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Perception of meaningful learning after the implementation of interactive simulations in the teaching of Physiology.

Percepción del aprendizaje significativo tras la implementación de simulaciones interactivas en la enseñanza de la Fisiología.

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Summary.
Introduction: Incorporating educational resources into the teaching of Human Physiology is a key strategy for promoting meaningful learning in medical students. Objective: To evaluate the perception of meaningful learning after the implementation of interactive simulations in the teaching process of Human Physiology at the University of The Gambia Medical School. **Methods:** A descriptive, cross-sectional study with a quantitative approach was conducted. The sample consisted of medical students from the University of The Gambia (n=73). A teaching strategy based on interactive simulations was implemented in a blended learning environment. The Meaningful Learning Perception Scale in Blended Learning was used for data collection. Descriptive statistics were applied, including frequency, percentage, and mean analyses. **Results:** A high level of acceptance was observed in all dimensions evaluated. The cognitive dimension reached the highest acceptance percentage (95.9%), followed by the social-collaborative (90.3%), procedural (89.0%), and attitudinal (89.0%) dimensions. The metacognitive dimension showed the lowest value (84.2%), although still high. Means ranged from 4.23 to 4.46 on a 5-point Likert scale. **Conclusions:** Interactive simulations are perceived as an effective strategy for promoting meaningful learning in the teaching of Human Physiology, positively impacting the cognitive, procedural, attitudinal, metacognitive, and social dimensions of the study group.

Keywords: meaningful learning, simulation, physiology, medical education, blended learning.

Resumen.
Introducción: La incorporación de recursos educativos en la enseñanza de la Fisiología Humana constituye una estrategia clave para favorecer el aprendizaje significativo en estudiantes de ciencias médicas. Objetivo: evaluar la percepción del aprendizaje significativo tras la implementación de simulaciones interactivas en el proceso de enseñanza de la Fisiología Humana en la universidad médica de Gambia. **Métodos:** Se realizó un estudio descriptivo de corte transversal con enfoque cuantitativo. La muestra estuvo conformada por estudiantes de medicina de la universidad de Gambia (n=73). Se implementó una estrategia didáctica basada en simulaciones interactivas en un entorno blended learning. Para la recolección de datos se utilizó la Escala de Percepción de Aprendizaje Significativo en Blended Learning. Se aplicó estadística descriptiva con análisis de frecuencias, porcentajes y medias. **Resultados:** Se evidenció un elevado nivel de aceptación en todas

las dimensiones evaluadas. La dimensión cognitiva alcanzó el mayor porcentaje de aceptación (95.9%), seguida de la social-colaborativa (90.3%), procedimental (89.0%) y actitudinal (89.0%). La dimensión metacognitiva presentó el menor valor (84.2%), aunque igualmente elevado. Las medias oscilaron entre 4.23 y 4.46 en escala Likert de 5 puntos. **Conclusiones:** Las simulaciones interactivas se perciben como una estrategia eficaz para promover el aprendizaje significativo en la enseñanza de la Fisiología Humana, al impactar positivamente en las dimensiones cognitiva, procedimental, actitudinal, metacognitiva y social del grupo objeto de estudio.

Palabras clave: aprendizaje significativo, simulación, Fisiología, educación médica, blended learning.

1. Introduction

Education, as a fundamental human right, is the driving force behind comprehensive development and the solution to global problems such as poverty and inequality (1). In the digital age, the traditional transmission-based model is monotonous for digital native students, which has forced a transition towards a constructivist approach centered on the learner and competency-based learning (1-2). In this context, the emergence of Information and Communication Technologies (ICTs) has given rise to modalities such as e-learning and blended learning (3). Blended learning allows for maintaining a face-to-face structure while promoting independent work, through technology that overcomes barriers of time and space (2). However, this modality requires specific designs that cater to individual learning paces. There is a significant terminological disparity in the English-speaking world, where terms such as hybrid or networked learning coexist, while in Spanish, the terms semi-presential or bimodal learning are used, with blended learning being the most widespread. Some authors such as Galán suggest that Anglo-Saxon terms focus on the learning process, while Latin terms emphasize the design of teaching (2).

