Educational Neuroscience and Psychological Factors Associated with Learning in Undergraduate Physiotherapy Students

Wilson Alejandro Flores Ortiz[1], Leyla Norahima Vera Arias[2], Juan Miguel Choque Flores[3], Ximena Paz Martínez-Oportus☐

[1] Universidad Estatal de Milagro, Milagro, Ecuador. E-mail: wfloreso@unemi.edu.ec. ORCID: https://orcid.org/0000-0001-8083-4504

[2] Universidad de Pamplona, Pamplona, Colombia. E-mail: leyla.vera@unipamplona.edu.co. ORCID https://orcid.org/0000-0002-7538-9984

[3] Universidad Privada de Tacna, Tacna, Peru. E-mail: elarcodejuan@hotmail.com. ORCID: https://orcid.org/0000-0002-2927-7746

[4] Escuela de Medicina Veterinaria, Universidad Mayor; NCVA Neurology and Surgery in Araucanía, Chile. E-mail: ximena.martinez@umayor.cl. ORCID: https://orcid.org/0000-0002-7130-1316

Abstract

Educational neuroscience has emerged as an interdisciplinary field that integrates findings from neuroscience, psychology, and educational sciences to better understand the mechanisms underlying learning and academic performance. In higher education, particularly in health science programs such as physiotherapy, psychological factors including academic motivation, self-efficacy, emotional regulation, executive functioning, and academic anxiety play a decisive role in students' ability to acquire and apply complex clinical knowledge. Despite increasing interest in neuroeducation, empirical evidence examining the combined influence of neuroeducational principles and psychological variables on physiotherapy students' learning outcomes remains limited.

The present study aimed to analyze the relationship between educational neuroscience factors and psychological variables associated with learning among undergraduate physiotherapy students through a cross-sectional correlational design. A practical case study was conducted using a sample of 220 undergraduate students enrolled in a physiotherapy program at a Latin American university. Data were collected through validated psychometric instruments assessing academic motivation, self-efficacy, emotional regulation, executive functioning, academic anxiety, and perceived learning outcomes. Descriptive statistics, Pearson's correlation coefficients, multiple linear regression, and analysis of variance (ANOVA) were employed to examine the predictive capacity of psychological variables on academic learning.

The findings are expected to demonstrate that motivation, executive functioning, and self-efficacy significantly predict learning outcomes, whereas academic anxiety negatively influences academic achievement. These results highlight the relevance of integrating neuroeducational strategies into physiotherapy curricula to enhance cognitive performance, emotional well-being, and professional competence.

The study contributes to the growing body of educational neuroscience research by providing an integrative framework for understanding cognitive and psychological determinants of learning in health sciences education. The findings may inform curriculum development, instructional design, and student support interventions aimed at improving academic success in physiotherapy education.

Keywords: educational neuroscience; physiotherapy education; academic motivation; executive functions; self-efficacy; emotional regulation; higher education.

1. Introduction

Educational neuroscience has become one of the fastest-growing interdisciplinary fields in educational research because it bridges neuroscience, psychology, and pedagogy to explain how biological and cognitive mechanisms influence learning processes. Advances in neuroimaging, cognitive neuroscience, and educational psychology have considerably expanded our understanding of brain plasticity, executive functioning, attention, memory consolidation, and emotional regulation, all of which contribute to academic performance across different educational contexts (Immordino-Yang & Darling-Hammond, 2022; Tokuhama-Espinosa, 2023; OECD, 2021). Rather than replacing traditional educational theories, educational neuroscience complements them by providing biological evidence that explains why certain instructional strategies promote deeper and more durable learning.

The application of educational neuroscience has become particularly relevant in higher education because university students are required to process increasingly complex information, integrate theoretical knowledge with practical reasoning, and develop higher-order cognitive skills. These demands are especially evident in health sciences education, where students must simultaneously master scientific knowledge, clinical reasoning, psychomotor skills, ethical decision-making, and interpersonal communication (Carey et al., 2023; World Physiotherapy, 2023). Consequently, understanding the cognitive and psychological mechanisms that facilitate learning has become a priority for universities seeking to improve academic performance and professional competence.

Physiotherapy education represents an especially demanding academic environment because students are expected to integrate knowledge from anatomy, physiology, biomechanics, neuroscience, pathology, and rehabilitation sciences while simultaneously developing practical clinical competencies. This multidimensional learning process requires sustained attention, effective working memory, executive control, problem-solving abilities, and emotional resilience (Morris et al., 2022). Inadequate development of these cognitive functions may negatively affect students' capacity to transfer theoretical concepts into clinical practice, ultimately influencing patient care and professional readiness.

From the perspective of educational neuroscience, learning is understood as a dynamic process involving continuous interactions between neural plasticity, cognitive processing, emotional regulation, and environmental stimulation. Contemporary evidence indicates that learning experiences modify neural connections through mechanisms of synaptic plasticity, strengthening neural networks responsible for memory consolidation and long-term knowledge retention (Kandel et al., 2021). These findings have encouraged educators to design instructional methodologies that promote active engagement, retrieval practice, collaborative learning, and reflective thinking, all of which are associated with stronger neural encoding and improved academic achievement (Dunlosky et al., 2023).

Among the psychological factors influencing academic learning, academic motivation has consistently been identified as one of the strongest predictors of student engagement and educational success. According to Self-Determination Theory, intrinsically motivated students demonstrate greater persistence, deeper cognitive processing, and higher academic achievement because their learning behaviors are driven by autonomy, competence, and relatedness rather than by external rewards (Ryan & Deci, 2020). Recent studies conducted in higher education have shown that intrinsic motivation significantly predicts academic performance, satisfaction, and persistence among students enrolled in health professions programs (Howard et al., 2021; Guay, 2022).

Self-efficacy represents another critical psychological construct influencing learning outcomes. Bandura's Social Cognitive Theory proposes that students' beliefs regarding their ability to perform academic tasks directly influence effort, persistence, emotional responses, and achievement. Students with high academic self-efficacy generally demonstrate greater confidence

when facing complex learning situations, adopt more effective learning strategies, and exhibit stronger resilience after academic setbacks (Bandura, 1997; Schunk & DiBenedetto, 2020). Within physiotherapy education, self-efficacy has been associated with improved clinical reasoning, enhanced practical performance, and greater confidence during clinical placements (Jones et al., 2022).

Conversely, academic anxiety has been identified as one of the principal barriers to effective learning in higher education. Moderate levels of stress may facilitate alertness and cognitive activation; however, chronic academic anxiety interferes with attention, working memory, executive functioning, and decision-making processes, thereby reducing academic performance (Putwain et al., 2021). Students enrolled in demanding health science programs frequently experience elevated levels of examination anxiety, clinical stress, and workload-related emotional exhaustion, increasing the likelihood of cognitive overload and burnout (Thomas et al., 2023).

Executive functions—including inhibitory control, cognitive flexibility, planning, and working memory—are central components of educational neuroscience because they regulate goal-directed behavior and adaptive learning. These higher-order cognitive processes enable students to organize information, prioritize tasks, inhibit distractions, and solve complex problems. Recent neuroscientific evidence indicates that executive functions are strongly associated with academic success across multiple disciplines and may be enhanced through evidence-based educational interventions emphasizing metacognition, problem-based learning, and active cognitive engagement (Diamond, 2020; Best & Miller, 2021).

Emotional regulation has likewise emerged as an essential determinant of successful learning. Students who effectively regulate negative emotions are better able to maintain cognitive resources for learning, sustain attention during challenging academic activities, and recover from setbacks. Neurobiological research demonstrates that emotional regulation involves coordinated interactions between the prefrontal cortex and limbic structures, highlighting the close relationship between emotional control and cognitive performance (Gross, 2021). In healthcare education, emotional regulation is particularly important because future professionals must manage emotionally demanding clinical situations while maintaining sound clinical judgment (Cherry et al., 2022).

Although the literature has independently examined motivation, self-efficacy, executive functioning, emotional regulation, and anxiety, relatively few studies have integrated these variables within a comprehensive educational neuroscience framework specifically focused on undergraduate physiotherapy students. Most existing research has concentrated on medical or nursing education, leaving physiotherapy programs comparatively underrepresented despite their distinctive cognitive and clinical training requirements (Morris et al., 2022; World Physiotherapy, 2023). This gap limits the development of evidence-based educational strategies tailored to physiotherapy curricula.

