Original Article

Construction of a Predictive Model for Theory and Practical Performance in '*Fundamentals of Nursing*' Based on Student Behavior – A Case Study of Nursing Students

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Abstract

Background: *Fundamentals of Nursing* is a core course essential for developing clinical competence. Variations in learning behaviors may lead to differences in academic performance. This study aimed to identify key behavioral predictors of both theoretical and practical outcomes and construct predictive models to support early intervention and teaching optimization. **Materials and Methods:** Machine learning techniques were applied to develop predictive models using data from undergraduate nursing students who enrolled the 2019 and 2020 cohorts. Demographic and learning behavior variables were collected and divided into training and testing sets (7:3 ratio). Least absolute shrinkage and selection operator regression was used for feature selection, and logistic regression identified independent risk factors. Five algorithms [Logit, RF, XGBoost, Artificial Neural Network, and Support Vector Machine (SVM)] were used to construct models. Model performance was evaluated using area under the curve (AUC), specificity, and sensitivity. **Results:** Data from 527 students were analyzed; 59 (11.19%) failed the theoretical exam, and 116 (22.01%) failed the practical exam. Predictors for practical exam included height, comprehensive assessment scores, periodic exam scores, comprehensive practical training scores, and practice frequency. Predictors for the theoretical exam included gender, research participation, academic background, height, periodic exam, and practice frequency. SVM showed the best performance for practical exams prediction (AUC = 0.737), while XGB performed best for theoretical exams (AUC = 0.833). No statistically significant differences in AUC were found between most models ($p \geq 0.05$). **Conclusions:** Height, assessment scores, training engagement, exam results, gender, and practice frequency significantly influenced nursing students' academic outcomes. These findings support personalized teaching strategies in foundational nursing education.

Keywords: *Artificial intelligence, behavior, nursing education, nursing students, predictive models*

Introduction

As a core component of Learning Analytics, learning behavior analysis involves the systematic collection and interpretation of multidimensional behavioral data throughout the learning process—such as online learning trajectories, classroom interactions, and hands-on practice. This approach reveals potential associations between behavior patterns and learning outcomes, providing empirical evidence to support educational decision-making.[1,2] The rise of this methodology is closely tied to the digital transformation of education, where data-driven instructional optimization has become a strategic priority in educational reform, especially in online and blended learning contexts.[3,4]

In nursing education, the *Fundamentals of Nursing* course, with its dual emphasis on theory and practice, serves as a critical checkpoint for evaluating students' professional competence. Its performance outcomes are increasingly viewed as indicators of future clinical capability in nursing practice.[5] According to the most recent *Essentials: Core Competencies for Professional Nursing Education,* issued by the American Association of Colleges of Nursing, it is crucial to establish a dynamic, evidence-based, "process–outcome" monitoring system to ensure the effective development of clinical competency.[6]

In recent years, with the rapid development of big data, technologies such as data

How to cite this article: Li RL, Lan Y, Han YF, Lan HX, Chen DD, Jiang WT. Construction of a predictive model for theory and practical performance in '*fundamentals of nursing*' based on student behavior – A case study of nursing students. Iran J Nurs Midwifery Res 2026;31:502-12.

Submitted: 31-Jan-2025. **Revised:** 05-Oct-2025. **Accepted:** 06-Oct-2025. **Published:** 16-Jun-2026.

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Access this article online

Website: https://journals.lww.com/jnmr

DOI: 10.4103/ijnmr.ijnmr_38_25

Quick Response Code:

mining, machine learning, and artificial intelligence have become prominent frontiers of research.[7] In the field of education, Educational Data Mining and Learning Analytics (LA) have emerged, offering new perspectives and tools for both research and practice.[4] The core objective of LA is to accurately identify patterns of learning behavior and examine their intrinsic associations with learning outcomes, ultimately aiming to enable more efficient and personalized education.[8]

Wang and Yu applied machine learning techniques to online learning behavior data (e.g., course participation, assignment submission) and developed a logistic regression model to predict student performance.[1] Similarly, Chen *et al*. utilized behavioral features to construct predictive models of academic achievement.[9]

While some studies have explored factors influencing nursing students' academic performance,[10,11] there is still a lack of systematic predictive models capable of accurately assessing both theoretical knowledge and practical skills in *Fundamentals of Nursing*. Developing a behavior-based predictive model specifically tailored to nursing students can enable educators to proactively identify learning behavior trends and provide timely, evidence-based guidance to optimize teaching strategies.

Therefore, this study focuses on analyzing both the theoretical and practical performances in the *Fundamentals of Nursing* course and independently constructs predictive models for each based on students' learning behaviors. The aim is to provide a scientific foundation for personalized instruction and timely intervention in nursing education, thereby enhancing teaching quality and improving student learning outcomes. The early identification of at-risk students early not only facilitates tailored instructional strategies but also helps ensure that future nurses possess the necessary competencies to deliver safe and effective care in real-world clinical settings. Poor performance in foundational courses may lead to reduced self-confidence, an increased likelihood of clinical errors, and suboptimal patient outcomes during internships or the stages of professional practice. The study seeks to apply machine learning techniques to behavioral data in order to predict academic and practical performance, with the ultimate goal of informing early intervention and instructional improvement in nursing education.