Within these new modalities, clinical simulation is consolidating itself as a fundamental pillar that responds to the historical evolution of practical learning. This has evolved from the use of rudimentary mannequins and fruit on battlefields to high-fidelity simulators (4). Today, given the restrictions on access to healthcare facilities to protect patients' rights, simulation is justified as an essential pedagogical resource (4-5). From a psychopedagogical perspective, simulation aligns with experiential learning and Ausubel's theory of meaningful learning, where knowledge is consolidated by linking it to prior structures (4, 6). In the teaching of Human Physiology, this is vital, as it allows for the articulation of theory with practice in a dynamic environment. To illustrate the concrete application of these simulations, it is useful to analyze a specific context. The Faculty of Medicine and Allied Health Sciences in The Gambia offers an example of an institution that implements a competency-based curriculum under particular circumstances. This institution plays a fundamental role in the country's healthcare system. Strategically located at the Edward Francis Small University Hospital in Banjul, the capital of Gambia, it offers students the opportunity to gain practical clinical experience in a real medical environment.

Within this curricular framework, Basic Biomedical Sciences (BBS) play an irreplaceable role in the training of health professionals. Their role transcends the mere provision of morphological and physiological foundations to constitute the basis upon which subsequent disciplines such as Pharmacology, Pathology, and Semiology are integrated (7-8). Furthermore, they develop logical and scientific thinking. It is precisely within the field of BBS that the ability to connect events through cause-and-effect relationships is practiced. This skill is essential for interpreting biopsychosocial phenomena related to health.

The meaningful learning approach posits that students construct knowledge by relating new information to prior cognitive structures, a process that can be enhanced through the use of educational technologies in blended learning environments. At the University of The Gambia, a teaching strategy based on interactive simulations was implemented to transform the teaching and learning process of Human Physiology toward more active, participatory, and student-centered models.

Therefore, how can we contribute to meaningful learning in the teaching of Human Physiology at the medical school of the University of The Gambia? To answer this question, the objective is to evaluate the perception of meaningful learning after the implementation of interactive simulations in the teaching of Human Physiology at the medical school of The Gambia.

2. Methods

A descriptive, cross-sectional study with a quantitative approach was conducted to evaluate the effects of implementing interactive simulations on meaningful learning in the teaching of Human Physiology to students at the University of The Gambia. The research was carried out at the Faculty of Medicine of the University of The Gambia during the academic period from June to December 2025. The sample consisted of all students enrolled in the 2025 academic year, corresponding to cohort 23; selected through purposive sampling, taking into account their participation in the Human Physiology course (n=73). The following procedure was applied:

- Implementation of the teaching strategy through simulations.
- Application of the Meaningful Learning Perception Scale in Blended Learning through a survey at the end of the experience.
- Data collection and cleaning.
- Statistical processing.

A didactic strategy based on interactive simulations was implemented within a blended learning environment, combining face-to-face activities with the use of whiteboard and virtual graphic materials. The simulations allowed for the recreation of complex physiological processes, promoting virtual experimentation, decision-making, and immediate feedback. The intervention lasted two academic periods, 28 weeks, and covered content related to: the basic structure of the functional components of the nephron, along with the tubular processes of filtration, reabsorption, secretion, and excretion, with an illustrative focus on the close anatomical and functional relationship between blood vessels and renal tubules under physiological conditions. Another simulation used was the balance diagram associated with the Henderson-Hasselbalch equation and the systemic regulatory mechanisms of acid-base balance in the human body, which allowed for the analysis of different pH disorders through problem-solving scenarios. An interactive virtual laboratory-type simulation created at the American University Boulder in the state of Colorado was also used, applied for the first time in this African context.

For the study, a complex variable was declared: "interactive simulations for meaningful learning in the teaching process of Human Physiology at the Gambia Medical University" which was divided into five dimensions and 15 indicators.

- Cognitive Dimension: This focuses on how the student perceives the logical organization and clarity of the concepts presented in the course. It seeks to measure whether the content is structured in a way that facilitates the assimilation and connection of ideas.
- Procedural Dimension: Evaluates the student's perception of the practical applicability of the knowledge acquired. It focuses on whether the course activities and tasks (both in-person and online) allow them to develop problem-solving skills and abilities.
- Attitudinal Dimension: Measures the student's perception of the motivation and interest generated by the course. It analyzes whether the teaching strategies and technological tools foster a positive attitude toward learning.

- Metacognitive dimension: This refers to the student's perception of their ability to reflect on their own learning process. This includes awareness of their study strategies, self-assessment, and regulating their learning in a blended learning environment.
- Social-collaborative dimension: Evaluates the student's perception of interaction and collaboration with peers and professors. It focuses on how online and in-person tools and activities facilitate the social construction of knowledge.

The instrument's scale was structured as a 5-point Likert scale (scale: 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree). To evaluate the results, the Perception of Meaningful Learning in Blended Learning Scale (14) was used, a validated instrument that measures student perception in different dimensions, which coincide with the dimensions used to operationalize the variable. The data were analyzed using descriptive and comparative statistical procedures. Absolute frequencies, percentages, and means were calculated for each dimension, and comparisons were made between the dimensions of meaningful learning.

