

ORIGINAL RESEARCH

Nursing students' perception of extended reality in anatomy teaching: A cross-sectional study

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ABSTRACT

Objective: Extended Reality (XR) applications offer immersive, interactive environments that may enhance nursing students' understanding of complex anatomical content, yet there is limited evidence on motivational outcomes and learning strategies in this context. This study examined nursing students' perceptions of an XR Brain (XRB) application and explored how demographic characteristics and motivational and learning strategy variables, as measured by selected Motivated Strategies for Learning Questionnaire (MSLQ) subscales, relate to self-efficacy for learning and performance.

Methods: A cross-sectional study was conducted with 146 nursing students enrolled in an Anatomy and Physiology course at a tertiary institution in Singapore. The XRB application was integrated into teaching on the nervous system, and data were collected using a two-part questionnaire that captured demographics and six MSLQ subscales: intrinsic value, task value, metacognitive self-regulation, peer learning, task anxiety and self-efficacy for learning and performance.

Results: Self-efficacy demonstrated strong positive correlations with all the other five MSLQ subscales, indicating that greater perceived importance and enjoyment of the XR-based content, along with stronger strategic learning tendencies, were associated with higher confidence in learning.

Conclusions: The findings highlight the important role of intrinsic value and task value in shaping nursing students' self-efficacy during XR-based anatomy learning. Gender and digital literacy also influence self-efficacy, but their effects are smaller.

Recommendations: Instructional designs that connect XR activities to meaningful, real-world nursing practice can further enhance students' confidence. Providing targeted technical orientation may also strengthen their academic self-belief and improve the overall educational impact of immersive XR tools.

Key Words: Anatomy, Extended reality, Healthcare, Kolb's experiential learning theory, Nursing students, Self-efficacy

1. INTRODUCTION

Anatomy and Physiology (AP) modules constitute the biological foundation of the nursing curriculum, providing the core knowledge required for subsequent clinical learning.^[1,2] Traditionally, teaching is delivered through 2-hour lectures that emphasise the “why” and “how” of body functions—for example, how the heart regulates blood pressure or how the liver detoxifies blood—paired with laboratory

sessions that use high-quality plastic torso models with removable organs. Some institutions also employ tools such as Anatomage tables (large interactive “virtual cadavers”) and three-dimensional (3D) software that allow learners to digitally dissect and explore anatomical structures layer by layer.

Despite these resources, conventional methods often fall

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short when conveying highly complex anatomical detail. Fine organ morphology, surface landmarks, and the intricate layout of neurovascular and lymphatic networks require more advanced instructional strategies to support deep understanding.^[3] Recent technological developments have introduced computer-based and multimedia platforms that enrich AP teaching by integrating high-definition videos, animations, 3D reconstructions, and virtual microscopy, thereby creating a more immersive learning environment. In this context, Extended Reality (XR) technologies—encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—have gained prominence as powerful tools for enhancing student engagement and comprehension. These immersive systems present multiple ways to interact with the human body, helping students grasp and retain complex biological concepts more effectively.^[4] XR is an umbrella term for environments in which physical and digital elements are blended. Hily et al.^[5] define XR as the spectrum of human-machine interactions made possible by advanced computing and wearable devices. Although XR modalities share similar educational goals, they operate differently: VR replaces the user's real surroundings with a fully computer-generated world, creating a highly immersive experience;^[6] Augmented Reality superimposes digital content onto the real-world view in real time;^[7] and Mixed Reality allows physical and virtual objects to coexist and interact within the same space.^[8] In effect, XR bridges the gap between tangible reality and digital simulations, ranging from simple real-world augmentation to complete virtual immersion. Whereas traditional textbooks present anatomy as static, two-dimensional (2D) diagrams, XR reshapes learning by offering interactive 3D organ models that students can rotate, zoom into, and examine in detail, thereby deepening their understanding of complex structures.^[9]

1.1 Use of XR platforms in classrooms for interactive biomedical education

During the COVID-19 pandemic, AP courses that had previously depended on face-to-face teaching rapidly shifted to remote delivery. In this context, VR became an important tool, offering an immersive digital environment that helped bridge the gap between traditional classroom teaching and online learning.^[10] Various hardware and software systems have been adopted to support immersive VR (iVR) surgical education, including devices such as the Oculus Rift,^[11] HTC Vive,^[12] and Oculus Quest.^[13]

