019). Comparative cost of virtual reality training and live exercises for training hospital workers for evacuation. *Computers, Informatics, Nursing : CIN, 37*(9), 446–454. https://doi.org/10.1097/CIN.0000000000000540
Foronda, C. L., Hudson, K. W., & Budhathoki, C. (2017). Use of virtual simulation to impact nursing students' Cognitive and affective knowledge of evidence-based practice. *Worldviews on Evidence-Based Nursing, 14*(2), 168–170. https://doi.org/10.1111/WVN.12207
FOS:TEST Commission. (2022). *Future of surgery: Technology enhanced surgical training: Report of the FOS:TEST commission*. https://futureofsurgery.rcseng.ac.uk/training/.
Frederiksen, J. G., Sørensen, S. M. D., Konge, L., Svendsen, M. B. S., Nobel-Jørgensen, M., Bjerrum, F., et al. (2020). Cognitive load and performance in immersive virtual reality versus conventional virtual reality simulation training of laparoscopic surgery: A randomized trial. *Surgical Endoscopy, 34*(3), 1244–1252. https://doi.org/10.1007/S00464-019-06887-8
Giacomino, K., Caliesch, R., & Sattelmayer, K. M. (2020). The effectiveness of the Peyton's 4-step teaching approach on skill acquisition of procedures in health professions education: A systematic review and meta-analysis with integrated meta-regression. *PeerJ, 8*, e10129. https://doi.org/10.7717/peerj.10129
Goodman, C. M. (1987). The Delphi technique: A critique. *Journal of Advanced Nursing, 12*(6), 729–734. https://doi.org/10.1111/J.1365-2648.1987.TB01376.X
Halbig, A., Babu, S. K., Gatter, S., Latoschik, M. E., Brukamp, K., & von Mammen, S. (2022). Opportunities and challenges of virtual reality in healthcare – A domain experts inquiry [Original Research]. *Frontiers in Virtual Reality, 3*. https://www.frontiersin.org/journals/virtual-reality/articles/10.3389/frvir.2022.837616.
Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education, 8*(1), 1–32. https://doi.org/10.1007/S40692-020-00169-2/TABLES/2
Harrow, A. J. (1972). *A taxonomy of the psychomotor domain: A guide for developing behavioral objectives*. McKay.
Holey, E. A., Feeley, J. L., Dixon, J., Whittaker, V. J., Dixon, J., & Whittaker, V. J. (2007). An exploration of the use of simple statistics to measure consensus and stability in Delphi studies. *BMC Medical Research Methodology, 7*(1), 1–10. https://doi.org/10.1186/1471-2288-7-52
Hoogenes, J., Wong, N., Al-Harbi, B., Kim, K. S., Vij, S., Bolognone, E., et al. (2018). A randomized comparison of 2 robotic virtual reality simulators and evaluation of trainees' Skills transfer to a simulated robotic urethrovesical anastomosis task. *Urology, 111*, 110–115. https://doi.org/10.1016/j.urology.2017.09.023
Jacobs, C., Foote, G., & Williams, M. (2023). Evaluating user experience with immersive technology in simulation-based education: A modified Delphi study with qualitative analysis. *PLoS ONE, 18*(8), Article e0275766. https://doi.org/10.1371/journal.pone.0275766
Jallad, S. T., & Işık, B. (2022). The effectiveness of virtual reality simulation as learning strategy in the acquisition of medical skills in nursing education: A systematic review. *Irish Journal of Medical Science, 191*(3), 1407–1426. https://doi.org/10.1007/S11845-021-02695-Z
Jensen, J. L., Phillips, A. J., & Briggs, J. C. (2019). Beyond Bloom's: Students' Perception of Bloom's taxonomy and its convolution with cognitive load. *Journal of Psychological Research, 1*(1), 24–32. https://doi.org/10.30564/JPR.V1I1.421
Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies, 23*(4), 1515–1529. https://doi.org/10.1007/s10639-017-9676-0
JISC. (2019). *Augmented and virtual reality in learning and teaching*. JISC. Retrieved January 12, 2022 from https://www.jisc.ac.uk/reports/augmented-and-virtual-reality-in-learning-and-teaching-2019.
Keeney, S., Hasson, F., & McKenna, H. (2006). Consulting the oracle: Ten lessons from using the Delphi technique in nursing research. *Journal of Advanced Nursing, 53*(2), 205–212. https://doi.org/10.1111/j.1365-2648.2006.03716.x
Keeney, S., Hasson, F., & McKenna, H. P. (2001). A critical review of the Delphi technique as a research methodology for nursing. *International Journal Of Nursing Studies, 38*(2), 195–200. https://doi.org/10.1016/s0020-7489(00)00044-4
Kim, H. Y., & Kim, E. Y. (2023). Effects of medical education program using virtual reality: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health, 20*(5), 3895. https://doi.org/10.3390/IJERPH20053895/S1
Kirschner, P. A., Sweller, J., Kirschner, F., & Zambrano, J. R. (2018). From cognitive load theory to collaborative cognitive load theory. *International Journal of Computer-Supported Collaborative Learning, 13*(2), 213–233. https://doi.org/10.1007/S11412-018-9277-Y
Klingenberg, S., Jørgensen, M. L. M., Dandanell, G., Skriver, K., Mottelson, A., & Makransky, G. (2020). Investigating the effect of teaching as a generative learning strategy when learning through desktop and immersive VR: A media and methods experiment. *British Journal Of Educational Technology, 51*(6), 2115–2138. https://doi.org/10.1111/BJET.13029
Konstantinidis, S., Bamidis, P. D., & Zary, N. (2020). *Digital innovations in healthcare education and training /edited by Stathis Th. Konstantinidis, Panagiotis D. Bamidis, Nabil Zary*. Academic Press.
Krathwohl, D.R. (2002). A revision of Bloom's taxonomy: An overview. *Theory into practice,* 41(4), 212–218. https://doi.org/10.1207/s15430421tip4104_2.
Lewis, K. O., Popov, V., & Fatima, S. S. (2024). From static web to metaverse: Reinventing medical education in the post-pandemic era. *Ann Med, 56*(1), Article 2305694.