Materials and Methods

This study adopted a retrospective observational design to analyze the relationship between learning behavior and academic performance among undergraduate nursing students. A consecutive total sampling strategy was used, encompassing all eligible full-time nursing undergraduates from the 2019 and 2020 cohorts at Guangxi University of Chinese Medicine, China. The minimum required sample size was calculated based on power analysis, assuming a significance level (α) of 0.05, a statistical power ($1-\beta$) of 0.80, and an expected effect size (r) of 0.25. This resulted in a minimum of 128 students per group, which was exceeded in the final dataset, ensuring sufficient statistical power. Inclusion criteria were: (1) full-time nursing undergraduates and (2) availability of complete records on both academic performance and learning behavior in the *Fundamentals of Nursing* course. Exclusion criteria included students who (1) transferred major, (2) repeated a year, (3) took academic leave, or (4) were enrolled in top-up or special programs not involving the course.

A total of 28 variables were retrospectively collected from class advisor records and the teaching department. These included student characteristics such as gender, ethnicity, height, entrance exam scores, academic track (science vs. humanities), political affiliation, computer and English proficiency (based on national exam levels), leadership roles, work-study status, scholarship level, number and type of awards, comprehensive assessment scores, number of university/district/national awards, highest award level, and involvement in social or research activities. Height was included as a potential predictor variable based on preliminary observations and prior studies suggesting possible associations between physical characteristics and practical performance in nursing education, particularly in tasks requiring dexterity, posture control, or physical coordination.[12] Learning behaviors included periodic test scores, assignment scores, practical tests performance, frequency of self-directed practice (number of check-ins at the open lab), comprehensive skill training scores, and final theoretical exams. All scores were standardized to a 100-point scale. In line with the course standards, final practical scores <80 and theoretical scores <60 were defined as failing, and such cases were labeled as positive outcomes in the binary classification task.

Statistical analyses were conducted using SPSS version 25.0 and R version 4.3.2, with a significance level set at $p \leq 0.05$. Descriptive statistics were reported as means ± standard deviations (SDs) for continuous variables and as frequencies and percentages (%) for categorical data. Feature selection, model training, and validation were conducted in R 4.3.2. The dataset was randomly split into training and testing sets at a 7:3 ratio. Binomial Least Absolute Shrinkage and Selection Operator (LASSO) regression was applied to identify key predictors, followed by logistic regression to determine independent risk factors. Five machine learning algorithms—Logistic Regression (Logit), Random Forest (RF), XGBoost (XGB), Artificial Neural Network (ANN), and SVM—were trained using 10-fold cross-validation. Model performance was assessed using receiver operating characteristic (ROC) curves, area under the curve (AUC), sensitivity, specificity, F1 scores, and accuracy. Comparisons of AUC values between models were conducted using Delong's test.

Ethical considerations

This study protocol was reviewed and approved by the Research Ethics Committee of St. Paul University Manila (SPU Manila REC) under approval number 2021-090-IGS-CNA. Educational data from the 2019 and 2020 cohorts of undergraduate nursing students were obtained through formal collaboration between St. Paul University Manila and Guangxi University of Chinese Medicine. All data were fully deidentified and provided by Guangxi University of Chinese Medicine. Based on the ethics committee's assessment, the requirement for informed consent was waived as the study involved only a retrospective analysis of anonymized educational records and did not entail direct interaction with participants. Although informed consent was waived, participants were not individually notified of the study because of the deidentified and aggregate nature of the data; however, the protocol and data use were reviewed and approved by institutional stakeholders to ensure transparency and compliance.

Results

Baseline data of students

After applying the inclusion and exclusion criteria and completing data preprocessing, a total of 527 undergraduate nursing students were included in the final analysis. Twenty-eight variables were analyzed. Among the participants, 59 students failed the theoretical final examination, and 116 students failed the practical final examination. The dataset was divided into two subsets: 369 cases for training and 158 cases for validation.

When grouped according to theoretical examination performance, significant differences were observed between the pass and fail groups in terms of height, class ranking, grade ranking, overall comprehensive assessment score, midterm exam score, assignment score, practical spot-check score, comprehensive skills training score, number of practice sessions, gender, political affiliation, English proficiency level, and high school academic track ($p < 0.05$).

When grouped by practical examination performance, significant differences were found in height, class ranking, grade ranking, overall comprehensive assessment score, midterm exam score, practical spot-check score, comprehensive skills training score, number of practice sessions, gender, and scholarship level ($p < 0.05$) [Tables 1 and 2].

Variable screening and modeling

Screening and modeling for predicting students' practical examination performance in the Fundamentals of Nursing course

In this study, binomial LASSO regression was applied in conjunction with logistic regression to analyze the variables. All 28 variables were subjected to LASSO regression analysis. The nonzero variables at Log Lambda = −2.893 [Figures 1 and 2] were subsequently entered into logistic regression, resulting in the identification of five independent factors associated with failure in the practical examination: height, general test score, sectional test score, comprehensive practical training score, and the number of exercises. All five variables were included in the final modeling process.

LASSO regression was performed prior to logistic regression to select the most informative variables, reduce multicollinearity, and enhance the robustness of the predictive model.