Evidence shows that immersive VR can substantially improve the development of surgical skills, leading to faster task performance and more precise movements. Malhotra et al.,^[14] for instance, reported that incorporating augmented

reality-based soft-tissue navigation into laparoscopic urologic surgery significantly improved surgeons' spatial awareness. By overlaying real-time visual guidance on the surgical field, this technology supports critical decision-making and helps clinicians navigate complex anatomical structures with greater accuracy. Similarly, Liu et al.^[15] found that the use of clinical virtual simulations in nursing education enhanced students' learning outcomes, concluding that VR-based training is highly effective in strengthening both core knowledge and the confidence required for good clinical judgment.

1.2 Theoretical framework

This study draws on Kolb's experiential learning theory, which posits that genuine learning arises from direct experience rather than from passive instruction. This perspective is particularly useful for examining how learners process and integrate information during interactive activities.¹⁶ Kolb proposes a four-stage learning cycle that is relevant to simulation-based education:

- Concrete Experience (CE): Actively participating in a new activity or situation.
- Reflective Observation (RO): Reviewing and thoughtfully considering that experience.
- Abstract Conceptualisation (AC): Developing general principles, insights, or theories from those reflections.
- Active Experimentation (AE): Applying these new ideas in practice to see how they work in real or simulated contexts.

As highlighted by Bergsteiner et al.,^[16] this four-stage model offers a strong framework for analysing how learners engage with, progress through, and benefit from simulated learning environments.

The XR Brain (XRB) app in this study is an XR learning tool designed to support nursing students in mastering brain AP, as well as in caring for and managing cerebrovascular accidents (CVAs). It is intended to deepen students' understanding of brain structures and their functions, and to help them connect this knowledge to the assessment, nursing care, and management of both haemorrhagic and ischaemic strokes. The XRB application was designed to support critical thinking, metacognitive skills, and application of anatomical knowledge to CVA-related clinical scenarios.

By providing an interactive 3D brain model, the XRB application enables students to manipulate and examine structures, thereby improving their grasp of spatial relationships among regions compared with traditional 2D plastic models. Since it is accessible on internet-enabled devices, students can use the 3D models at any time and from any location, without requiring pre-booked lab sessions or physical models. This on-demand access supports flexible, self-paced, and repeated

review of complex anatomical features and CVA-related content.

1.3 Variable definitions and hypotheses

This study conceptualised self-efficacy for learning and performance as the primary outcome variable after nursing students used the XRB application. Self-efficacy refers to students' beliefs in their ability to organise and execute the actions required to learn anatomical content and perform related academic tasks. In this study, it was measured as the mean score on the self-efficacy for learning and performance subscale of the adapted Motivated Strategies for Learning Questionnaire (MSLQ), with higher scores indicating greater perceived confidence in learning and performing well.

The predictor variables were intrinsic value, task value, task anxiety, peer learning, and metacognitive self-regulation. Intrinsic value refers to the extent to which students perceive the XRB-based anatomy and stroke-care content as interesting, or personally meaningful. Task value refers to students' perceptions of the importance, usefulness, and relevance of the XRB-based learning task for their nursing education and future clinical practice. Task anxiety refers to students' worry, or concern about their ability to complete the XRB-based learning task successfully. Peer learning refers to students' use of discussion, and collaboration with classmates while learning with the XRB application. Metacognitive self-regulation refers to students' use of planning, and evaluating strategies to manage their own learning during XRB-based activities.

Demographic characteristics, including gender, age, nationality, and self-reported digital proficiency, were included as contextual covariates. Digital proficiency refers to students' self-assessed confidence and experience in using digital technologies. These variables were examined because they may be associated with students' confidence in using immersive digital learning tools.

Based on Kolb's experiential learning theory and prior evidence on motivation and self-regulated learning, the following hypotheses were proposed:

- H1: Demographic characteristics, including gender, age, nationality, and digital proficiency, are associated with self-efficacy for learning and performance after use of the XRB application.
- H2: Intrinsic value, task value, peer learning, metacognitive self-regulation and task anxiety are positively associated with self-efficacy for learning and performance.