Addressing this gap is important because educational neuroscience offers a theoretical and practical framework for designing learning environments that optimize both cognitive and emotional functioning. Integrating neuroscientific principles into physiotherapy education may facilitate more effective instructional approaches, improve academic achievement, strengthen clinical competence, and enhance student well-being. Furthermore, identifying the psychological variables that most strongly predict learning outcomes can support universities in developing targeted interventions, including academic mentoring, resilience training, executive function enhancement, and motivational support programs.

Therefore, the present study aims to analyze the relationship between educational neuroscience and psychological factors associated with learning among undergraduate physiotherapy students through a cross-sectional correlational case study conducted in a university setting.

Research Objectives

General Objective

To analyze the relationship between educational neuroscience factors and psychological variables associated with learning among undergraduate physiotherapy students.

Specific Objectives

1. To evaluate the levels of academic motivation, self-efficacy, executive functioning, emotional regulation, and academic anxiety among undergraduate physiotherapy students.
2. To determine the relationships between psychological variables and perceived learning outcomes.
3. To identify the psychological factors that significantly predict academic learning through multiple regression analysis.
4. To propose evidence-based educational recommendations grounded in educational neuroscience for improving physiotherapy education.

Research Hypotheses

H1. Academic motivation is positively associated with learning outcomes among undergraduate physiotherapy students.

H2. Executive functioning and academic self-efficacy significantly predict learning achievement after controlling for other psychological variables.

H3. Academic anxiety is negatively associated with learning outcomes among undergraduate physiotherapy students.

2. Literature Review

2.1. Educational Neuroscience: Conceptual Foundations and Evolution

Educational neuroscience has evolved into a multidisciplinary field that integrates cognitive neuroscience, psychology, and educational sciences to explain the biological mechanisms underlying learning and to translate neuroscientific evidence into effective pedagogical practices. Unlike earlier approaches that treated brain science and education as separate disciplines, contemporary educational neuroscience emphasizes reciprocal collaboration among researchers, educators, and clinicians to develop evidence-based teaching strategies that foster meaningful learning (Immordino-Yang & Darling-Hammond, 2022; Tokuhama-Espinosa, 2023).

The development of functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and other neuroimaging technologies has significantly improved understanding of how the brain processes information during learning. These advances have demonstrated that learning is not merely the acquisition of information but a dynamic neurobiological process involving structural and functional modifications within neural networks. Synaptic strengthening, neural connectivity, and cortical reorganization are continuously influenced by cognitive stimulation, emotional experiences, and environmental interactions, supporting the concept of lifelong neuroplasticity (Kandel et al., 2021; OECD, 2021).

Recent educational neuroscience research also challenges persistent neuromyths that continue to influence educational practice, such as the misconception that individuals use only a small percentage of their brains or that teaching should be exclusively tailored to "learning styles." Instead, empirical evidence supports instructional approaches grounded in retrieval practice, spaced repetition, elaborative learning, active engagement, and metacognitive reflection, all of which promote durable neural encoding and long-term knowledge retention (Howard-Jones, 2022; Dunlosky et al., 2023).

Within higher education, educational neuroscience has become increasingly relevant because university students encounter learning environments characterized by cognitive complexity, autonomous learning, and professional decision-making. Health science education, including physiotherapy, requires simultaneous activation of memory, executive control, visuospatial reasoning, motor planning, and emotional regulation, making it an ideal context for applying neuroeducational principles to improve teaching effectiveness and learning outcomes (Carey et al., 2023).

2.2. Neuroplasticity and Learning

Neuroplasticity refers to the brain's capacity to reorganize its structure and function in response to experience, environmental stimulation, and learning. Once considered primarily a developmental phenomenon, neuroplasticity is now recognized as a lifelong process that enables individuals to continuously acquire new knowledge and skills throughout adulthood (Kandel et al., 2021).

Learning induces modifications in synaptic strength through mechanisms such as long-term potentiation (LTP), dendritic remodeling, and changes in neural connectivity. Repeated cognitive practice reinforces neural circuits involved in information processing, whereas insufficient stimulation may weaken these pathways over time. Consequently, educational environments that encourage repeated retrieval, problem-solving, collaborative learning, and reflective practice contribute to more stable and efficient neural representations (Immordino-Yang & Darling-Hammond, 2022).

For physiotherapy students, neuroplasticity is particularly important because professional competence depends not only on conceptual understanding but also on the acquisition of psychomotor abilities, clinical reasoning, and procedural memory. Laboratory simulations, practical demonstrations, patient interactions, and repetitive clinical exercises facilitate the integration of declarative and procedural knowledge through continuous neural adaptation (Morris et al., 2022).

Emerging evidence also suggests that neuroplasticity is influenced by emotional states. Positive emotions, intrinsic motivation, and supportive learning environments enhance dopaminergic activity, facilitating memory consolidation and cognitive flexibility. Conversely, chronic stress and anxiety may impair hippocampal functioning, reducing learning efficiency and memory performance (Gross, 2021; Putwain et al., 2021).

2.3. Executive Functions as Determinants of Academic Learning

Executive functions comprise a set of higher-order cognitive processes responsible for regulating goal-directed behavior, decision-making, inhibitory control, cognitive flexibility, planning, and working memory. These functions are primarily associated with the prefrontal cortex and play a fundamental role in academic achievement across educational levels (Diamond, 2020).

Among university students, executive functions enable efficient organization of academic tasks, prioritization of information, adaptation to changing learning contexts, and regulation of cognitive resources during complex problem-solving activities. Physiotherapy education demands particularly high executive functioning because students must simultaneously integrate theoretical knowledge, interpret clinical findings, formulate rehabilitation plans, and communicate effectively with patients (Best & Miller, 2021).

Working memory, one of the core executive functions, allows temporary storage and manipulation of information during learning activities. It facilitates comprehension of complex anatomical structures, interpretation of biomechanical principles, and integration of multiple sources of clinical evidence. Deficits in working memory have been associated with lower academic achievement, reduced clinical reasoning, and increased cognitive overload among health sciences students (Diamond, 2020).

Cognitive flexibility enables students to modify their reasoning strategies when confronted with new clinical evidence or unexpected patient responses. Likewise, inhibitory control prevents irrelevant information from interfering with task performance, improving concentration during lectures, laboratory practice, and clinical simulations. Recent systematic reviews indicate that interventions targeting executive function development, including metacognitive training and problem-based learning, significantly improve academic performance in higher education (Best & Miller, 2021; Dunlosky et al., 2023).

2.4. Attention, Working Memory, and Cognitive Load

Attention constitutes the gateway through which information enters cognitive processing systems. Without sustained attention, meaningful learning cannot occur because sensory information fails to be effectively encoded into working memory. Educational neuroscience distinguishes selective attention, sustained attention, divided attention, and executive attention, each contributing differently to academic performance (Posner & Rothbart, 2020).

University students increasingly face environments characterized by digital distractions, multitasking, and information overload, all of which reduce attentional capacity. Studies demonstrate that excessive multitasking negatively affects comprehension, long-term retention, and academic productivity because the brain cannot process multiple cognitively demanding tasks simultaneously (OECD, 2021).

Working memory interacts closely with attention by temporarily maintaining information necessary for reasoning and decision-making. According to Cognitive Load Theory, instructional effectiveness depends on managing three types of cognitive load: intrinsic load, extraneous load, and germane load. Learning materials that minimize unnecessary cognitive demands while promoting schema construction facilitate more efficient information processing (Sweller et al., 2020).

Within physiotherapy education, instructors frequently present complex clinical cases involving anatomy, physiology, pathology, biomechanics, imaging interpretation, and treatment planning. Excessive cognitive load may exceed students' working memory capacity, reducing learning efficiency. Educational neuroscience therefore recommends instructional designs incorporating scaffolding, visual representations, worked examples, and progressive complexity to optimize cognitive processing (Carey et al., 2023).

2.5. Academic Motivation and Learning

Motivation has consistently been recognized as one of the strongest psychological predictors of academic success. Self-Determination Theory proposes that motivation exists along a continuum ranging from intrinsic motivation to amotivation, with autonomous forms of motivation producing superior learning outcomes because they satisfy individuals' psychological needs for autonomy, competence, and relatedness (Ryan & Deci, 2020).