Screening and modeling for predicting students' theoretical examination performance in the Fundamentals of Nursing course

Similarly, binomial LASSO regression combined with logistic regression was applied to analyze the 28 variables

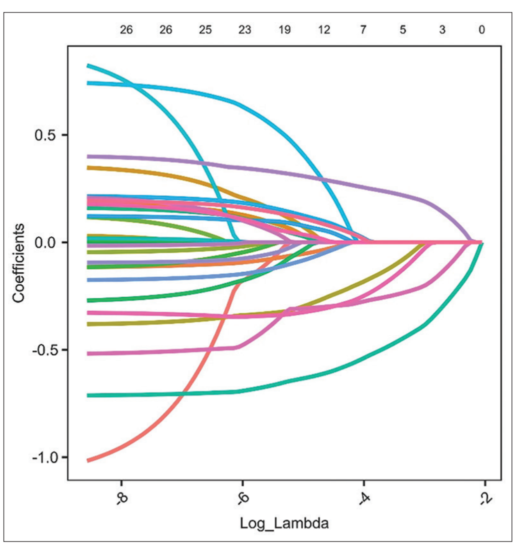

Figure 1: Coefficient path plot for predictive factors of failing practical performance scores

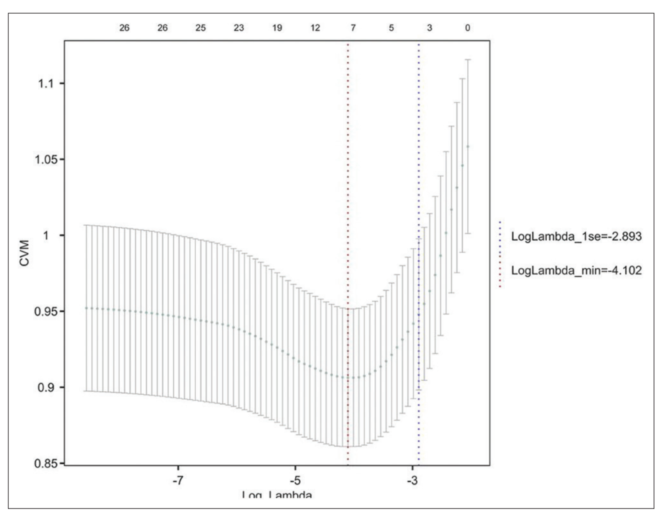

Figure 2: Cross-validation plot for predictive factors of failing practical performance scores

Table 1: Baseline data of student practical performance (*n* [%])/(M [P25, P75])

Variable names	Overall (*n*=527)	Passed practical final exam (*n*=411)	Failed practical final exam (*n*=116)	*p*
Number of university awards	2 (1–4)	2 (1–4)	2 (1–4)	0.057
Number of district awards	0 (0–0)	0 (0–0)	0 (0–0)	0.865
Number of national awards	0 (0–1)	0 (0–1)	0 (0–1)	0.156
Number of awards	3 (1–5)	3 (1–5)	2 (1–5)	0.057
Height (cm)	162 (159–165)	161 (159–165)	164.5 (160–172.25)	<0.001***
Class ranking	38 (20–55)	35 (17.5–52)	51.5 (31–63)	<0.001***
Grade ranking	150 (77.5–221)	134 (66.50–206)	208 (134.50–251.25)	<0.001***
Comprehensive assessment scores (patients)	75.17 (72.185–78.165)	75.67 (72.99–78.89)	72.85 (69.31–75.59)	<0.001***
Entrance exam scores (patients)	466 (457–484)	466 (458–484)	465 (454.75–484.5)	0.515
Scores on periodic exams (patients)	73 (64.5–83)	74.5 (66.5–84)	67.5 (59.88–79.50)	<0.001***
Assignment scores (patients)	89.975 (87.317–92.558)	89.9 (87.48–92.43)	90.5 (86.07–92.83)	0.577
Practical test scores (patients)	86.667 (82.7–89.875)	86.667 (83–90.13)	86.333 (81.85–89.08)	0.023*
Comprehensive practical training scores (patients)	85.167 (82.265–88.25)	85.45 (82.44–88.7)	83.333 (81.40–86.34)	<0.001***
Frequency of practice	12.5 (11–14)	13 (11.50–14.50)	11.5 (10–12.5)	<0.001***
Gender, *n* (%)				
Male	81 (15.37)	44 (10.71)	37 (31.90)	<0.001***
Female	446 (84.63)	367 (89.29)	79 (68.10)	
Political affiliation, *n* (%)				
General public	41 (7.78)	32 (7.79)	9 (7.76)	0.114
Communist Youth League member	409 (77.61)	312 (75.91)	97 (83.62)	
Probationary Party member/Party member	77 (14.61)	67 (16.30)	10 (8.62)	
English proficiency, n (%)				
Not passed	314 (59.58)	237 (57.66)	77 (66.38)	0.166
College English test band 4	194 (36.81)	157 (38.20)	37 (31.90)	
College English test band 6	19 (3.61)	17 (4.14)	2 (1.72)	
Highest award level, *n* (%)				
None	75 (14.23)	57 (13.87)	18 (15.52)	0.740
University-level award	187 (35.48)	142 (34.55)	45 (38.79)	
District-level award	75 (14.23)	60 (14.60)	15 (12.93)	
National-level award	190 (36.05)	152 (36.98)	38 (32.76)	
Computer proficiency, *n* (%)				
None	466 (88.43)	366 (89.05)	100 (86.21)	0.084
Computer level 1	52 (9.87)	36 (8.76)	16 (13.79)	
Computer level 2	9 (1.71)	9 (2.19)	0 (0.00)	
Leadership roles, *n* (%)				
None	91 (17.27)	66 (16.06)	25 (21.55)	0.103
Class position	73 (13.85)	57 (13.87)	16 (13.79)	
Club position	169 (32.07)	126 (30.66)	43 (37.07)	
Both class and club positions	194 (36.81)	162 (39.42)	32 (27.59)	
Work-study status, *n* (%)				
None	496 (94.12)	387 (94.16)	109 (93.97)	1
Work-study program	31 (5.88)	24 (5.84)	7 (6.03)	
Scholarship level, *n* (%)				
None	477 (90.51)	364 (88.56)	113 (97.41)	0.036*
University-level scholarship	27 (5.12)	26 (6.33)	1 (0.86)	
District-level scholarship	2 (0.38)	2 (0.49)	0 (0.00)	
National-level scholarship	21 (3.98)	19 (4.62)	2 (1.72)	
Participation in social practice, *n* (%)				
Met the standard	355 (67.36)	272 (66.18)	83 (71.55)	0.328
Did not meet the standard	172 (32.64)	139 (33.82)	33 (28.45)	
Involvement in research projects, *n* (%)				
Did not participate	437 (82.92)	340 (82.73)	97 (83.62)	0.931
Participated	90 (17.08)	71 (17.27)	19 (16.38)	