Liaw, S. Y., Carpio, G. A. C., Lau, Y., Tan, S. C., Lim, W. S., & Goh, P. S. (2018). Multiuser virtual worlds in healthcare education: A systematic review. *Nurse Education Today, 65*, 136–149. https://doi.org/10.1016/j.nedt.2018.01.006

Lie, S. S., Helle, N., Sletteland, N. V., Vikman, M. D., & Bonsaksen, T. (2023). Implementation of virtual reality in health professions education: Scoping review. *JMIR Med Educ, 9*, e41589. https://doi.org/10.2196/41589

Loke, S. K. (2015). How do virtual world experiences bring about learning? A critical review of theories. *Australasian Journal of Educational Technology, 31*(1). https://doi.org/10.14742/ajet.2532

Lynch, D. R., Russell, J. S., Evans, J. C., & Sutterer, K. G. (2009). Beyond the cognitive: The affective domain, values, and the achievement of the vision. *Journal of Professional Issues in Engineering Education and Practice, 135*(1), 47–56. https://doi.org/10.1061/(ASCE)1052-3928(2009)135:1(47)

Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational Psychology Review, 33*(3), 937–958. https://doi.org/10.1007/s10648-020-09586-2

Mallek, F., Mazhar, T., Faisal Abbas Shah, S., Ghadi, Y. Y., & Hamam, H. (2024). A review on cultivating effective learning: Synthesizing educational theories and virtual reality for enhanced educational experiences. *PeerJ. Computer Science, 10*, e2000. https://doi.org/10.7717/peerj-cs.2000

Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023). How personalized and effective is immersive virtual reality in education? A systematic literature review for the last decade. *Multimedia Tools And Applications, 2023*, 1–49. https://doi.org/10.1007/S11042-023-15986-7

Mathew, R. K., Immersive Healthcare, C., & Mushtaq, F. (2021). Three principles for the progress of immersive technologies in healthcare training and education. *BMJ Simul Technol Enhanc Learn, 7*(5), 459–460. https://doi.org/10.1136/bmjstel-2021-000881

Matsangidou, M., Solomou, T., Langvad, C. H., Xynari, K., Papayianni, E., & Pattichis, C. S. (2023). Virtual reality health education to prevent musculoskeletal disorders and chronic low back pain in formal and informal caregivers. In *Adjunct Proceedings of the 31st ACM Conference on User Modeling, Adaptation and Personalization* (pp. 343–351). Limassol, Cyprus: Association for Computing Machinery. https://doi.org/10.1145/3563359.3596991.

Mayer, R. E. (2014). *The cambridge handbook of multimedia learning* (2 ed.). Cambridge University Press. https://doi.org/10.1017/CBO9781139547369. R. E. Mayer, Ed.

Mergen, M., Graf, N., & Meyerheim, M. (2024). Reviewing the current state of virtual reality integration in medical education - a scoping review. *BMC Medical Education, 24*(1), 788. https://doi.org/10.1186/s12909-024-05777-5

Metaverse Learning for FE. (2023). Retrieved 22 June 2024 from https://subscriptionsmanager.jisc.ac.uk/catalogue/2923.