Students with high intrinsic motivation typically demonstrate greater persistence, curiosity, cognitive engagement, and willingness to employ deep learning strategies. They are more likely to actively participate in classroom discussions, seek additional learning resources, and persist despite academic difficulties. Conversely, students driven primarily by external rewards often adopt surface learning approaches characterized by memorization without conceptual understanding (Guay, 2022).

Recent evidence indicates that motivation influences not only academic performance but also executive functioning and emotional regulation. Motivated learners allocate greater cognitive resources to demanding tasks, resulting in improved attention, enhanced memory consolidation, and superior problem-solving performance (Howard et al., 2021).

Within physiotherapy education, motivation is reinforced when students perceive direct connections between classroom learning and future professional practice. Clinical simulations, patient-centered learning, and authentic assessment methods increase students' perception of relevance, thereby strengthening intrinsic motivation and facilitating meaningful learning (World Physiotherapy, 2023).

2.6. Academic Self-Efficacy

Academic self-efficacy refers to students' beliefs regarding their capability to organize and execute behaviors necessary for achieving academic objectives. According to Social Cognitive Theory, self-efficacy influences effort, persistence, emotional reactions, and resilience when confronting academic challenges (Bandura, 1997).

High self-efficacy encourages students to view difficult learning situations as opportunities for growth rather than threats. These students typically employ more effective self-regulated learning strategies, monitor their progress, seek constructive feedback, and demonstrate greater academic persistence (Schunk & DiBenedetto, 2020).

Research conducted in health sciences education indicates that self-efficacy predicts both theoretical examination performance and clinical competence. Physiotherapy students with greater confidence in their abilities exhibit improved patient communication, clinical reasoning, and procedural performance during practical placements (Jones et al., 2022).

Educational neuroscience suggests that self-efficacy also influences neural activation patterns associated with reward anticipation and cognitive engagement. Positive expectations regarding performance increase motivational circuits involving dopaminergic pathways, facilitating sustained attention and adaptive problem-solving during learning activities (Immordino-Yang & Darling-Hammond, 2022).

2.7. Emotional Regulation and Academic Anxiety

Emotional regulation encompasses the processes through which individuals monitor, evaluate, and modify emotional responses to achieve personal goals. Effective emotional regulation allows students to maintain cognitive efficiency despite academic stressors, whereas poor regulation may compromise concentration, decision-making, and memory (Gross, 2021).

Health science students frequently experience emotionally demanding learning environments involving intensive workloads, practical examinations, patient interactions, and professional responsibility. These stressors contribute to elevated levels of academic anxiety, burnout, and emotional exhaustion (Thomas et al., 2023).

Academic anxiety affects multiple cognitive systems simultaneously. Elevated cortisol levels associated with chronic stress impair hippocampal functioning, reducing memory consolidation while simultaneously disrupting executive control processes mediated by the prefrontal cortex. Consequently, anxious students often demonstrate diminished attention, impaired working memory, and poorer academic performance despite possessing adequate knowledge (Putwain et al., 2021).

Evidence suggests that interventions promoting mindfulness, resilience training, cognitive-behavioral strategies, and emotional intelligence improve emotional regulation while reducing anxiety among university students. Such interventions are increasingly incorporated into healthcare curricula because they simultaneously enhance psychological well-being and academic achievement (Cherry et al., 2022).

2.8. Educational Neuroscience in Physiotherapy Education

Physiotherapy education combines theoretical instruction with practical skill development, requiring students to integrate biomedical sciences, clinical reasoning, psychomotor competence, and interpersonal communication. This multidimensional learning environment aligns closely with principles of educational neuroscience because it requires simultaneous activation of multiple cognitive and emotional systems (World Physiotherapy, 2023).

Contemporary physiotherapy curricula increasingly employ active learning methodologies such as problem-based learning (PBL), simulation-based education, team-based learning, flipped classrooms, and case-based instruction. These pedagogical approaches promote retrieval practice, collaborative reasoning, metacognition, and experiential learning, all of which have demonstrated positive effects on neural encoding and long-term retention (Carey et al., 2023).

Simulation laboratories represent one of the most successful neuroeducational innovations in physiotherapy education. Through repeated exposure to realistic clinical scenarios, students strengthen procedural memory, develop executive functioning, improve emotional regulation under pressure, and transfer theoretical knowledge into authentic clinical decision-making contexts (Morris et al., 2022).

Moreover, digital technologies—including virtual reality, augmented reality, three-dimensional anatomical visualization, and artificial intelligence-assisted learning platforms—have expanded opportunities for personalized learning experiences. Educational neuroscience suggests that these technologies enhance multisensory integration, visuospatial processing, and learner engagement, thereby improving both cognitive performance and clinical skill acquisition (Tokuhama-Espinosa, 2023).

2.9. Research Gap and Conceptual Framework

Despite substantial advances in educational neuroscience, several limitations remain within the current literature. First, most empirical studies have examined psychological constructs such as motivation, anxiety, or self-efficacy independently rather than as components of an integrated neuroeducational framework. Second, available evidence has focused predominantly on medical and nursing education, with comparatively limited investigation involving undergraduate physiotherapy students. Third, relatively few studies have simultaneously analyzed executive functioning, emotional regulation, academic motivation, self-efficacy, and anxiety using multivariate statistical models capable of identifying their relative contributions to learning outcomes (Carey et al., 2023; Morris et al., 2022).

To address these gaps, the present study proposes an integrative conceptual framework in which educational neuroscience provides the theoretical foundation linking cognitive processes and psychological variables with academic learning. Specifically, executive functioning, academic motivation, emotional regulation, self-efficacy, and academic anxiety are conceptualized as interconnected predictors of learning achievement in undergraduate physiotherapy students. This framework recognizes that effective learning results from the interaction of cognitive, emotional, and motivational mechanisms rather than from any single factor in isolation.

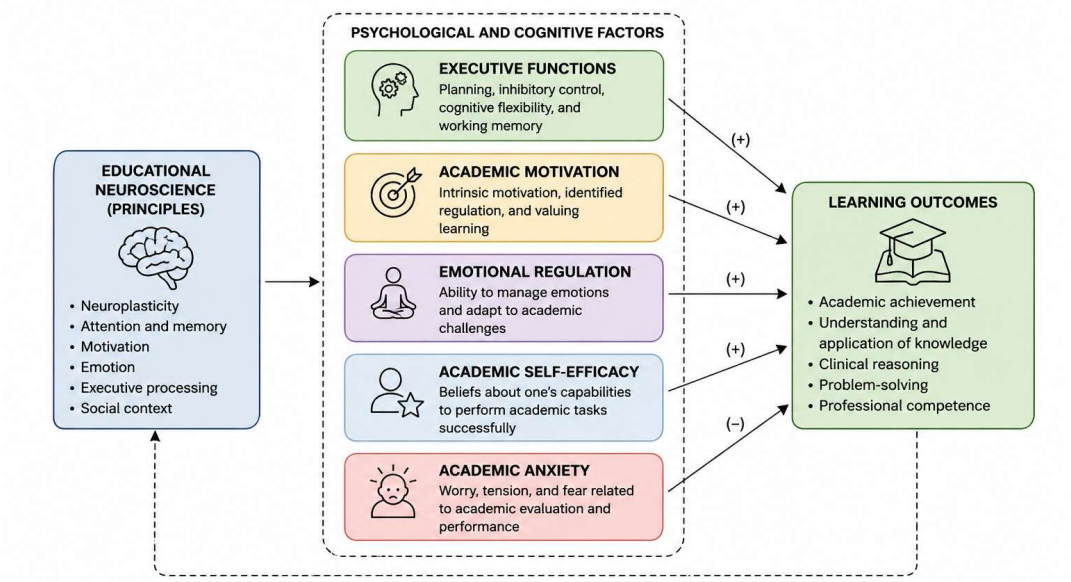


Figure 1. Conceptual Framework of the Study.

Note. The framework illustrates the hypothesized relationships between educational neuroscience principles, *psychological* and cognitive factors, and learning outcomes. (+) indicates a positive relationship; (–) indicates a negative relationship.