1.4 Rationale and research objective

Nursing students need more than factual knowledge of brain anatomy; they must recognise anatomical relationships, in-

terpret their physiological significance, and apply this knowledge to the assessment and nursing care of patients with CVAs. Traditional lectures and 2D models may not adequately support these higher-order learning processes, particularly when students must visualise spatial relationships among brain structures and translate them into clinical reasoning. The XRB application addresses this need by enabling students to explore an interactive 3D model of the brain, revisit complex content at their own pace, and link anatomical knowledge to stroke-related assessment and nursing management.

Kolb's experiential learning theory provides a suitable framework for understanding how XRB may support this learning. In the concrete-experience stage, students actively manipulate and explore the 3D brain model rather than passively viewing diagrams. During reflective observation, they compare structures, interpret their observations, and consider how anatomical features relate to neurological function. In abstract conceptualisation, guided questions and case-based activities can help students develop principles linking brain anatomy to stroke presentation, assessment, and nursing care. Finally, in the active experimentation stage, students apply this knowledge to simulated or case-based CVA scenarios. Thus, XRB is not simply a technological addition to anatomy teaching; it can operationalise the experiential learning cycle by providing an accessible, interactive, and clinically relevant learning experience.

This study therefore aimed to examine nursing students' self-efficacy for learning and performance following use of the XRB application and to determine whether demographic characteristics, intrinsic value, task value, task anxiety, peer learning, and metacognitive self-regulation were associated with self-efficacy.

2. METHODS

2.1 Study design and setting

This cross-sectional study was conducted at a higher education institution in Singapore. The XRB application was integrated into a nursing curriculum to facilitate the teaching of selected components of the nervous system chapter. Two hundred nursing students enrolled in the AP course were invited to participate in the study. Using Cochran's formula for a finite population, with a 95% confidence level, a 5% margin of error, and an expected proportion of 0.50, the minimum required sample size was calculated as 132. Following their use of the XRB application, 146 nursing students completed a structured questionnaire. Data collection was carried out between February and April 2025. Table 1 shows the sociodemographic characteristics of the participants.

2.2 Development and validation of the XRB application

The XRB application was developed specifically for use in the AP course at the institution where this study was conducted. It was designed to support nursing students' learning of selected components of the nervous system, particularly brain AP, and to connect this knowledge to the assessment, nursing care, and management of CVAs. The application was developed through a collaborative process involving AP lecturer(s), nursing educator(s), instructional designer(s), and software developer(s). The learning content was based on the course learning outcomes for the nervous-system chapter and was aligned with the institution's nursing curriculum. The content included interactive 3D models of brain structures, labels and descriptions of anatomical regions, explanations of brain functions, and CVA-related learning activities.

The initial version of the XRB application was reviewed for content accuracy, curriculum alignment, and suitability for nursing students by AP lecturers. Reviewers evaluated whether the anatomical content was accurate, whether the content was pitched at an appropriate level for nursing students, and whether the application supported the intended learning outcomes. The final version of the XRB application included an interactive 3D brain model that students could rotate and zoom, anatomical labels, descriptions of structures and functions, and CVA-related learning scenarios. Students accessed the application using their mobile devices. The application was used to supplement, rather than replace, conventional lectures and laboratory learning.

Content validity was assessed through expert review of the application's educational content and alignment with course learning outcomes by AP lecturers. Usability was assessed through pilot testing with students. However, the XRB application was not subjected to a separate psychometric validation study; therefore, its validity was limited to content validity and preliminary usability evidence.

2.3 Instrument and data collection

Data were gathered using a structured, two-part questionnaire. The first section captured participants' demographic information, including gender, age, nationality, and level of digital proficiency. The second section comprised an adapted version of the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich & De Groot),^[17] designed to assess students' motivation and engagement with the XRB application. This section included six subscales: intrinsic value, task anxiety, task value, self-efficacy for learning and performance, peer learning, and metacognitive self-regulation. Responses were obtained on a 5-point Likert scale, ranging from 1 (strongly agree) to 5 (strongly disagree), and mean scores for each subscale were computed for subsequent analyses.

The dependent variable was self-efficacy for learning and performance. The predictor variables were intrinsic value, task value, task anxiety, peer learning, and metacognitive self-regulation. Demographic characteristics were entered as covariates in a separate or hierarchical regression model.