Contd...

Table 1: Contd...

Variable names	Overall (n=527)	Passed practical final exam (n=411)	Failed practical final exam (n=116)	p
Ethnicity, n (%)				
Han ethnicity	309 (58.63)	243 (59.12)	66 (56.90)	0.746
Ethnic minorities	218 (41.37)	168 (40.88)	50 (43.10)	
High school academic track, n (%)				
Science and engineering category	335 (63.57)	266 (64.72)	69 (59.48)	0.354
Humanities and social sciences category	192 (36.43)	145 (35.28)	47 (40.52)	

Continuous variables are presented as median (25th percentile, 75th percentile); categorical variables are presented as n (%). p-values were calculated using the Mann–Whitney U test for continuous variables and the Chi-square or Fisher's exact test for categorical variables, as appropriate. *p<0.05, **p<0.01, ***p<0.001

for predicting theoretical performance. The nonzero variables at log Lambda = −2.937 [Figures 3 and 4] were selected for logistic regression analysis, resulting in the identification of six independent factors associated with failure in the theoretical examination: gender, participation in the Undergraduate Innovation and Entrepreneurship Training Program (IETP), high school academic track, height, sectional exam results, and the number of practice sessions. All six variables were included in the final modeling process.

Model evaluation

Evaluation of the model for predicting students' practical exam performance in the Fundamentals of Nursing course

In this study, *five algorithms*—Logit, RF, XGB, ANN, and SVM—were applied to predict students' risk of failing final examination. Model performance was evaluated using ROC curves and AUC values: Logit (AUC = 0.723), RF (AUC = 0.699), XGB (AUC = 0.687), ANN (AUC = 0.698), and SVM (AUC = 0.737) [Figure 5]. According to Delong's test, the AUC of the SVM model was significantly higher than that of XGB model, while no statistical significance was observed among the other models ($p \geq 0.05$).

The AUC reflects the model's ability to distinguish between students who failed and those who passed; a higher AUC indicates better discriminatory performance.

Evaluation of the model for predicting students' theoretical exam performance in the Fundamentals of Nursing course

Similarly, five algorithms—Logit, RF, XGB, ANN, and SVM—were used to predict students' risk of failing the theoretical final examination. Model performance was evaluated using ROC curves and AUC values: Logit (AUC = 0.757), RF (AUC = 0.739), XGB (AUC = 0.833), ANN (AUC = 0.762), and SVM (AUC = 0.645) [Figure 6]. According to Delong's test, the AUC values of the Logit, ANN, and XGB models were significantly higher than that of the SVM model, and the XGB model outperformed the RF model. No statistically significant differences were observed among the remaining models ($p \geq 0.05$).

Discussion

The *Fundamentals of Nursing* course is a core component of nursing education, directly influencing students' acquisition of both theoretical knowledge and practical skills. Accurate prediction of student performance allows educators to identify potential learning difficulties at an early stage and implement personalized interventions, thereby supporting balanced development across cognitive and psychomotor domains. Such efforts not only improve course pass rates but also enhance students' overall professional competence.

In this study, machine learning models were employed to predict undergraduate students' theoretical and practical performance in the *Fundamentals of Nursing* course using a comprehensive set of behavioral and academic variables. The analysis identified several key predictors associated with students' performance outcomes, including general and sectional test scores, comprehensive practical training scores, gender, high school academic track (arts vs. science), participation in major academic projects, frequency of practical sessions, and anthropometric characteristics such as height.

The key factors influencing practical performance in the *Fundamentals of Nursing* course include height, comprehensive assessment scores, sectional exam scores, and the number of comprehensive practical training sessions and hands-on exercises. Interestingly, students with greater height were statistically more likely to face challenges in passing the practical examinations. This finding does not imply an inherent disadvantage associated with height; rather, it may reflect potential ergonomic mismatches between students' physical stature and standardized training environments or equipment configurations.