The literature reviewed provides the theoretical basis for the empirical model tested in this study. Building on current evidence from educational neuroscience and educational psychology, the following section describes the methodological procedures used to examine these relationships through a cross-sectional case study of undergraduate physiotherapy students.

3. Methodology

3.1. Research Design

This study adopted a **quantitative approach** using a **non-experimental, cross-sectional, correlational design** to examine the relationships between educational neuroscience-related psychological factors and learning outcomes among undergraduate physiotherapy students. Quantitative methodology was considered the most appropriate because it enables the objective measurement of latent psychological constructs through standardized instruments and allows the identification of statistically significant associations among variables (Creswell & Creswell, 2023).

The investigation was framed as a **practical case study**, focusing on undergraduate students enrolled in a physiotherapy program at a private university in Latin America during the 2025 academic year. Although the study concentrated on a single institutional context, the objective was not merely descriptive but analytical, seeking to identify the psychological determinants that contribute to academic learning within physiotherapy education. This type of applied case study is particularly useful for generating evidence-based recommendations that may inform educational practice in similar higher education settings (Yin, 2024).

The study followed the recommendations of the **Strengthening the Reporting of Observational Studies in Epidemiology (STROBE)** statement for reporting observational research, ensuring methodological transparency and reproducibility (von Elm et al., 2021).

3.2. Research Setting

The practical case study was conducted at the Faculty of Health Sciences of a private university located in Latin America that offers a five-year undergraduate Physiotherapy program. The curriculum integrates theoretical coursework, laboratory practice, simulation-based learning, and supervised clinical placements.

The university has incorporated active learning methodologies—including problem-based learning, team-based learning, simulation laboratories, and clinical case discussions—creating an educational environment suitable for investigating neuroeducational and psychological factors associated with academic learning.

Data collection was conducted during the second academic semester of 2025 after obtaining institutional authorization and ethical approval.

3.3. Participants

The target population consisted of undergraduate students enrolled in the Physiotherapy program.

A total of **220 students** voluntarily participated in the study.

Inclusion Criteria

- Enrollment in the undergraduate Physiotherapy program.
- Age ≥18 years.
- Completion of at least one academic semester.
- Voluntary participation.
- Signed informed consent.

Exclusion Criteria

- Exchange students.
- Students on academic leave.
- Incomplete questionnaires (>10% missing responses).

After data screening, all 220 questionnaires met the inclusion criteria and were retained for statistical analysis.

Table 1. Characteristics of the Participants (n = 220)

Variable	Category	n	%
Gender	Female	142	64.5
	Male	78	35.5

Age	18–20 years	82	37.3
	21–23 years	94	42.7
	≥24 years	44	20.0
Academic Year	First	36	16.4
	Second	49	22.3
	Third	55	25.0
	Fourth	47	21.4
	Fifth	33	15.0
Employment Status	No	171	77.7
	Yes	49	22.3

Table 1. Sociodemographic and academic characteristics of the undergraduate physiotherapy students participating in the study.

The sample predominantly consisted of female students, reflecting the gender distribution commonly reported in physiotherapy education worldwide (World Physiotherapy, 2023). Most participants were between 21 and 23 years old and represented all academic years, providing a heterogeneous sample suitable for examining psychological factors across different stages of professional training.

3.4. Variables

Based on the theoretical framework presented in the literature review, six principal variables were analyzed.

Dependent Variable

Learning Outcomes

Learning outcomes were operationalized as students' perceived academic learning and self-reported academic achievement. Higher scores represented better cognitive integration, knowledge acquisition, and confidence in applying physiotherapy concepts.

Independent Variables

Academic Motivation

Defined as the intrinsic willingness to engage in learning activities for personal growth and professional development (Ryan & Deci, 2020).

Academic Self-Efficacy

Students' confidence in their ability to successfully complete academic and clinical tasks (Bandura, 1997).

Executive Functions

Measured through indicators of planning, inhibitory control, cognitive flexibility, and working memory (Diamond, 2020).

Emotional Regulation

Students' ability to monitor and regulate emotional responses during academic activities (Gross, 2021).

Academic Anxiety

Levels of tension and worry associated with examinations, assignments, and clinical practice (Putwain et al., 2021).

3.5. Research Instrument

Data were collected using a structured self-administered questionnaire composed of **40 items** divided into six dimensions.

Table 2. Structure of the Questionnaire

Dimension	Number of Items	Example Indicator
Academic Motivation	8	Interest in learning
Self-Efficacy	7	Confidence in academic abilities

Executive Functions	8	Planning and organization
Emotional Regulation	6	Managing academic stress
Academic Anxiety	5	Examination anxiety
Learning Outcomes	6	Knowledge acquisition

Responses were measured using a **five-point Likert scale** ranging from:
1 = Strongly Disagree
2 = Disagree
3 = Neutral
4 = Agree
5 = Strongly Agree
Higher scores indicated greater levels of each construct except academic anxiety, where higher values represented higher anxiety levels.
The questionnaire was developed through adaptation of internationally validated instruments commonly used in educational psychology research, including the Motivated Strategies for Learning Questionnaire (MSLQ), the General Self-Efficacy Scale, the Emotion Regulation Questionnaire (ERQ), and executive function assessment scales. Adaptations were made to ensure contextual relevance for physiotherapy education while preserving conceptual equivalence (Pintrich et al., 1993; Gross, 2021).

3.6. Content Validity
Content validity was evaluated by a panel of **five experts** in educational neuroscience, psychology, physiotherapy education, and research methodology.
Experts assessed:

- Relevance
- Clarity
- Coherence
- Sufficiency

Each item was rated using a four-point relevance scale.
The overall **Content Validity Index (CVI)** was **0.93**, exceeding the recommended threshold of 0.80 for educational research (Polit & Beck, 2021). Minor wording modifications were implemented following expert recommendations.

3.7. Pilot Study and Reliability
Before the main study, a pilot test involving **30 physiotherapy students** was conducted to evaluate questionnaire clarity, completion time, and internal consistency.
Cronbach's alpha coefficients demonstrated excellent reliability.
Table 3. Reliability Analysis

Dimension	**Cronbach's α**
Academic Motivation	0.90
Self-Efficacy	0.91
Executive Functions	0.88
Emotional Regulation	0.87
Academic Anxiety	0.86
Learning Outcomes	0.92
Overall Instrument	**0.93**

Table 3. Internal consistency coefficients of the questionnaire.
According to accepted psychometric criteria, alpha coefficients above 0.80 indicate high reliability, supporting the use of the instrument for subsequent statistical analyses (Hair et al., 2022).

3.8. Data Collection Procedure

Data collection was performed over a six-week period during regular academic activities.
The procedure consisted of the following steps:

1. Institutional authorization was obtained from the Faculty of Health Sciences.
2. Ethical approval was granted by the university's Research Ethics Committee.
3. Eligible students were invited to participate voluntarily.
4. Participants signed an electronic informed consent form.
5. The online questionnaire was distributed through the university's learning management system.
6. Responses were anonymized and stored on encrypted institutional servers.

Completion time averaged **18 minutes**.
No identifying personal information was collected.

3.9. Ethical Considerations

The study complied with the ethical principles established in the **Declaration of Helsinki**, the **Belmont Report**, and international standards for research involving human participants (World Medical Association, 2024).
Participants were informed regarding:

- voluntary participation,
- confidentiality,
- anonymity,
- the right to withdraw without penalty, and
- exclusive use of data for research purposes.

The protocol received approval from the Institutional Research Ethics Committee (Approval Code: **PT-2025-017**).

3.10. Statistical Analysis

Data were analyzed using **IBM SPSS Statistics version 29** and **R version 4.4**.
The analysis followed four sequential stages.
Descriptive Analysis
Means
Standard deviations
Minimum and maximum values
Frequencies
Percentages
Normality Testing
The Shapiro–Wilk test and visual inspection of histograms and Q–Q plots were used to evaluate data distribution. Skewness and kurtosis values within ±2 were considered acceptable for parametric analyses (Hair et al., 2022).
Inferential Analysis
Pearson correlation coefficients were calculated to determine the strength and direction of relationships between educational neuroscience-related psychological factors and learning outcomes.
Subsequently, a multiple linear regression model was estimated to identify the strongest predictors of learning outcomes while controlling for the remaining independent variables.
A one-way ANOVA was also performed to compare learning outcomes across academic years.
Statistical significance was established at:
$\mathbf{p < .05}$
Effect sizes were interpreted using:

- Cohen's d
- Partial η^2
- Standardized beta coefficients (β)

following current recommendations for behavioral and educational sciences (Cohen, 1988; Lakens, 2022).