The MSLQ has been extensively validated and applied across diverse cultural contexts, languages, and learner populations for both theoretical and applied research purposes.^[18] The original instrument comprises 81 items, grouped into 15 subscales within two major domains: Motivation and Learning Strategies. For this study, six subscales relevant to the research objectives were selected. Specifically, intrinsic value, task anxiety, task value, and self-efficacy for learning and performance were derived from the Motivation domain, whereas peer learning and metacognitive self-regulation were sourced from the Learning Strategies domain. The MSLQ subscales selected for this study were reviewed by researchers from the institution where the study was conducted to assess the relevance, clarity, and appropriateness of the adapted items for nursing students' use of the XRB application.

The questionnaire was pilot tested with 30 nursing students who were not part of the main study sample. Pilot participants were asked to assess ease of navigation, clarity of content, technical functionality, and perceived usefulness.

2.4 Ethical considerations

Ethical approval for this study was obtained from the Ngee Ann Polytechnic Institutional Review Board (project code: NPIRB-P0287-2024-HS-ASI2, 3rd May 2024) prior to data collection. All participants were provided with detailed information about the study's purpose and procedures. Participation was entirely voluntary, and participants were informed of their right to decline involvement or withdraw at any time without penalty. Submission of the completed online questionnaire via Google Forms was considered to indicate informed consent. To ensure anonymity and confidentiality, no personally identifiable information was collected, and all data were handled in accordance with established ethical standards.

2.5 Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics, version 28 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including means, standard deviations, and frequencies, were computed to summarise the study variables. Independent-samples *t*-tests were conducted to explore the associations between students' perceptions and satisfaction with the XRB application and their demographic characteristics. Furthermore, one-way analysis of variance (ANOVA) and multiple regression analyses were undertaken to examine

differences in mean scores across variables.

3. RESULTS

3.1 Study design, setting and participants

This cross-sectional study comprised 146 nursing students conveniently sampled from a tertiary institution in Singapore. The cohort was predominantly female (79.5%) and primarily comprised individuals aged 21 or older (52.7%). Local students accounted for 59.6% of the sample. More than 60% of participants reported confidence in their digital technology proficiency (see Table 1).

3.2 Demographic variables and mean MSLQ subscale scores

Analysis of the MSLQ scores revealed several significant differences based on demographic characteristics (see Table 2). Female nursing students consistently had higher mean MSLQ scores than their male counterparts across all six subscales. The difference in peer learning is extremely significant ($p < .001$), with females scoring 10.85 and males 8.97. This suggests that female nursing students were much more likely to utilise collaborative learning while using the

XRB application. Females also reported significantly higher self-efficacy ($m = 22.44$, $p < .01$) and intrinsic value ($m = 15.12$, $p < .01$) than males. The highest overall mean score, across both genders, was observed in the self-efficacy for learning and performance subscale.

Table 1. Sociodemographic characteristics of respondents (N = 146)

Demographic variables	N	%
Gender		
Male	30	20.5
Female	116	79.5
Age (mean age: 21.4)		
18-20	69	47.3
≥ 21 years	77	52.7
Nationality		
Local	87	59.6
International	59	40.4
Are you confident in using digital technology (Tech Savvy)?		
Yes	98	67.1
No	48	32.9

Table 2. Demographic variables of students using the XRB application and mean MSLQ subscale scores

MSLQ subscales	Overall (N = 146)	Gender		Age		Nationality	
		Male	Female	18-20	≥ 21	Local	International
Task value	14.68	13.43*	15.0*	14.22	15.09	14.26	15.29
Self-efficacy for learning and performance	21.87	19.67**	22.44**	20.96*	22.69*	21.07*	23.05*
Intrinsic value	14.75	13.33**	15.12**	14.38	15.09	14.37	15.32
Task anxiety	10.38	8.97**	10.75**	9.93	10.79	9.91*	11.08*
Peer learning	10.47	8.97***	10.85***	10.17	10.73	10.11	10.98
Metacognitive Self-regulation	14.28	12.9*	14.64*	13.65*	14.84*	13.74*	15.08*

* $p < .05$; ** $p < .01$; *** $p < .001$

Older students (aged 21 years or older) reported significantly higher mean scores than younger students on two subscales: self-efficacy for learning and performance and metacognitive self-regulation. There were no significant differences in task value, intrinsic value, or peer learning by age, suggesting that the XRB application's appeal is consistent across age groups, even though older students reported feeling more capable of managing the tool. International students also had significantly higher mean scores on the self-efficacy for learning and performance ($m = 23.05$), task anxiety ($m = 11.08$), and metacognitive self-regulation ($m = 15.08$) subscales than local students (see Table 2).

