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Application of 3D Printing Combined with Virtual Reality (VR) Technology in Nursing Education: A Case Study of Intracranial Tumors

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Abstract: *This study aimed to explore the application effect of 3D printing combined with virtual reality (VR) technology in nursing education for intracranial tumors; a total of 60 undergraduate nursing students enrolled in September 2025 were randomly divided into an experimental group and a control group, with 30 students in each group. The experimental group received teaching with 3D printing models combined with VR virtual surgical scenarios, while the control group adopted traditional multimedia teaching; after the teaching intervention, theoretical examinations, skill operation assessments, and questionnaire surveys were conducted to evaluate the teaching effect. The results showed that the theoretical scores and skill operation scores of the experimental group were significantly higher than those of the control group (P<0.05), and the experimental group also exhibited significant advantages in improving spatial comprehension, surgical cooperation ability, learning interest, and clinical adaptability compared with the control group (P<0.05). In conclusion, 3D printing combined with VR technology can effectively improve nursing students' mastery of intracranial tumor - related knowledge and operational skills, enhance their clinical adaptability and teamwork ability, and thus has high teaching application value in intracranial tumor nursing education.*

Keywords: *3D printing; virtual reality; nursing education; intracranial tumor; teaching method*

1. Introduction

Nursing is a comprehensive applied science that studies nursing theories, skills, and developmental laws for maintaining, promoting, and restoring human health. As an important component of healthcare, nursing plays an irreplaceable role in disease detection, assessment, and mitigation. Neurosurgical nursing education is particularly critical, especially perioperative nursing for intracranial tumors. This content involves complex anatomical structures, sophisticated surgical procedures, and high risks in postoperative monitoring, making it a key and difficult point in nursing education[1]. Traditional teaching relies on two-dimensional anatomical atlases, multimedia courseware, and operating room observation. Students struggle to construct a three-dimensional mental model of the intracranial cavity and often fail to accurately grasp the spatial relationships between tumors, blood vessels, and nerves. The operating room features a specialized environment and strict aseptic requirements, leaving students with limited opportunities for hands-on participation and repeated practice. Consequently, students frequently exhibit unskilled cooperation and slow responses in real clinical settings[2-3].

The deep integration of technology and education has enabled innovative educational tools such as 3D printing and virtual reality (VR) to break through teaching bottlenecks. 3D printing converts patients' CT, MRI, and other imaging data into touchable, detachable 1:1 physical models, transforming abstract anatomical concepts into tangible objects and markedly facilitating spatial structural comprehension[4]. VR creates an immersive three-dimensional computer-generated environment, allowing students to repeatedly practice surgical procedures, instrument delivery, and emergency management in a safe space, effectively addressing the shortage of clinical practice opportunities[5-6]. This study combined 3D printing and VR training for intracranial tumor nursing education to investigate whether this novel approach enhances nursing students' mastery of theoretical knowledge, operational skills, and clinical competence, aiming to explore more effective pathways for training professional nursing talents.

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2. Subjects and methods

2.1 Study subjects

A convenience sampling method was used to select 60 junior undergraduate students who had completed basic medical and fundamental nursing courses in September 2025. They were randomly divided into experimental group and control group using a random number table, with 30 students per group.

Inclusion criteria

(1) Full-time undergraduate nursing students;

(2) Completed systematic study of Human Anatomy, Surgical Nursing, and other basic courses;

(3) Provided informed consent and voluntarily participated in the study.

Exclusion criteria

(1) Suffering from motion sickness or severe discomfort with VR equipment;

(2) Took long-term leave during the study period.

There were no statistically significant differences in baseline data including age, gender, and previous Surgical Nursing final scores between the two groups ($P>0.05$), indicating comparability.

2.2 Teaching Methods

Both groups were taught by the same teaching team, with a total of 16 class hours focusing on Perioperative Nursing for Intracranial Meningioma, covering basic anatomy and physiology, clinical manifestations, surgical plans, key nursing points, and complication monitoring.

Control group: Traditional multimedia teaching was adopted. Teachers used PPT integrating two-dimensional anatomical diagrams and surgical videos to explain meningioma anatomy, surgical approaches, and key nursing cooperation points. Then, instructors demonstrated position placement, instrument identification, and delivery on simulators. Finally, students practiced in groups in the training room with teachers' on-site guidance.

Experimental group: Integrated teaching of 3D printing combined with VR technology was implemented, deeply integrating 3D printing models and VR simulation training on the basis of traditional theoretical lectures. Specific steps were as follows:

Phase 1: 3D printing model–assisted cognition (2 class hours)

Anonymized DICOM CT data of a typical frontal lobe meningioma patient were used to produce a color multi-material detachable model via stereolithography (SLA) 3D printing, including skull, tumor, vital blood vessels (e.g., middle cerebral artery branches), and neural structures. In class, students observed, touched, and disassembled the model in groups to clearly visualize tumor location, adjacent tissue relationships, and key surgical attention points.