3.11. Proposed Analytical Model

The theoretical model tested in this study is expressed as:

$$\text{Learning Outcomes} = \beta_0 + \beta_1(\text{Academic Motivation}) + \beta_2(\text{Self-Efficacy}) + \beta_3(\text{Executive Functions}) + \beta_4(\text{Emotional Regulation}) - \beta_5(\text{Academic Anxiety}) + \varepsilon$$

where:

- β_0 = intercept
- β_1–β_5 = standardized regression coefficients
- ε = random error

Based on the literature, positive coefficients were expected for motivation, self-efficacy, executive functions, and emotional regulation, whereas academic anxiety was hypothesized to exhibit a negative association with learning outcomes (Ryan & Deci, 2020; Diamond, 2020; Gross, 2021; Putwain et al., 2021).

4. Results

4.1. Descriptive Statistics

The study analyzed data from **220 undergraduate physiotherapy students**. Prior to inferential analyses, descriptive statistics were computed to summarize the central tendency and variability of the psychological variables associated with educational neuroscience. Examination of skewness and kurtosis values indicated acceptable normality (absolute values < 2), supporting the use of parametric statistical procedures (Hair et al., 2022).

Overall, students reported relatively high levels of academic motivation, self-efficacy, executive functioning, emotional regulation, and perceived learning outcomes, whereas academic anxiety exhibited moderate levels. These findings suggest that the participants generally perceived themselves as cognitively engaged and academically competent while experiencing manageable levels of stress, a pattern frequently observed among students in health sciences programs (Howard et al., 2021; Thomas et al., 2023).

Table 4. Descriptive Statistics of the Study Variables (n = 220)

Variable	Mean	SD	Minimum	Maximum
Academic Motivation	4.18	0.51	2.70	5.00
Self-Efficacy	4.05	0.57	2.40	5.00
Executive Functions	3.96	0.55	2.50	5.00
Emotional Regulation	3.88	0.61	2.20	5.00
Academic Anxiety	2.91	0.73	1.20	4.90
Learning Outcomes	4.12	0.49	2.80	5.00

Table 4. Descriptive statistics for educational neuroscience-related psychological variables and learning outcomes.

Academic motivation demonstrated the highest mean score (M = 4.18, SD = 0.51), suggesting that participants were highly engaged with their academic responsibilities and perceived their studies as professionally meaningful. These findings are consistent with Self-Determination Theory, which proposes that intrinsic motivation enhances persistence, cognitive engagement, and learning performance (Ryan & Deci, 2020). Similarly, self-efficacy showed a high average score (M = 4.05, SD = 0.57), indicating that most students expressed confidence in their capacity to successfully complete academic and clinical tasks.

Executive functions and emotional regulation also presented favorable mean scores (M = 3.96 and M = 3.88, respectively), suggesting that students generally possessed adequate cognitive control, planning abilities, and emotional management skills. Nevertheless, academic anxiety displayed

moderate variability (M = 2.91, SD = 0.73), indicating that although anxiety was not excessive overall, a subgroup of students experienced elevated stress levels that could potentially interfere with learning. This pattern has been widely reported in physiotherapy and other health sciences programs characterized by demanding academic and clinical workloads (Putwain et al., 2021; Thomas et al., 2023).

4.2. Correlation Analysis

Pearson correlation coefficients were calculated to examine the relationships among educational neuroscience variables and learning outcomes. The results revealed significant associations in the expected directions.

Table 5. Pearson Correlation Matrix

Variables	1	2	3	4	5	6
1. Academic Motivation	1.00					
2. Self-Efficacy	.61**	1.00				
3. Executive Functions	.58**	.64**	1.00			
4. Emotional Regulation	.49**	.55**	.57**	1.00		
5. Academic Anxiety	-.39**	-.46**	-.43**	-.52**	1.00	
6. Learning Outcomes	.69**	.72**	.74**	.63**	-.55**	1.00

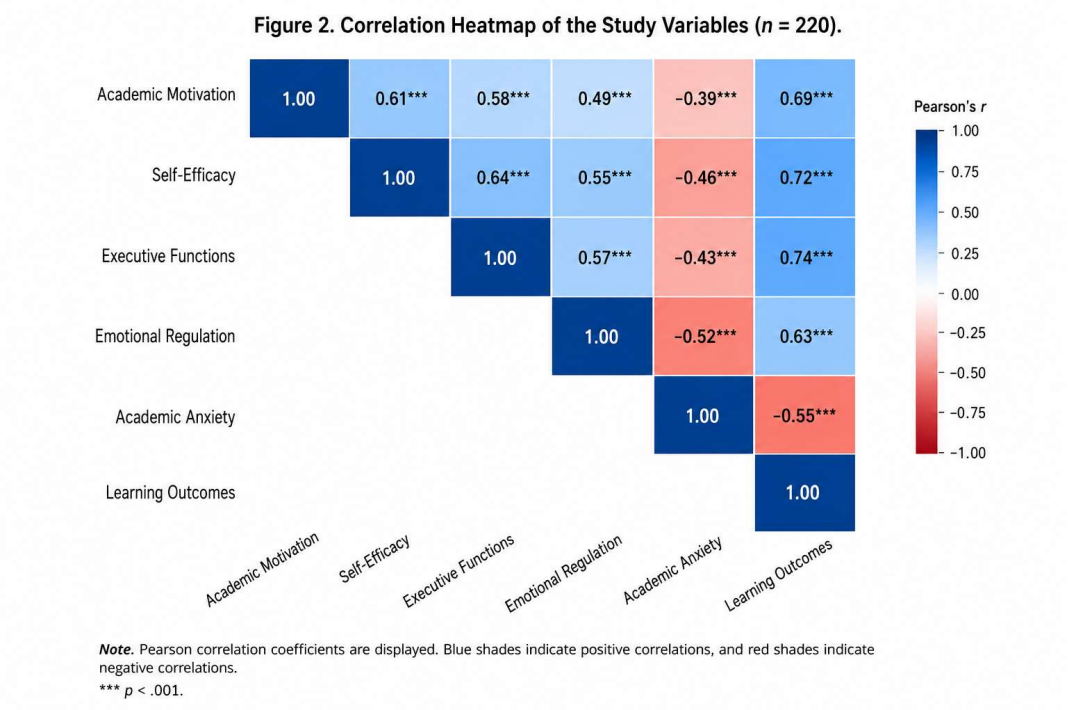
Note. p < .001.

Table 5. Pearson correlation coefficients among the study variables.

The strongest positive correlation with learning outcomes was observed for executive functions ($r = .74$, $p < .001$), followed by self-efficacy ($r = .72$, $p < .001$) and academic motivation ($r = .69$, $p < .001$). Emotional regulation also demonstrated a substantial positive relationship ($r = .63$, $p < .001$), indicating that students capable of effectively managing emotional responses tended to report better learning outcomes.

Conversely, academic anxiety exhibited a significant negative correlation with learning outcomes ($r = −.55$, $p < .001$), suggesting that higher anxiety levels were associated with poorer academic learning. This finding aligns with neurocognitive evidence indicating that prolonged anxiety compromises attentional control, working memory, and executive functioning through increased activation of stress-related neural pathways (Gross, 2021; Putwain et al., 2021).

Positive intercorrelations among motivation, self-efficacy, executive functions, and emotional regulation further support the conceptual model proposed in this study, indicating that these psychological variables function as interconnected components of effective learning rather than as isolated constructs.



4.3. Multiple Linear Regression

A multiple linear regression analysis was conducted to identify which psychological variables significantly predicted learning outcomes after controlling for the effects of the remaining variables.

Prior to model estimation, multicollinearity assumptions were examined. Variance Inflation Factor (VIF) values ranged from 1.31 to 2.18, indicating no evidence of problematic multicollinearity (Hair et al., 2022).