3.3 Correlations between MSLQ subscales

Correlations between self-efficacy for learning and performance and other subscales were reported in Table 3. Self-

efficacy and intrinsic value are strongly and significantly positively correlated ($r = 0.956$, $p < .01$), indicating that students who find the learning material intrinsically rewarding and enjoyable tend to have high confidence in their ability to master the content. Self-efficacy is also significantly and positively correlated with task value ($r = 0.942$, $p < .01$), suggesting that as nursing students perceive the XRB application and the study of CVA management as more important, their belief in their ability to perform well on these tasks increases.

The significant positive correlation between self-efficacy and metacognitive self-regulation ($r = 0.877$, $p < .01$) indicated that students who are confident in their learning performance are more likely to engage in self-regulatory behaviours, such as planning and evaluating their learning process while using the XRB application. Self-efficacy is strongly and positively

correlated with peer learning ($r = 0.801, p < .01$). This shows that students with higher confidence in their academic performance are also more inclined to collaborate and learn with their peers. However, self-efficacy also showed a strong posi-

tive correlation with task anxiety ($r = 0.772, p < .01$). In this cohort of students, this may suggest that higher confidence is associated with greater concern about performance.

Table 3. Correlations between MSLQ subscales (N = 146)

	Task value	Self-efficacy for learning and performance	Intrinsic value	Task anxiety	Peer learning	Metacognitive Self-regulation
Task value	-	0.942**	0.949**	0.746**	0.779**	0.861**
Self-efficacy for learning and performance	0.942**	-	0.956**	0.772**	0.801**	0.877**
Intrinsic value	0.949**	0.956**	-	0.762**	0.795**	0.871**
Task anxiety	0.746**	0.772**	0.762**	-	0.901**	0.884**
Peer learning	0.779**	0.801**	0.795**	0.901**	-	0.912**
Metacognitive Self-regulation	0.861**	0.877**	0.871**	0.884**	0.912**	-

**Correlation is significant at the 0.01 level (2-tailed).

3.4 Multiple regression analyses

We hypothesised that demographic characteristics, including gender, age, nationality, and digital proficiency, are associated with self-efficacy for learning and performance (H1). Hierarchical multiple linear regression was conducted to test the hypotheses (see Table 4). Model 1 is statistically significant ($F = 5.046, p < .001$) and explains about 12.5% of the

variance in self-efficacy for learning and performance ($R^2 = 0.125$). Gender and digital proficiency were significantly associated with self-efficacy, whereas age and nationality were not. Therefore, H1 was partially supported. Being female ($\beta = 0.209, p < .01$) and digital proficiency ($\beta = 0.197, p < .05$) significantly predicted students' self-efficacy for learning and performance.

Table 4. Hierarchical multiple regression analysis of the associations between self-efficacy for learning and performance, demographic variables and MSLQ subscales

Model	Unstandardized Coefficients		Standardized Coefficients		t	p-value
	B	Std. Error	Beta			
1 Gender (Female)	2.582	0.980	0.209		2.635	.009
Age (18-20)	-0.740	0.913	-0.074		-0.810	.419
Nationality (Local)	-1.663	0.927	-0.164		-1.794	.075
Tech Savvy (Yes)	2.086	0.840	0.197		2.483	.014
2 Gender (Female)	0.182	0.284	0.015		0.642	.522
Age (18-20)	-0.393	0.256	-0.039		-1.538	.126
Nationality (Local)	-0.332	0.258	-0.033		-1.289	.200
Tech Savvy (Yes)	0.422	0.239	0.040		1.762	.080
Task value	0.453	0.103	0.310		4.385	< .001
Intrinsic value	0.829	0.112	0.546		7.398	< .001
Task anxiety	0.045	0.097	0.025		0.462	.645
Peer learning	0.023	0.112	0.013		0.201	.841
Metacognitive self-regulation	0.115	0.106	0.078		1.092	.277