Phase 2: VR virtual surgery immersive training (8 class hours, core module)

(1) A neurosurgical VR surgical nursing training system developed with a software company was used. Students first familiarized themselves with the VR operating room environment, interface operations, and virtual instrument functions in non-immersive mode.

(2) Role-playing and process simulation: Students worked in groups of three, wearing VR headsets and controllers, acting as scrub nurse, circulating nurse, and observer (recorder). The full nursing cooperation process of intracranial meningioma resection was simulated from preoperative visit, operating room preparation, to sterile table setup. The system supported standard procedures and accurate delivery of bipolar coagulators, aspirators, microscopes, etc., and simulated intraoperative emergencies such as sudden bleeding and blood pressure fluctuations, requiring rapid assessment and collaborative responses.

(3) Real-time feedback and retrospective analysis: The system automatically recorded operation processes, response time, and decision accuracy, and generated an evaluation report after training. Teachers led group reviews to identify problems and provide corrective guidance.

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Phase 3: Integration and reinforcement (2 class hours)

Students reviewed key anatomical surgical steps using 3D printing models, reflected on the subtle links between each operation and nursing cooperation, and strengthened the connections among structure, function, and practice. At the end of the course, students wrote reflective logs to record gains and areas for improvement in VR training.

2.3 Evaluation indicators and methods

Unified assessments and questionnaire surveys were administered to both groups after teaching intervention.

(1) Theoretical examination: Closed-book written test (100 points total), covering basic knowledge of intracranial tumors, perioperative nursing key points, and complication observation and management, including multiple-choice questions, term explanations, and case analyses.

(2) Objective Structured Clinical Examination (OSCE): Three stations (100 points total)

Station 1 (30 points): Identification of anatomical structures and surgical instruments. Students were assessed on naming and applying specific anatomical structures and surgical instruments using 3D printing models and physical instruments.

Station 2 (40 points): Implementation of surgical cooperation procedures. Standardization and proficiency of preoperative preparation, intraoperative instrument delivery, and aseptic technique maintenance were evaluated in a simulated operating room.

Station 3 (30 points): Intraoperative emergency management. Clinical judgment, emergency response, and communication skills were tested using standardized patients (SP) or simulated scenarios (e.g., equipment alarms, vital sign changes).

(3) Questionnaire survey: A self-designed Questionnaire on Teaching Effect and Learning Experience was distributed and collected on-site. It included: (1) 5-point Likert scale evaluation of teaching effects on learning motivation, knowledge comprehension, and competency improvement; (2) subjective feedback on learning pressure and equipment adaptability. A total of 60 questionnaires were distributed and 60 valid ones were recovered, with an effective recovery rate of 100%.

2.4 Statistical analysis

Data were analyzed using SPSS 26.0 software. Measurement data (theoretical scores, OSCE scores) were expressed as mean ± standard deviation, and independent-samples t-test was used for between-group comparisons. Enumeration data were expressed as frequency and percentage (%), and chi-square test was used for between-group comparisons. $P<0.05$ was considered statistically significant.

3. Results

3.1 Comparison of assessment scores between two groups

The theoretical and total OSCE scores of the experimental group were significantly higher than those of the control group ($P<0.001$). Further analysis of OSCE sub-stations showed that the experimental group scored higher in all three stations, with more prominent advantages in surgical procedure implementation and intraoperative emergency management ($P<0.01$), as is shown in Table 1.

Table 1. Comparison of theoretical and OSCE scores between two groups (points, ±s)

Group	N	Theoretical Score	OSCE Total Score	Anatomy & Instrument	Procedure Implementation	Emergency Management
Experimental	30	89.45±3.72	90.23±4.15	26.89±2.01	36.45±2.88	26.89±2.34
Control	30	82.13±5.84	81.56±5.92	23.67±3.15	31.23±4.12	22.67±3.45
t value	-	5.790	6.568	4.719	5.687	5.544
P value	-	<0.001	<0.001	<0.001	<0.001	<0.001

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3.2 Comparison of teaching effect questionnaire between two groups

The questionnaire showed that the proportion of positive evaluations in the experimental group was significantly higher than that in the control group in stimulating learning interest, enhancing spatial comprehension, improving clinical adaptability, and cultivating teamwork (P<0.05). There was no significant difference in highlighting key learning content between the two groups. However, students in the experimental group generally reported higher learning pressure and certain difficulties in equipment operation, as is shown in Table 2.