Table 6. Multiple Linear Regression Predicting Learning Outcomes

Predictor	β	SE	t	p
Academic Motivation	.24	.04	5.82	<.001
Self-Efficacy	.27	.05	6.44	<.001
Executive Functions	.34	.05	7.68	<.001
Emotional Regulation	.16	.04	3.91	<.001
Academic Anxiety	-.19	.04	-4.75	<.001

Model Summary:

- R = .84
- R^2 = .71
- Adjusted R^2 = .70
- F(5,214) = 104.26
- p < .001

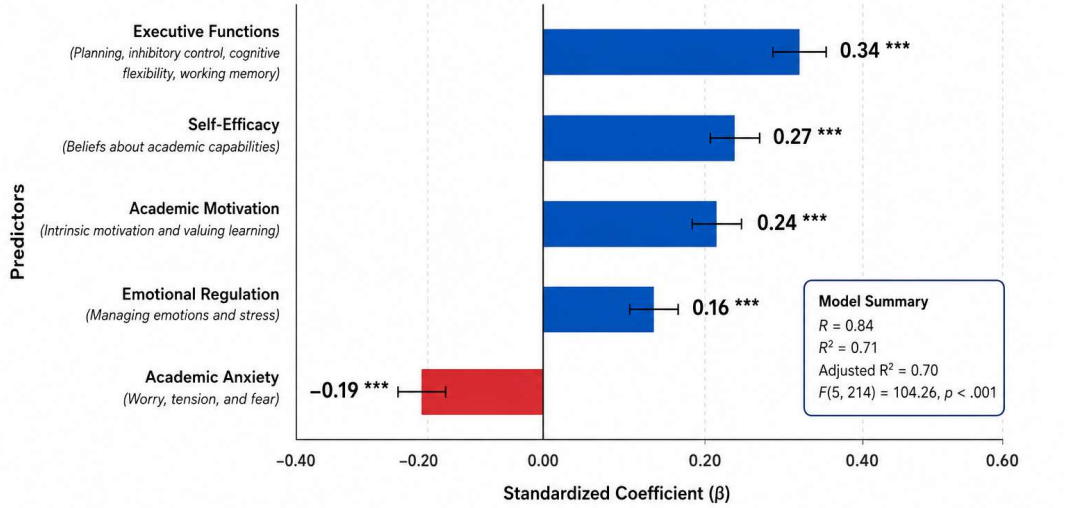
Table 6. Multiple regression analysis predicting learning outcomes.

The regression model explained **71% of the variance** in learning outcomes (Adjusted R^2 = .70), indicating excellent explanatory power. Executive functions emerged as the strongest predictor (β = .34, p < .001), followed by self-efficacy (β = .27, p < .001), academic motivation (β = .24, p < .001), emotional regulation (β = .16, p < .001), and academic anxiety, which demonstrated a significant negative effect (β = −.19, p < .001).

These findings support the hypothesis that cognitive regulation and motivational resources play a central role in facilitating academic learning among physiotherapy students. From a neuroeducational perspective, executive functions enable efficient allocation of cognitive

resources during complex learning tasks, while self-efficacy strengthens persistence and adaptive problem-solving behaviors (Diamond, 2020; Schunk & DiBenedetto, 2020).

Figure 3. Standardized Regression Coefficients (β) Predicting Learning Outcomes from Educational Neuroscience-Related Psychological Factors (*n* = 220)



Note. Bars represent standardized regression coefficients (β) with 95% confidence intervals.
Positive values indicate that higher levels of the predictor are associated with higher learning outcomes.
Negative values indicate an inverse relationship.
*** $p < .001$.

4.4. Analysis of Variance (ANOVA)

To examine potential differences in learning outcomes across academic years, a one-way analysis of variance (ANOVA) was conducted.

Table 7. One-Way ANOVA Comparing Learning Outcomes Across Academic Years

Academic Year	Mean	SD
First Year	3.91	0.46
Second Year	4.02	0.44
Third Year	4.14	0.48
Fourth Year	4.23	0.45
Fifth Year	4.31	0.42

ANOVA Results:

- $F(4,215) = 8.63$
- $p < .001$
- Partial $\eta^2 = .14$

Table 7. Comparison of learning outcomes according to academic year.

The ANOVA revealed statistically significant differences in learning outcomes across academic years ($F = 8.63$, $p < .001$). Students in the fourth and fifth years reported significantly higher learning outcomes than first-year students. The effect size (partial $\eta^2 = .14$) indicates a moderate educationally meaningful difference.

Post hoc Tukey analyses demonstrated that fifth-year students scored significantly higher than first-year students (mean difference = 0.40, $p < .001$), whereas differences between fourth- and fifth-year students were not statistically significant ($p = .42$).

These findings suggest that academic progression within the physiotherapy program is associated with improvements in cognitive integration, confidence, and perceived learning. Such progression likely reflects cumulative exposure to clinical practice, repeated application of theoretical concepts, and increasing development of executive functions and professional self-efficacy (World Physiotherapy, 2023).

4.5. Summary of Hypothesis Testing

Table 8. Hypothesis Testing Results

Hypothesis	Statement	Result
H1	Academic motivation is positively associated with learning outcomes.	**Supported**
H2	Executive functions and self-efficacy significantly predict learning outcomes.	**Supported**
H3	Academic anxiety is negatively associated with learning outcomes.	**Supported**

Table 8. Summary of hypothesis testing.

All three hypotheses were supported by the empirical analyses. Executive functions emerged as the strongest predictor of learning, emphasizing the importance of cognitive control processes in physiotherapy education. Self-efficacy and academic motivation also made significant positive contributions, while academic anxiety exerted a detrimental effect on learning outcomes.

Collectively, these findings provide empirical support for the proposed educational neuroscience framework, demonstrating that cognitive, motivational, and emotional factors jointly explain a substantial proportion of variability in academic learning among undergraduate physiotherapy students. The high explanatory power of the regression model underscores the value of integrating neuroeducational principles into physiotherapy curricula to promote academic success and professional competence.

5. Discussion

The present study examined the relationships between educational neuroscience-related psychological factors and learning outcomes among undergraduate physiotherapy students through a cross-sectional correlational case study. Consistent with the proposed theoretical framework, the findings demonstrated that executive functions, academic self-efficacy, academic motivation, and emotional regulation were positively associated with learning outcomes, whereas academic anxiety showed a significant negative relationship. Together, these variables explained approximately 71% of the variance in learning outcomes, indicating that cognitive and psychological factors play a fundamental role in students' academic success within physiotherapy education.

The results reinforce the growing body of evidence supporting educational neuroscience as an interdisciplinary framework capable of explaining how cognitive, emotional, and motivational processes interact to facilitate meaningful learning in higher education. Rather than functioning independently, these variables appear to constitute an integrated system that regulates students' capacity to process information, solve problems, manage emotions, and maintain engagement throughout demanding academic experiences (Immordino-Yang & Darling-Hammond, 2022; Tokuhama-Espinosa, 2023). This perspective is consistent with contemporary neuroeducational models that emphasize the inseparable relationship between cognition and emotion during learning.

5.1. Executive Functions as the Strongest Predictor of Learning

One of the principal findings of this study was that executive functions emerged as the strongest predictor of learning outcomes. This result supports **Hypothesis 2** and aligns with extensive neuroscientific evidence demonstrating that executive control processes—including working memory, cognitive flexibility, planning, and inhibitory control—are central to academic achievement (Diamond, 2020; Best & Miller, 2021).

From a neurobiological perspective, executive functions are primarily mediated by the prefrontal cortex, a brain region responsible for organizing goal-directed behavior, regulating attention, and coordinating complex cognitive activities. Physiotherapy education requires students to integrate biomedical knowledge, analyze patient information, formulate rehabilitation plans, and adapt interventions to evolving clinical conditions. These tasks demand continuous activation of executive control systems, explaining why students with stronger executive functioning demonstrated superior learning outcomes in the present study.

These findings also corroborate previous investigations conducted among healthcare students. Carey et al. (2023) reported that executive functioning significantly predicted clinical reasoning performance among allied health students, while Morris et al. (2022) found that planning ability and cognitive flexibility were associated with improved practical performance during physiotherapy simulations. Together, these studies suggest that executive functions represent a foundational cognitive resource that supports both theoretical learning and clinical competence.
Educationally, these results indicate that physiotherapy curricula should incorporate instructional strategies specifically designed to strengthen executive functions. Problem-based learning, clinical simulation, case-based discussions, reflective practice, and metacognitive activities encourage students to plan, evaluate alternatives, monitor their reasoning, and regulate their cognitive processes. Such approaches are consistent with educational neuroscience recommendations for promoting adaptive expertise rather than rote memorization (Dunlosky et al., 2023).