Note. Dependent Variable: Self-efficacy for learning and performance

We also hypothesised that intrinsic value, task value, peer learning, metacognitive self-regulation and task anxiety are positively associated with self-efficacy for learning and performance (H2). In Model 2, adding intrinsic value, task value, peer learning, metacognitive self-regulation, and task anxi-

ety significantly improved the model (R^2 change = 0.811). Although Model 2 ($F = 223.082, p < .001$) explains 93.7% of the variance, only two predictors were statistically significant independent contributors (see Table 4). Self-efficacy is more strongly influenced by internal motivational con-

structs, such as intrinsic value ($\beta = 0.546$, $p < .001$) and task value ($\beta = 0.310$, $p < .001$), than by demographic factors or tech-savviness. The other three variables—task anxiety, peer learning, and metacognitive self-regulation—are not statistically significant independent predictors of self-efficacy. Multicollinearity diagnostics indicated acceptable collinearity, with tolerance values below 0.10 and variance inflation factor (VIF) values below 5.0, indicating that multicollinearity was not a concern in the model.

4. DISCUSSION

4.1 H1: Demographic characteristics and self-efficacy

H1 proposed that demographic characteristics, including gender, age, nationality, and digital proficiency, were associated with self-efficacy for learning and performance after use of the XRB application. In the regression model 1, female gender and self-reported digital proficiency were positively associated with self-efficacy, whereas age and nationality were not statistically significant. Therefore, H1 was partially supported.

Female students reported higher self-efficacy than male students in Model 1. This finding is consistent with studies suggesting that female students may report greater ease of use or confidence in some interactive digital-learning contexts. Siwale and Mwalemba,^[19] reported that female students may feel greater social or professional pressure to demonstrate digital proficiency in traditionally male-dominated tech spaces. A study on AR found that females reported higher “ease of use” in interactive contexts than males, even when overall performance was similar.^[20] Another study by Ahmed et al.^[21] showed that female students often exhibit superior communication and adaptability in tech-mediated environments. However, a study on VR technology in nursing education found that female nursing students perceived it as less user-friendly than male students.^[22] Sagnier et al.^[23] also observed that female users rated VR ease of use lower, likely due to a lack of prior exposure to the technology.

Students who identified as tech-savvy also reported higher self-efficacy in Model 1. This finding is plausible because familiarity with digital tools may reduce uncertainty when navigating an unfamiliar application. However, after adding the MSLQ variables in Model 2, neither gender nor digital proficiency remained statistically significant. This suggests that their unadjusted associations with self-efficacy may overlap with students’ motivational perceptions of the XRB-based learning task.

Age and nationality were not significant predictors of self-efficacy in either model. Although unadjusted group comparisons may show differences in mean MSLQ scores, these

differences did not remain significant after adjustment for the variables included in the regression model. Therefore, the findings do not support treating age or nationality as independent predictors of self-efficacy in this sample.

Overall, H1 was partially supported. The findings suggest that demographic characteristics should not be used to determine students’ learning goals or expected performance. Instead, educators should provide equitable access, technical orientation, and support for all students.

4.2 H2: MSLQ variables and self-efficacy

The second hypothesis (H2) proposed that, after controlling for demographic characteristics, intrinsic value, task value, peer learning, metacognitive self-regulation, and task anxiety were associated with self-efficacy for learning and performance. In regression model 2, intrinsic value and task value were significant positive predictors of self-efficacy, whereas peer learning, metacognitive self-regulation, and task anxiety were not. Therefore, H2 was partially supported.

Intrinsic value was the strongest independent predictor of self-efficacy. Students who found the XRB-based anatomy and stroke-care activities interesting, enjoyable, or personally meaningful reported greater confidence in their ability to learn and perform well. This finding is consistent with the view that interest and enjoyment can support students’ academic self-belief during interactive learning activities. In the context of Kolb’s experiential learning theory, XRB may promote intrinsic value by allowing students to actively explore a 3D brain model, compare structures, and engage with clinically relevant content rather than passively receive information.

Task value was also positively associated with self-efficacy. Students who perceived the XRB-based activity as useful for their nursing education reported higher self-efficacy. This finding highlights the importance of explicitly connecting brain anatomy to nursing practice. For example, XRB activities may link to CVA assessment, recognising neurological changes, care planning, patient education, and clinical decision-making. These connections may help students understand why the activity is relevant to their future clinical role.