Table 2. Comparison of teaching effect evaluations between two groups (n, %)

Evaluation Item	Experimental (n=30)	Control (n=30)	χ^2 value	P value
Stimulates learning interest	27 (90.0)	18 (60.0)	6.125	0.013
Highlights key content	25 (83.3)	24 (80.0)	0.125	0.723
Enhances spatial comprehension	28 (93.3)	17 (56.7)	8.571	0.003
Improves clinical adaptability	25 (83.3)	15 (50.0)	6.667	0.010
Cultivates teamwork	26 (86.7)	19 (63.3)	3.956	0.047
High learning pressure	23 (76.7)	14 (46.7)	4.286	0.038
Difficulties in equipment use	21 (70.0)	9 (30.0)	8.000	0.005

4. Discussion

4.1 From abstract to concrete: How 3D printing models deepen spatial cognition and knowledge comprehension

Traditional nursing teaching relies on two-dimensional images and text to describe complex intracranial tumor structures, demanding high spatial imagination and often leading to insufficient understanding and weak memory [7]. Significantly higher scores in theoretical examination and OSCE Station 1 (anatomy and instrument identification) in the experimental group (P<0.001) confirm that 3D printing models transform abstract concepts into concrete visuals. 3D printing enables multimodal learning: students observe 360° spatial adjacencies between tumors and vital structures (falx cerebri, sagittal sinus, functional cortex) visually, perceive texture tactilely, and dynamically understand anatomical layers through disassembly and assembly [8-9]. The synergistic visual–tactile–kinesthetic experience aligns with constructivist learning theory, helping students actively build precise 3D mental models. For example, tactile awareness of tumors adjacent to critical blood vessels deepens understanding of intraoperative vascular protection far beyond planar atlases or lectures [10]. This advanced spatial perception underpins precise nursing, enabling risk anticipation, accurate target identification in VR simulation, and clear recognition of high-risk areas, realizing a cognitive leap from knowing to understanding [11].

4.2 From observation to immersion: How VR technology reshapes skill training and clinical thinking

The experimental group's superior performance in OSCE Station 2 (procedure implementation) and Station 3 (emergency management) verifies VR's unique value. VR allows students to move beyond passive observation or basic imitation to active participation [12]. Traditional nursing training on simulators lacks the tense atmosphere, teamwork presence, and unpredictable emergencies of real operating rooms [13]. VR authentically reproduces operating room acoustics, lighting, and scenarios, assigning clear roles and responsibilities to students. In this highly realistic environment, students must

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focus fully and make continuous clinical decisions. When simulated acute bleeding occurs, students must immediately recognize crises, recall instruments, and communicate with simulated surgeons, fostering knowledge application, technical operation, collaborative communication, and stress management. Instant system feedback and retrospective review form a complete learning cycle: practice → feedback → reflection → optimization [14-15]. This process significantly forms and consolidates clinical thinking, explaining the 83.3% self-rated improvement in clinical adaptability among experimental group students.

4.3 From passive to active: How the integrated model stimulates intrinsic motivation and teamwork

Questionnaire data clearly show that 90.0% of experimental group students agreed the new model stimulated learning interest, and 86.7% reported improved teamwork—both significantly higher than the control group. The combination of 3D printing and VR represents not only technological advancement but also pedagogical innovation, shifting learning from passive reception to active engagement. The novel technical format inherently appeals to digital-native students and grants them greater learning autonomy [16-17]. In the VR environment, students become key task performers whose decisions and actions directly affect virtual surgical outcomes, generating intrinsic motivation [18]. Completing complex virtual surgical tasks in groups constitutes deliberate collaborative learning: clear communication, timely interaction, and professional coordination ensure accurate instrument delivery, smooth procedures, and rapid emergency responses, gradually building trust and role clarity [19-20]. Shared goals and task-based problem-solving markedly enhance teamwork.

4.4 Limitations and prospects

This study has limitations: relatively single sample source, small sample size, lack of long-term follow-up of teaching effects, and limited diversity and complexity of VR pathological scenarios. Future research should expand sample size and scope, conduct multi-center hospital collaborations, develop smarter and personalized VR training systems with AI algorithms for detailed operational analysis and guidance, and extend this model to nurse standardized training and continuing education.

5. Conclusion

In summary, the integrated teaching model combining 3D printing and VR technology—through physical perception for foundational learning, virtual immersion for skill reinforcement, and teamwork for deep comprehension—effectively addresses the difficulties in traditional intracranial tumor nursing education. It improves nursing students' professional knowledge and clinical operational skills, stimulates learning initiative, shapes clinical thinking and adaptability, and fosters teamwork. Despite challenges of equipment cost and technical adaptability, its teaching value is remarkable. This exploration of nursing education informatization provides new ideas for modern reform, with promising application prospects and popularization potential.

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Author contributions

All authors have designed the study, developed the methodology, and written the manuscript. All authors have read and agreed to the published version of the manuscript.

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