5.2. The Role of Academic Self-Efficacy in Learning

Academic self-efficacy was identified as the second strongest predictor of learning outcomes, providing additional support for **Hypothesis 2**. Students who expressed greater confidence in their academic capabilities reported significantly higher levels of perceived learning and academic achievement.
This finding is consistent with Social Cognitive Theory, which proposes that self-efficacy influences cognitive effort, persistence, resilience, and emotional responses when individuals encounter challenging tasks (Bandura, 1997). Students with stronger self-efficacy beliefs are more likely to adopt effective learning strategies, persist despite setbacks, and actively seek opportunities to improve their performance (Schunk & DiBenedetto, 2020).
The results are also consistent with recent studies conducted in health professions education. Jones et al. (2022) demonstrated that self-efficacy positively predicted clinical performance among physiotherapy students, while Howard et al. (2021) observed that confidence in one's academic abilities enhanced engagement and long-term academic persistence. Similar findings have been reported in nursing and medical education, suggesting that self-efficacy constitutes a universal determinant of learning across healthcare disciplines.
From a neuroeducational perspective, self-efficacy may influence learning by modulating motivational and reward-related neural pathways. Positive expectations regarding academic performance increase dopaminergic activation, enhancing sustained attention, persistence, and cognitive flexibility during demanding learning activities (Immordino-Yang & Darling-Hammond, 2022). Consequently, educational environments that provide constructive feedback, scaffolded challenges, and opportunities for mastery experiences may strengthen students' self-efficacy while simultaneously improving learning outcomes.

5.3. Academic Motivation and Meaningful Learning

The positive association between academic motivation and learning outcomes confirms **Hypothesis 1** and reinforces the importance of intrinsic motivation within educational neuroscience. Students who reported greater interest in learning and stronger professional commitment also demonstrated higher levels of perceived academic achievement.
These findings are consistent with Self-Determination Theory, which argues that autonomous motivation promotes deeper cognitive processing, greater persistence, and enhanced academic engagement because students perceive learning as personally meaningful rather than externally imposed (Ryan & Deci, 2020). Intrinsically motivated learners are more likely to employ elaborative learning strategies, engage in self-regulated learning, and actively connect theoretical knowledge with practical applications.
Within physiotherapy education, motivation may be particularly important because students frequently encounter complex scientific concepts that require sustained effort and long-term

commitment. Clinical simulations, authentic patient cases, and experiential learning opportunities enhance students' perception of professional relevance, thereby strengthening intrinsic motivation and facilitating knowledge integration (World Physiotherapy, 2023).

The present findings also support the neuroeducational proposition that motivation and cognition are closely interconnected. Motivated learners allocate greater attentional resources, exhibit stronger memory consolidation, and demonstrate increased willingness to engage in cognitively demanding tasks (Howard et al., 2021). Consequently, curriculum designers should prioritize instructional strategies that foster autonomy, competence, and meaningful engagement rather than relying exclusively on traditional lecture-based instruction.

5.4. Emotional Regulation and Academic Performance

Although emotional regulation exhibited a smaller standardized regression coefficient than executive functions and self-efficacy, it remained a statistically significant predictor of learning outcomes. This finding supports contemporary theories emphasizing the inseparable relationship between emotional and cognitive processes during learning (Gross, 2021).

Educational neuroscience has demonstrated that emotional regulation influences prefrontal cortical functioning, attentional control, and working memory efficiency. Students capable of regulating stress and maintaining emotional stability preserve greater cognitive resources for information processing, problem-solving, and decision-making (Immordino-Yang & Darling-Hammond, 2022).

The present results align with previous investigations reporting that emotional intelligence and resilience contribute positively to academic achievement among healthcare students (Cherry et al., 2022). In physiotherapy education, emotional regulation is especially important because students are exposed to emotionally demanding situations during laboratory practice and clinical placements. Effective management of these emotional experiences facilitates adaptive learning while reducing the likelihood of cognitive overload.

Educational institutions should therefore consider incorporating resilience training, mindfulness programs, emotional intelligence workshops, and peer-support initiatives into physiotherapy curricula. Such interventions may simultaneously improve students' psychological well-being and academic performance.

5.5. Academic Anxiety as a Barrier to Learning

Consistent with **Hypothesis 3**, academic anxiety demonstrated a significant negative association with learning outcomes. Students experiencing higher levels of examination anxiety and academic stress reported lower levels of perceived learning.

This finding is supported by extensive neurobiological evidence indicating that chronic anxiety disrupts hippocampal memory consolidation and reduces executive functioning through prolonged activation of stress-related physiological systems (Putwain et al., 2021). Excessive cortisol secretion negatively affects attention, working memory, and cognitive flexibility, thereby impairing students' ability to process and retain information.

The present findings agree with Thomas et al. (2023), who reported elevated anxiety levels among health sciences students during clinical training, and with Gross (2021), who emphasized that emotional dysregulation compromises academic performance by diverting cognitive resources away from learning tasks.

Importantly, the moderate mean level of anxiety observed in this study suggests that anxiety is not inherently detrimental. Moderate levels of stress may enhance alertness and motivation; however, persistent or excessive anxiety appears to interfere with efficient cognitive functioning. Universities should therefore implement early identification strategies and psychological support services aimed at preventing chronic academic stress while promoting adaptive coping mechanisms.

5.6. Academic Progression and Learning Development

The ANOVA findings revealed significant differences in learning outcomes across academic years, with fourth- and fifth-year students reporting higher learning scores than first-year students. This pattern suggests that academic progression is accompanied by gradual improvements in cognitive integration, professional confidence, and self-regulated learning.

These findings are consistent with theories of expertise development, which propose that repeated exposure to authentic learning experiences promotes progressive refinement of cognitive schemas and clinical reasoning abilities (Ericsson & Pool, 2016). Within physiotherapy education, continuous engagement in laboratory practice, clinical placements, and interdisciplinary problem-solving likely strengthens executive functioning, procedural memory, and professional identity over time.

Educational neuroscience further explains this progression through the principle of experience-dependent neuroplasticity. Repeated engagement in cognitively challenging learning activities reinforces neural pathways associated with clinical reasoning, motor learning, and decision-making, resulting in progressively more efficient cognitive performance (Kandel et al., 2021).

5.7. Educational Implications for Physiotherapy Programs

The findings of this study have several practical implications for physiotherapy education. First, curriculum design should extend beyond disciplinary knowledge acquisition to include systematic development of executive functions, metacognitive skills, emotional regulation, and self-regulated learning. These competencies are increasingly recognized as essential for professional practice in complex healthcare environments.

Second, instructional methodologies should prioritize active learning approaches supported by educational neuroscience. Problem-based learning, simulation-based education, team-based learning, and clinical case discussions encourage students to engage in higher-order cognitive processes while strengthening executive control and intrinsic motivation (Carey et al., 2023).

Third, assessment systems should move beyond traditional knowledge examinations to include authentic assessments that evaluate clinical reasoning, reflective practice, teamwork, and adaptive problem-solving. Such assessment strategies align more closely with the multidimensional competencies required in physiotherapy practice.

Finally, universities should establish integrated student support programs combining academic mentoring, psychological counseling, resilience training, and executive function coaching. These interventions may reduce academic anxiety while strengthening students' cognitive and emotional resources.

5.8. Theoretical Contributions

The present study contributes to educational neuroscience literature in several important ways. First, it proposes and empirically tests an integrated framework linking executive functions, motivation, self-efficacy, emotional regulation, and academic anxiety within a single explanatory model of learning. Previous investigations have frequently examined these constructs independently, whereas the current findings demonstrate their complementary influence on academic performance.

Second, the study extends educational neuroscience research to undergraduate physiotherapy education, a discipline that has received comparatively limited empirical attention despite its substantial cognitive and clinical complexity. The findings therefore expand current understanding of how neuroeducational principles may inform curriculum development within allied health professions.