A significant association was observed between increased height and a higher likelihood of failing the practical examination, with each unit increase in height corresponding to an approximately 1.38-fold increase in risk. This relationship may be influenced by the need for precise postural control and motor coordination during nursing tasks, which can be disrupted when standardized equipment and training environments are not optimally aligned with an individual's body dimensions. Previous studies have noted

Table 2: Baseline data of student theoretical performance, (*n* [%])/(M [P25, P75])

Variable names	Overall (*n*=527)	Passed theoretical final exam (*n*=468)	Failed theoretical final exam (*n*=59)	*p*
Number of university awards	2 (1–4)	2 (1–4)	1 (0.5–4)	0.105
Number of district awards	0 (0–0)	0 (0–0)	0 (0–0)	0.658
Number of national awards	0 (0–1)	0 (0–1)	0 (0–1)	0.84
Number of awards	3 (1–5)	3 (1–5)	3 (1–4)	0.147
Height (cm)	162 (159–165)	161 (159–165)	165 (160–171.50)	<0.001***
Class ranking	38 (20–55)	36 (19–53)	57 (29–71)	<0.001***
Grade ranking	150 (77.5–221)	144 (74.75–210.25)	225 (116.50–282.50)	<0.001***
Comprehensive assessment scores (patients)	75.17 (72.185–78.165)	75.38 (72.60–78.31)	72.96 (69.38–76.31)	<0.001***
Entrance exam scores (patients)	466 (457–484)	466 (457–483.25)	477 (457–489)	0.816
Scores on periodic exams (patients)	73 (64.5–83)	73.5 (65.50–84)	71 (56.50–79.75)	<0.001***
Assignment scores (patients)	89.975 (87.317–92.558)	90 (87.48–92.67)	89.25 (84.417–91.35)	<0.001***
Practical test scores (patients)	86.667 (82.7–89.875)	86.875 (82.93–90.03)	84.55 (81.67–88.28)	0.016*
Comprehensive practical training scores (patients)	85.167 (82.265–88.25)	85.25 (82.31–88.31)	83.8 (82.27–86.78)	0.003**
Frequency of practice (patients)	12.5 (11–14)	13 (11.50–14.50)	11 (9.75–13)	<0.001***
Gender, *n* (%)				
Male	81 (15.37)	56 (11.97)	25 (42.37)	<0.001***
Female	446 (84.63)	412 (88.03)	34 (57.63)	
Political affiliation, *n* (%)				
General public	41 (7.78)	38 (8.12)	3 (5.08)	0.049*
Communist youth league member	409 (77.61)	356 (76.07)	53 (89.83)	
Probationary party member/party member	77 (14.61)	74 (15.81)	3 (5.08)	
English proficiency, *n* (%)				
Not passed	314 (59.58)	270 (57.69)	44 (74.58)	0.027*
College English Test Band 4	194 (36.81)	179 (38.25)	15 (25.42)	
College English Test Band 6	19 (3.61)	19 (4.06)	0 (0.00)	
Highest award level, *n* (%)				
None	75 (14.23)	64 (13.68)	11 (18.64)	0.70
University-level award	187 (35.48)	169 (36.11)	18 (30.51)	
District-level award	75 (14.23)	66 (14.10)	9 (15.25)	
National-level award	190 (36.05)	169 (36.11)	21 (35.59)	
Computer proficiency, *n* (%)				
None	466 (88.43)	418 (89.32)	48 (81.36)	0.153
Computer level 1	52 (9.87)	42 (8.97)	10 (16.95)	
Computer level 2	9 (1.71)	8 (1.71)	1 (1.69)	
Leadership roles, *n* (%)				
None	91 (17.27)	81 (17.31)	10 (16.95)	0.727
Class position	73 (13.85)	62 (13.25)	11 (18.64)	
Club position	169 (32.07)	151 (32.26)	18 (30.51)	
Both class and club positions	194 (36.81)	174 (37.18)	20 (33.90)	
Work-study status, *n* (%)				
None	496 (94.12)	439 (93.80)	57 (96.61)	0.569
Work-study program	31 (5.88)	29 (6.20)	2 (3.39)	
Scholarship level, *n* (%)				
None	477 (90.51)	420 (89.74)	57 (96.61)	0.313
University-level scholarship	27 (5.12)	25 (5.34)	2 (3.39)	
District-level scholarship	2 (0.38)	2 (0.43)	0 (0.00)	
National-level scholarship	21 (3.98)	21 (4.49)	0 (0.00)	
Participation in social practice, *n* (%)				
Met the standard	355 (67.36)	317 (67.74)	38 (64.41)	0.714
Did not meet the standard	172 (32.64)	151 (32.26)	21 (35.59)	
Involvement in research projects, *n* (%)				
Did not participate	437 (82.92)	393 (83.97)	44 (74.58)	0.104
Participated	90 (17.08)	75 (16.03)	15 (25.42)	

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Table 2: Contd...

Variable names	Overall (*n*=527)	Passed theoretical final exam (*n*=468)	Failed theoretical final exam (*n*=59)	*p*
Ethnicity, *n* (%)				
Han ethnicity	309 (58.63)	276 (58.97)	33 (55.93)	0.759
Ethnic minorities	218 (41.37)	192 (41.03)	26 (44.07)	
High school academic track, *n* (%)				
Science and engineering category	335 (63.57)	305 (65.17)	30 (50.85)	0.044*
Humanities and social sciences category	192 (36.43)	163 (34.83)	29 (49.15)	

Continuous variables are presented as median (25th percentile, 75th percentile); categorical variables are presented as *n* (%). *p*-values were calculated using the Mann–Whitney *U*-test for continuous variables and the Cchi-square or Fisher's exact test for categorical variables, as appropriate. *$p<0.05$, **$p<0.01$, ***$p<0.001$