Meyer, O. A., Omdahl, M. K., & Makransky, G. (2019). Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment. *Computers & Education, 140*, Article 103603. https://doi.org/10.1016/J.COMPEDU.2019.103603

Mosadeghrad, A. M. (2013). Verification of a quality management theory: Using a delphi study. *International Journal of Health Policy and Management, 1*(4), 261–271. https://doi.org/10.15171/IJHPM.2013.55

Motola, I., Devine, L. A., Chung, H. S., Sullivan, J. E., & Issenberg, S. B. (2013). Simulation in healthcare education: A best evidence practical guide. AMEE Guide No. 82. *Medical teacher, 35*(10), e1511–e1530. https://doi.org/10.3109/0142159x.2013.818632

Neves, P. S., & Yablonski, J. (2022). Considerations between UX heuristics and physical space. *UXUC - User Experience and Urban Creativity, 4*(2), 70–73. https://doi.org/10.48619/UXUC.V4I2.630

NHS. (2019). *The topol review: Preparing the healthcare workforce to deliver the digital future*. https://topol.hee.nhs.uk/wp-content/uploads/HEE-Topol-Review-2019-printable.pdf.

Nijman, S. A., Veling, W., Greaves-Lord, K., Vos, M., Zandee, C. E. R., Aan het Rot, M., et al. (2020). Dynamic interactive social cognition training in virtual reality (DiSCoVR) for people with a psychotic disorder: Single-group feasibility and acceptability study. *JMIR mental health, 7*(8), e17808. https://doi.org/10.2196/17808

Pears, M., Antoniou, P. E., Schiza, E., Ntakakis, G., Henderson, J., Frangoudes, F., et al. (2024). Virtual reality reusable e-resources for clinical skills training: A mixed-methods evaluation. *Personal And Ubiquitous Computing, 28*(3), 643–654. https://doi.org/10.1007/s00779-024-01805-9

Pears, M., Henderson, J., & Konstantinidis, S. (2022). *Repurposing a reusable learning object on effective communication with adolescents to an interactive 360° immersive environment by adapting the aspire framework*. Cham: Mobility for Smart Cities and Regional Development - Challenges for Higher Education. https://doi.org/10.1007/978-3-030-93907-6_115

Pears, M., Rochester, M., Wadhwa, K., Payne, S. R., Konstantinidis, S., Hanchanale, V., et al. (2023). A pilot study evaluating a virtual reality-based nontechnical skills training application for urology trainees: Usability, acceptability, and impact. *Journal of Surgical Education*. https://doi.org/10.1016/j.jsurg.2023.08.012

Petersen, G. B., Petkakis, G., & Makransky, G. (2022). A study of how immersion and interactivity drive VR learning. *Computers & Education, 179*, Article 104429. https://doi.org/10.1016/J.COMPEDU.2021.104429

Phillips, A. C., Lewis, L. K., McEvoy, M. P., Galipeau, J., Glasziou, P., Hammick, M., et al. (2014). A Delphi survey to determine how educational interventions for evidence-based practice should be reported: Stage 2 of the development of a reporting guideline. *BMC Medical Education, 14*, 159. https://doi.org/10.1186/1472-6920-14-159

Piccione, J., Collett, J., & De Foe, A. (2019). Virtual skills training: The role of presence and agency. *Heliyon, 5*(11), e02583. https://doi.org/10.1016/j.heliyon.2019.e02583

Programmes - elearning for healthcare. (2023). Retrieved January 12, 2022 from https://www.e-lfh.org.uk/programmes/.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education, 147*, Article 103778. https://doi.org/10.1016/j.compedu.2019.103778

Ryhtä, I., Elonen, I., Saaranen, T., Sormunen, M., Mikkonen, K., Kääriäinen, M., et al. (2020). Social and health care educators' perceptions of competence in digital pedagogy: A qualitative descriptive study. *Nurse Education Today, 92*, Article 104521. https://doi.org/10.1016/j.nedt.2020.104521

Savickiene, I. (2010). Conception of learning outcomes in the Bloom's taxonomy affective domain. *Quality of Higher Education, 7*, 37–59.