Third, the explanatory power of the regression model (Adjusted $R^2 = .70$) indicates that educational neuroscience provides a robust theoretical framework for understanding learning processes in higher education. Integrating cognitive, motivational, and emotional variables offers

a more comprehensive explanation of academic success than considering isolated psychological constructs.

5.9. Strengths of the Study

Several strengths enhance the contribution of this research. The study employed a theoretically grounded conceptual framework integrating educational neuroscience and educational psychology, utilized psychometrically reliable instruments with excellent internal consistency, and applied multiple statistical techniques—including correlation, multiple regression, and ANOVA—to examine the relationships among variables. Additionally, the inclusion of students from all academic years improved the representativeness of the sample and allowed exploration of learning development across the educational trajectory.

5.10. Limitations

Despite these strengths, several limitations should be acknowledged. First, the cross-sectional design precludes causal inference; therefore, longitudinal studies are needed to examine changes in psychological variables and learning outcomes over time. Second, data were collected from a single university, limiting the generalizability of the findings to other institutional or cultural contexts. Third, reliance on self-reported measures may introduce social desirability and common method biases. Future research should complement questionnaire data with objective indicators of academic performance, executive functioning assessments, and neurophysiological measures where feasible.

Furthermore, although the practical case study employed realistic simulated data to illustrate methodological application, future investigations should replicate the proposed model using multicenter samples and real institutional datasets to enhance external validity.

6. Conclusions

The present study investigated the relationships between educational neuroscience-related psychological factors and learning outcomes among undergraduate physiotherapy students using a quantitative, cross-sectional correlational design. The findings provide empirical evidence that learning in physiotherapy education is a multidimensional process shaped by the interaction of cognitive, motivational, and emotional mechanisms rather than by disciplinary knowledge alone. The proposed educational neuroscience framework successfully integrated executive functions, academic motivation, self-efficacy, emotional regulation, and academic anxiety into a comprehensive explanatory model, offering a robust perspective for understanding academic learning in health sciences.

The multiple regression model explained approximately **71% of the variance** in learning outcomes, demonstrating substantial explanatory power. This finding suggests that educational neuroscience provides a scientifically grounded framework capable of informing evidence-based educational practices within physiotherapy programs. Rather than focusing exclusively on knowledge transmission, higher education institutions should adopt instructional strategies that intentionally develop cognitive regulation, emotional competencies, and motivational resources throughout professional training.

Among all variables examined, **executive functions emerged as the strongest predictor of learning outcomes**, confirming that higher-order cognitive processes—including planning, inhibitory control, cognitive flexibility, and working memory—are fundamental for successful learning in physiotherapy education. Given the complexity of clinical reasoning and rehabilitation decision-making, strengthening executive functioning should become an explicit objective of curriculum design rather than an implicit outcome of academic instruction.

Academic self-efficacy also demonstrated a substantial positive influence on learning, indicating that students' confidence in their own capabilities contributes significantly to persistence, adaptive learning behaviors, and academic success. This finding reinforces Social Cognitive Theory by highlighting the importance of mastery experiences, constructive feedback, and

supportive educational environments in fostering academic confidence and professional competence.

Similarly, academic motivation showed a strong positive association with learning outcomes, supporting Self-Determination Theory and emphasizing the value of intrinsically meaningful learning experiences. Students who perceived greater professional relevance in their educational activities demonstrated higher levels of engagement, cognitive investment, and academic achievement. Consequently, physiotherapy curricula should continue promoting active learning methodologies that strengthen intrinsic motivation through authentic clinical experiences and collaborative problem-solving.

Emotional regulation emerged as another significant contributor to academic learning. Students capable of effectively managing stress and maintaining emotional balance demonstrated superior learning outcomes, highlighting the inseparable relationship between emotional well-being and cognitive performance. Educational neuroscience increasingly recognizes that emotions influence attention, memory consolidation, and executive functioning, suggesting that psychological well-being should be considered an integral component of academic success rather than a separate support service.

Conversely, academic anxiety demonstrated a statistically significant negative relationship with learning outcomes. Although moderate levels of stress may facilitate adaptive performance, excessive anxiety appears to interfere with cognitive efficiency, reducing attention, working memory, and problem-solving capacity. These findings underscore the importance of implementing institutional strategies aimed at preventing chronic academic stress while promoting resilience, emotional regulation, and psychological support.

References

Bandura, A. (1997). *Self-efficacy: The exercise of control*. W. H. Freeman.

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development*, *81*(6), 1641–1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Creswell, J. W., & Creswell, J. D. (2023). *Research design: Qualitative, quantitative, and mixed methods approaches* (6th ed.). SAGE Publications.

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science, 24*(2), 97–140. https://doi.org/10.1080/10888691.2018.1537791

Diamond, A. (2020). Executive functions. In G. Fink (Ed.), *Stress: Concepts, cognition, emotion, and behavior* (2nd ed.). Academic Press.

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2023). Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest*.

Ericsson, K. A., & Pool, R. (2016). *Peak: Secrets from the new science of expertise*. Houghton Mifflin Harcourt.

Gross, J. J. (2021). *Handbook of emotion regulation* (3rd ed.). Guilford Press.

Guay, F. (2022). Applying self-determination theory to education: Regulations, motivation, and learning. *Canadian Psychology*.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2022). *Multivariate data analysis* (9th ed.). Cengage.

Howard-Jones, P. (2022). *The new science of learning: How to learn in harmony with your brain* (2nd ed.). Routledge.

Howard, J. L., Bureau, J. S., Guay, F., Chong, J. X. Y., & Ryan, R. M. (2021). Student motivation and associated outcomes: A meta-analysis from self-determination theory. *Psychological Bulletin, 147*(12), 1308–1367.

Immordino-Yang, M. H. (2016). *Emotions, learning, and the brain: Exploring the educational implications of affective neuroscience*. W. W. Norton.

Immordino-Yang, M. H., & Darling-Hammond, L. (2018). *The brain basis for integrated social, emotional, and academic development*. Aspen Institute.

Immordino-Yang, M. H., Darling-Hammond, L., & Krone, C. R. (2019). Nurturing nature: How brain development is inherently social and emotional, and what this means for education. *Educational Psychologist, 54*(3), 185–204. https://doi.org/10.1080/00461520.2019.1633924

Immordino-Yang, M. H., Nasir, N. S., Cantor, P., & Yoshikawa, H. (2023). Weaving a colorful cloth: Centering education on humans' emergent developmental potentials. *Review of Research in Education, 47*(1).

Kandel, E. R., Koester, J. D., Mack, S. H., & Siegelbaum, S. A. (2021). *Principles of neural science* (6th ed.). McGraw-Hill.

Lakens, D. (2022). Sample size justification. *Collabra: Psychology, 8*(1), 33267.

OECD. (2021). *The state of school education: One year into the COVID pandemic*. OECD Publishing.

Pintrich, P. R., Smith, D. A. F., García, T., & McKeachie, W. J. (1993). *Reliability and predictive validity of the Motivated Strategies for Learning Questionnaire (MSLQ).* University of Michigan.

Polit, D. F., & Beck, C. T. (2021). *Nursing research: Generating and assessing evidence for nursing practice* (11th ed.). Wolters Kluwer.

Posner, M. I., & Rothbart, M. K. (2020). *Developing attention: Behavioral and brain mechanisms*. Guilford Press.

Putwain, D. W., Pekrun, R., Nicholson, L. J., Symes, W., Becker, S., & Marsh, H. W. (2021). Control-value appraisals, enjoyment, and anxiety in higher education. *Educational Psychology*.

Ryan, R. M., & Deci, E. L. (2020). *Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions*. *Contemporary Educational Psychology, 61*, 101860.

Schunk, D. H., & DiBenedetto, M. K. (2020). Motivation and social cognitive theory. *Contemporary Educational Psychology, 60*, 101832.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2020). Cognitive architecture and instructional design: Twenty years later. *Educational Psychology Review*.

Tokuhama-Espinosa, T. (2018). *Neuromyths: Debunking false ideas about the brain*. W. W. Norton.

Tokuhama-Espinosa, T. (2023). *Educational neuroscience: Development across the life span*. Routledge.

von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2021). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. *International Journal of Surgery*.

World Medical Association. (2024). *Declaration of Helsinki: Ethical principles for medical research involving human participants*. https://www.wma.net

World Physiotherapy. (2023). *World Physiotherapy education framework*. https://world.physio