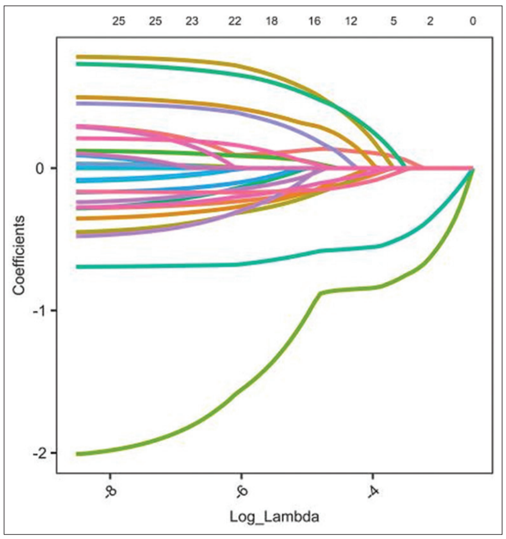

Figure 3: Coefficient path plot for predictive factors of failing theoretical performance scores

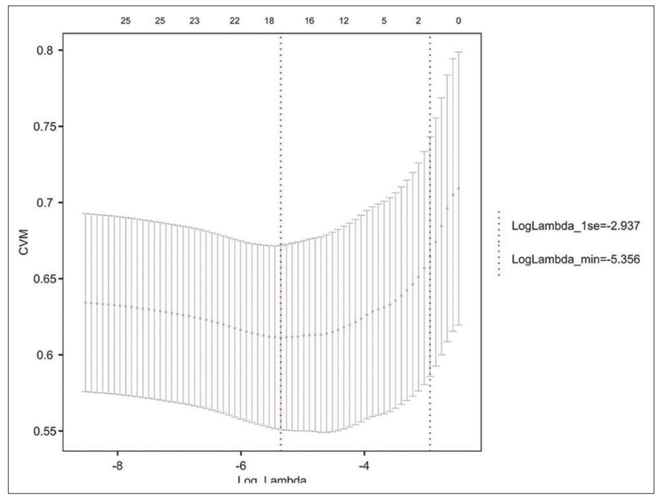

Figure 4: Cross-validation plot for predictive factors of failing theoretical performance scores

that individuals with taller stature may require more frequent postural adjustments when interacting with standardized equipment—such as fixed-height beds or tables—potentially resulting in awkward positioning or decreased task fluidity. This is consistent with findings that nursing students often lack ergonomic awareness and report increased musculoskeletal discomfort, which may impair performance under physically constrained training conditions.[13] Similarly, research on nurses performance manual patient handling tasks has demonstrated that suboptimal working postures significantly elevate physical strain.[14] In addition, anthropometric mismatches between student body dimensions and fixed laboratory furniture have been associated with decreased comfort and potential declines in task performance.[15]

A significant negative correlation was observed between sectional exam scores and the likelihood of failing the practical examination. Students with higher sectional exam scores were less likely to fail, with each unit increase in score associated with approximately 27.8% (odds ratio [OR] = 0.72). This finding suggests that performance on sectional exams may partially reflect students' understanding of theoretical concepts, particularly those that underpin essential nursing procedures. As the *Fundamentals of Nursing* course encompasses numerous details protocols and key steps related to clinical practice, mastery of the underlying theory may directly contribute to improved practical performance.

Students with higher academic achievement often demonstrate stronger self-discipline, achieve better learning outcomes, and gain greater satisfaction and a sense of accomplishment in their studies. In contrast, students with lower grades may feel frustration and reduced self-esteem when their exam results are unsatisfactory, which can undermine their confidence in independent learning.[16] As a result, those with higher sectional exam scores are generally better equipped to succeed in practical tasks as they are more proficient in applying theoretical knowledge to hands-on scenarios, thereby reducing their risk of failure.

Additionally, a significant negative correlation was found between participation in integrated practical training and the likelihood of failing the practical examination. Participation in such training was associated with an approximately 33.2% reduction in failure risk, highlighting its critical role in strengthening students' practical competencies. During integrated training sessions, students are required to carry out the entire nursing process--, from patient admission to monitoring changes in condition and eventual discharge.

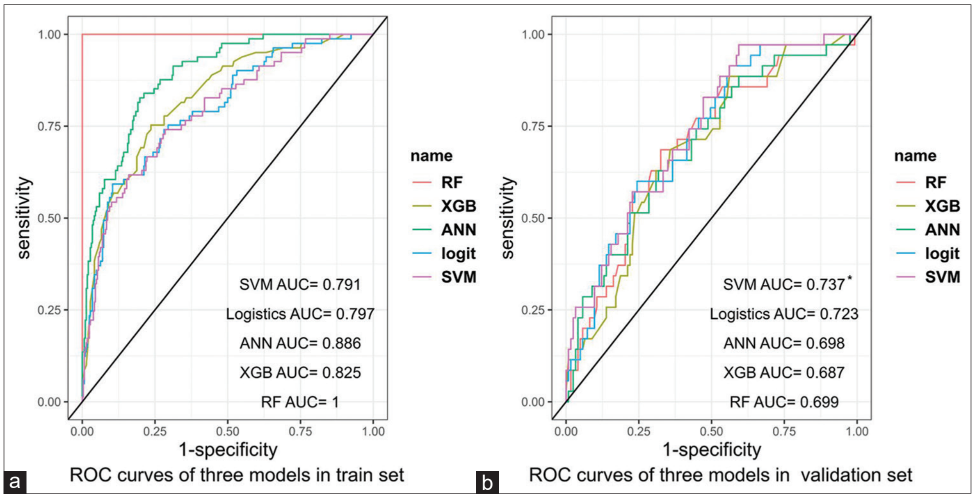

Figure 5: ROC curve for predicting failing practical performance scores. (a) Training set; (b) Validation set. *$p < 0.05$, based on DeLong`s test for pairwise AUC comparison (SVM vs. XGB). No significant differences among the remaining models. SVM = Support Vector Machine, XGB = XGBoost, AUC = Area under the curve, ROC = Receiver operating characteristic