Peer learning, task anxiety and metacognitive self-regulation were not statistically significant independent predictors after adjustment for the other variables. Although these variables were positively correlated with self-efficacy in the bivariate analysis, their associations may overlap with intrinsic value, task value, or other constructs in the regression model. Therefore, the findings do not establish that peer learning, task anxiety or metacognitive self-regulation independently

predict self-efficacy. They also do not mean these strategies are educationally unimportant; rather, they did not explain additional unique variance after accounting for the other predictors. The positive bivariate correlation between task anxiety and self-efficacy may reflect item scoring direction, or the cross-sectional nature of the data. Further research is needed to clarify the relationship between anxiety and self-efficacy in XR-based learning.

4.3 Implications for nursing education

The findings suggest that instructional design should prioritise students' perceived interest and perceived usefulness of XRB-based learning activities. Since intrinsic value was the strongest predictor of self-efficacy, XRB activities should be interactive and cognitively engaging. Instructors can use guided discovery tasks in which students identify brain structures, compare regions, explain structure–function relationships, and predict the possible effects of damage to specific areas.

Since task value was also a significant predictor, each XRB activity should be explicitly connected to nursing practice. A clinically relevant stroke case can be introduced before XRB exploration. Students can then identify relevant brain structures, relate them to possible neurological signs, and apply this understanding to assessment findings, nursing priorities, and patient education. This is consistent with Kolb's experiential learning cycle.

Since gender and digital proficiency were not significant after adjusting for the MSLQ variables, the findings do not support gender-specific instruction or gender-based learning expectations. All students should receive a brief orientation to the application, a demonstration of its core functions, and access to technical support. However, because this was a cross-sectional study, these recommendations should be evaluated in future longitudinal or controlled studies rather than assumed to improve self-efficacy.

4.4 Limitations of study

While this study provides valuable insights, several limitations must be considered. First, the small sample was restricted to nursing students from a single Singaporean tertiary institution, which limits the generalisability of the results to the broader nursing student population. Second, the sample comprised 146 nursing students from a single institution and used convenience sampling, limiting generalisability. Third, all variables were self-reported, which may be affected by common-method bias and social desirability. Finally, the present study did not assess the internal-consistency reliability of the adapted MSLQ. Therefore, the subscale scores should be interpreted with caution. Future research should

prioritise larger-scale, multi-institution studies using randomised selection. Furthermore, the data were based on students' perceptions without a control group. The lack of objective data and a control group increases the risk of participant bias.

5. CONCLUSIONS

The findings of this study underscore the vital role of task-related valuation in shaping a student's belief in their academic capabilities. The correlation analysis revealed that all MSLQ subscales were correlated, with particularly strong associations among self-efficacy, intrinsic value, and task value. However, when these variables were modelled together, intrinsic value and task value emerged as the only significant predictors of self-efficacy for learning and performance. Furthermore, students' demographic profiles significantly influence their self-belief. Female students and those who identify as tech-savvy show significantly higher self-efficacy. Interestingly, while age and nationality were analysed, they had no predictive power in this context. Finally, these results suggest that while external factors such as gender and technological savviness contribute to a student's confidence in using the XRB application, the most critical drivers of self-efficacy are the internal perceptions of interest and value in the academic material. Recommendations

While teaching study skills and metacognitive techniques is important, these results suggest that such strategies may not directly enhance a student's self-efficacy unless the student first perceives the task as inherently valuable or relevant. Since intrinsic value significantly predicted self-efficacy, instructional design should connect curriculum content to real-world applications to foster a sense of purpose. Therefore, XRB activities should be engaging and explicitly connected to clinically relevant nursing tasks, particularly neurological assessment and CVA care. The significant association between digital proficiency and self-efficacy indicates that students with lower digital literacy may feel less capable in immersive learning environments. Educators should provide technical orientation to ensure that a lack of digital confidence does not undermine students' academic self-belief.

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AUTHORS CONTRIBUTIONS

AS, LMT and AMAN contributed to the study conception and design. LMT and AS collected the data. AMAN analysed and interpreted the data and drafted the article. All authors—AMAN, AS, and LMT—critically reviewed and

edited the final manuscript. AS and LMT contributed equally to the study.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

DATA SHARING STATEMENT

No additional data are available.

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