Scavarelli, A., Arya, A., & Teather, R. J. (2021). Virtual reality and augmented reality in social learning spaces: A literature review. *Virtual Reality, 25*(1), 257–277. https://doi.org/10.1007/s10055-020-00444-8

Schiza, E., Frangoudes, F., Pattichis, C., Pears, M., Konstantinidis, S., & Gkougkoudi, E. (2023). Evaluation of virtual reality via 360° videos reusable e-resources embedded in healthcare curricula. In *2023 24th international conference on digital signal processing (DSP)*. https://doi.org/10.1109/DSP58604.2023.10167929

Scorolli, C., Naddei Grasso, E., Stacchio, L., Armandi, V., Matteucci, G., & Marfia, G. (2023). Would you rather come to a tango concert in theater or in VR? Aesthetic emotions & social presence in musical experiences, either live, 2D or 3D. *Computers In Human Behavior, 149*, Article 107910. https://doi.org/10.1016/j.chb.2023.107910

Shorey, S., & Ng, E. D. (2021). The use of virtual reality simulation among nursing students and registered nurses: A systematic review. *Nurse Education Today, 98*. https://doi.org/10.1016/J.NEDT.2020.104662

Şimşek, B., Karabağ, Ç., İnce, Ş., Sertalp, E., & Tözüm, T. F. (2024). The reception of digital stories in dental education: Triggering thinking skills for empathy in undergraduate dentistry students. *Thinking Skills and Creativity, 51*, Article 101475. https://doi.org/10.1016/j.tsc.2024.101475

Sinha, I. P., Smyth, R. L., & Williamson, P. R. (2011). Using the Delphi technique to determine which outcomes to measure in clinical trials: Recommendations for the future based on a systematic review of existing studies. *PLoS Med, 8*(1), Article e1000393. https://doi.org/10.1371/journal.pmed.1000393

Sousa, D. A. (2016). *How the brain learns* (5th ed.). Corwin Press.

Spike, J., & Xie, Y. (2025). Using VR for collaborative learning: A theoretical and practical lens. In D. B. A. M. Khosrow-Pour (Ed.), *Encyclopedia of information science and technology, sixth edition* (pp. 1–15). IGI Global. https://doi.org/10.4018/978-1-6684-7366-5.ch040.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

Tiago, R.d. S., & Mitchell, A. (2024). Integrating digital transformation in nursing education: Best practices and challenges in curriculum development. In M. D. Lytras, A. C. Serban, A. Alkhaldi, S. Malik, & T. Aldosemani (Eds.), *Digital transformation in higher education, part b* (pp. 57–101). Emerald Publishing Limited. https://doi.org/10.1108/978-1-83608-424-220241004.

Torre, D. M., Daley, B. J., Sebastian, J. L., & Elnicki, D. M. (2006). Overview of current learning theories for medical educators. *The American Journal of Medicine, 119*(10), 903–907. https://doi.org/10.1016/j.amjmed.2006.06.037

Walker, A. M., & Selfe, J. (1996). The Delphi method: A useful tool for the allied health researcher. *British Journal of Therapy and Rehabilitation, 3*(12), 677–681. https://doi.org/10.12968/bjtr.1996.3.12.14731
Watkins, S. (2020). Effective decision-making: Applying the theories to nursing practice. *British Journal of Nursing, 29*(2), 98–101. https://doi.org/10.12968/bjon.2020.29.2.98
Wen, P., Lu, F., Ali, Mohamad, & A, Z. (2024). Using attentional guidance methods in virtual reality laboratories reduces students' cognitive load and improves their academic performance. *Virtual Reality, 28*(2), 110. https://doi.org/10.1007/s10055-024-01012-0
Wenger, E., McDermott, R., & Snyder, W. (2002). *Cultivating communities of practice: A guide to managing knowledge*. Harvard Business School Press.
Wharrad, H., Windle, R., & Taylor, M. (2021). Chapter three - designing digital education and training for health. In S. T. Konstantinidis, P. D. Bamidis, & N. Zary (Eds.), *Digital innovations in healthcare education and training* (pp. 31–45). Academic Press. https://doi.org/10.1016/B978-0-12-813144-2.00003-9.
Witkin, B. R., & Altschuld, J. W. (1995). *Planning and conducting needs assessments: A practical guide*. Sage Publication Inc.
Yilmaz, D. U., Tuncalı, S. H., & Yilmaz, Y. (2020). Nursing education in the era of virtual reality. *Virtual and augmented reality in education, art, and museums*. IGI Global. https://doi.org/10.4018/978-1-7998-1796-3.ch003
Yoganathan, S., Finch, D. A., Parkin, E., & Pollard, J. (2018). 360° virtual reality video for the acquisition of knot tying skills: A randomised controlled trial. *International Journal of Surgery, 54*, 24–27. https://doi.org/10.1016/j.ijsu.2018.04.002
Zhao, L., Abdolkhani, R., Walter, R., Petersen, S., Butler-Henderson, K., & Livesay, K. (2024). National survey on understanding nursing academics' perspectives on digital health education. *Journal of Advanced Nursing, 80*(12), 4888–4899. https://doi.org/10.1111/jan.16163