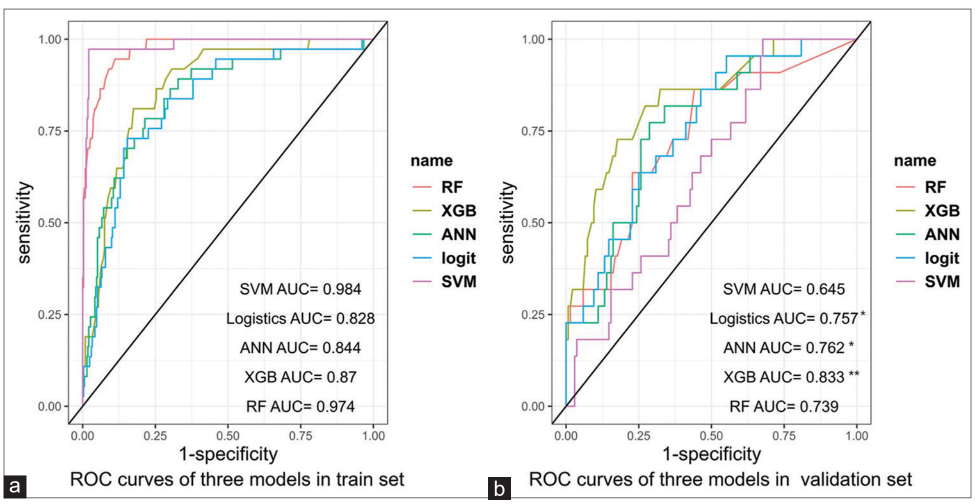

Figure 6: ROC curve for predicting failing theoretical performance scores. (a) Training set; (b) Validation set. $p < 0.05$, $p < 0.01$ based on DeLong`s test for pairwise AUC comparison. Significant differences were observed for XGB versus SVM (**), ANN versus SVM (*), Logit versus SVM (*). SVM = Support Vector Machine, ANN = Artificial Neural Network, XGB = XGBoost, AUC = Area under the curve, ROC = Receiver operating characteristic

This comprehensive, hands-on experience fosters the development of procedural fluency and critical thinking, thereby enhancing practical performance and reducing the probability of failure in skill-based assessments.

The number of practical exercises was significantly and negatively associated with the likelihood of failing the practical examination. The more practice sessions students completed, the lower their risk of failure. Repetitive practice is a well-established method for enhancing students' mastery of nursing skills. Through frequent hands-on training, students can improve their technical proficiency, refine hand–eye coordination, and build confidence—factors that collectively help reduce errors and improve overall performance.[17,18] Therefore, increasing the frequency of practical exercises is essential for improving practical outcomes. It is recommended that nursing programs incorporate more opportunities for hands-on practice into the curriculum to provide students with sufficient experiential learning.

These findings underscore the importance of students' holistic development—encompassing theoretical knowledge, practical experience, and physical adaptability—in enhancing performance on practical examinations. Increasing the frequency of practice sessions and participation in comprehensive practical training can substantially reduce the likelihood of failure in skill-based assessments. Collectively, the results emphasize the need to reinforce theoretical foundations, optimize ergonomic conditions, and expand access to targeted hands-on practice and integrated training opportunities to improve students'overall practical performance.

Gender, participation in the IETP, high school academic track (arts vs. sciences), height, sectional exam scores, and the number of practical exercises were all significantly associated with students' theoretical performance. Variables with negative regression coefficients, such as female gender, greater height, higher sectional exam scores, and a greater number of practical exercises, served as protective factors, reducing the likelihood of failure. In contrast, variables with positive coefficients, such as participation in the IETP and a liberal arts academic background, were associated with an increased risk of failing the theoretical examination.

The observed impact of gender on theoretical performance may be attributed to differences in learning styles and subject preferences. The results indicated that female students were significantly less likely to fail the theoretical examination, with an odds ratio of 0.114, representing an approximately 88.6% reduction in failure risk compared to male students. Prior research suggests that female learners often demonstrate an academic advantage, particularly in domains involving language processing, attention to detail, and self-regulated learning strategies. Additionally, female students are also more likely to engage in social support networks and adopt relationship-oriented learning approaches, which may contribute to their success in theoretical coursework. In contrast, male students tend to rely more on individualistic strategies and reported to perform slightly lower in theoretical domains.[19,20]

These findings underscore the presence of gender-related differences in theoretical performance, suggesting that educators should consider providing gender-sensitive learning resources and targeted academic support to address specific areas of vulnerability and enhance overall student outcomes.

Students who participated in the IETP were more likely to fail the theoretical examination, with an odds ratio of 2.27—indicating that their risk of failure was more than twice that of nonparticipants. This association may be attributed to the increased time and cognitive resources devoted to research and practical activities within the IETP, which could detract from students' engagement with theoretical coursework. Previous studies have shown that involvement in extracurricular initiatives may lead students to prioritize these activities over academic responsibilities or struggle with time management, ultimately resulting in reduced academic performance.[21,22]

Additionally, height, sectional exam performance, and the number of practice sessions were identified as protective factors for theoretical performance. Height was negatively associated with the likelihood of failing the theoretical examination, with each unit increase in height corresponding to a reduced probability of failure (OR = 0.594). Although this association does not imply causality, it is possible that individuals with taller stature may experience indirect academic advantages—such as physical presence or enhanced self-confidence during class participation—which have been linked to stronger academic engagement. Active classroom involvement and self-assurance, potentially supported by physical presence or communication style, may promote more frequent interaction with instructors, thereby contributing to a deeper understanding of theoretical content and improved academic outcomes.[23,24]

Furthermore, stronger performance in sectional examinations was associated with a reduced risk of failing the final theoretical exam, indicating that sectional scores may serve as a reliable predictor of overall academic success. Regular quizzes and midterm assessments play a critical role in enhancing students' learning outcomes and final exam performance. Frequent, low-stakes testing has been shown to promote more effective content review, support the retention of knowledge, and encourage timely adjustments in learning strategies—all of which contribute to improved academic achievement.[25-27]

Increasing the number of practical exercises was negatively correlated with the risk of failure, indicating that greater hands-on engagement significantly reduces the likelihood of students failing the practical exam. Practical exercises not only strengthen students' technical proficiency but also facilitate the application of theoretical knowledge, thereby reinforcing conceptual understanding. Existing studies have demonstrated interdependence between theoretical learning and practical training, suggesting that increased engagement in hands-on activities enhances retention and deepens comprehension of theoretical content.[28,29] Additionally, students who perform well in theoretical coursework often excel in practical tasks as they are better equipped to translate academic knowledge into clinical competencies.[30] These findings offer several actionable implications for curriculum design and instructional strategy: First, integrating regular sectional assessments into the course framework can provide timely academic feedback, enabling both students and instructors to adjust learning strategies and teaching approaches accordingly. Second, expanding the frequency and accessibility of practice sessions—particularly those that explicitly link theoretical content to practical skills—can support deeper learning and improved academic outcomes. Third, greater attention should be paid to optimizing the physical and psychosocial learning environments, especially in laboratory-based settings, to promote inclusivity and reduce ergonomic or emotional barriers to learning. Finally, gender-responsive pedagogical approaches and balanced workload distribution, particulary in project-based programs such as IETP, should be considered to accommodate diverse learning needs. Embedding these pedagogical elements into nursing curriculum may enable early identification of at-risk students, foster personalized learning, and ultimately enhance both theoretical and practical competencies.

Although this study identified several factors significantly associated with students' performance in the *Fundamentals* *of Nursing* course, it is not without limitations. Given that the data were obtained from historical academic records, the types and scope of available variables were limited by the original intent of data collection. As a result, certain potentially influential factors—such as learning motivation, classroom engagement, or psychosocial stressors—could not be assessed due to their subjective nature and the absence of systematic documentation.

Moreover, the data were not originally collected for predictive modeling purposes. Missing information on key covariates—such as instructor evaluation criteria and variability in practical training environments—may have influenced the accuracy, generalizability, and interpretability of the models. Future research should consider diversifying data sources, enriching the variable framework to include both objective and subjective measures, and conducting multicenter validation studies to improve the robustness, external validity, and practical utility of predictive modeling in nursing education.

This study has several limitations. First, the data were collected retrospectively from a single institution, which may limit the generalizability of the findings to other nursing programs or educational settings. Second, although the study included a wide range of student characteristics and behavioral indicators, some potentially influential factors—such as psychological status, learning motivation, or teaching style—were not captured due to data unavailability. Third, the behavioral data were limited to those recorded within the institutional system and may not fully reflect informal or unstructured learning activities. Fourth, the model's predictive performance, although acceptable, was not externally validated with independent cohorts, which restricts its applicability beyond the current sample. Future research should consider multicenter prospective designs and incorporate additional behavioral, psychological, and contextual factors to improve the model's robustness and external validity.

Conclusion

This study revealed that student performance in the *Fundamentals of Nursing* course is shaped by multiple factors. Practical performance was negatively associated with height, whereas theoretical knowledge, hands-on training, and the frequency of practice were positively correlated with improved practical outcomes. In contrast, theoretical performance was influenced by gender, academic background, and the extent of engagement in practical activities. These findings highlight the need for differentiated instructional strategies that account for individual learner characteristics, alongside an integration approach that bridges theoretical instruction with practical application; to enhance educational effectiveness, nursing curricula should also support students in balancing academic demands with research commitments. Moving forward, curriculum development should prioritize inclusive learning environments, flexible and adaptive assessment frameworks, and data-driven early warning systems capable of identifying at-risk students and delivering personalized support. Embedding predictive mechanisms into the educational process may enable more proactive, evidence-informed reforms, ultimately advancing the quality, equity, and responsiveness of nursing education and workforce preparation.

Acknowledgments

The authors would like to express their sincere gratitude to all undergraduate nursing students and faculty members who participated in and supported this study. Special thanks go to the research team members for their contributions to data collection, organization, and analysis. (Grant No. 2023JGA215 and 2024JGA227) and the Guangxi University of Chinese Medicine Education and Teaching Reform Research Project (Grant No. 2024A012 and 2024B020).

Financial support and sponsorship

Guangxi Higher Education Undergraduate Teaching Reform Project

Conflicts of interest

Nothing to declare.

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