3. Results

Analysis of the data obtained using the Meaningful Learning Perception Scale in Blended Learning revealed a highly positive assessment of the implementation of interactive simulations in the teaching of Human Physiology. In general, responses in the "strongly agree" (5) and "agree" (4) categories predominated across all dimensions evaluated, indicating a favorable perception of the impact of this teaching strategy on meaningful learning.

3.1 Analysis by dimensions

1. Cognitive Dimension. A clear predominance of positive ratings was observed: Indicator 1: 63% (5) and 37% (4), Indicator 2: 44% (5) and 56% (4), Indicator 3: 48% (5) and 38% (4), with only 14% in medium or low categories. The results demonstrate that the interactive simulations fostered a deep understanding of the physiological content, facilitating the assimilation of complex concepts. The low number of negative responses confirms the effectiveness of the teaching strategy on the cognitive level.

2. Procedural Dimension. This dimension shows the highest results in absolute terms: Indicator 1: 56% (5), 38% (4), 6% (3); Indicator 2: 33% (5), 45% (4), 19% (3), 3% (2); Indicator 3: 59% (5), 36% (4), 5% (3). A strong impact on the development of practical skills and the application of knowledge is evident, which is consistent with the use of interactive simulations. The tools used facilitated experimentation, decision-making, and the strengthening of meaningful learning.

3. Attitudinal Dimension. The results reflect a highly favorable attitude: Indicator 1: 71% (5), 23% (4). Indicator 2: 51% (5), 36% (4), 12% (3). Indicator 3: 39% (5), 48% (4), 12% (3). The results obtained in this dimension showed a significant increase in motivation, interest, and willingness to learn. The high concentration of maximum values indicates that the simulations create an attractive and stimulating environment.

4. Metacognitive Dimension. Positive results were observed, although with greater dispersion: Indicator 1: 37% (5), 44% (4), 11% (3), 8% (2); Indicator 2: 38% (5), 46% (4), 14% (3); Indicator 3: 56% (5), 32% (4), 10% (3). In this case, it was found that the simulations contributed to the development of self-regulated learning, although to a lesser extent than other dimensions. The presence of responses at intermediate levels suggests that some students are still in the process of developing metacognitive skills, which is an obstacle to achieving meaningful learning.

5. Social-collaborative dimension. Highly favorable results were observed: Indicator 1: 48% (5), 44% (4), 8% (3), Indicator 2: 51% (5), 44% (4), Indicator 3: 55% (5), 30% (4), 10% (3), 5% (2). The results obtained reflect that the use of interactive simulations fostered interaction, collaborative work, and active participation, essential elements in blended learning environments.

Table 1 presents a summary by dimension. All dimensions showed acceptance levels above 80%, confirming a highly positive impact. The weighted means ranged from 4.23 to 4.46, indicating a high overall rating, as it is close to the maximum. Although the cognitive dimension had the highest average value, the differences observed between dimensions were small, and all showed high levels of acceptance, with means above 4 points on the Likert scale. This demonstrated a homogeneous behavior of the complex variable, showing that the impact of the interactive simulations was not limited to a specific dimension but manifested itself in the cognitive, procedural, attitudinal, metacognitive, and socio-collaborative components. A comprehensive analysis of the variable, based on the five evaluated dimensions—cognitive, procedural, attitudinal, metacognitive, and socio-collaborative—represents essential components of this construct in blended learning environments. The following results were obtained: the variable interactive simulations for meaningful learning in the teaching of physiology; presents a high level of development, supported by the high acceptance percentages obtained in all dimensions, with values above 80%; with a general average of the variable (≈ 4.37 on Likert scale) which confirms a positive overall assessment, close to the maximum level of the scale.

These results demonstrate that the implementation of interactive simulations in the teaching of Human Physiology at the Gambian Medical University significantly contributes to the development of meaningful learning as a complex variable, integrating cognitive, procedural, attitudinal, metacognitive, and social components. This finding confirms the effectiveness of the proposed approach and its impact on the development of competencies in medical students.

Table 1. Distribution of the perception of learning by dimensions (n=73).

Dimension	% Acceptance (4/5)	Average
Cognitive	95.9%	4.46
Procedural	89.0%	4.37
Attitudinal	89.0%	4.41
Metacognitive	84.2%	4.23
Social-collaborative	90.3%	4.39
Variable	89.6%	4.37

4. Discussion

The results of this study demonstrate a highly favorable perception of the use of interactive simulations in teaching Human Physiology, with 89.6% of responses being positive. This finding is consistent with recent literature, which recognizes simulation as a transformative teaching strategy in medical education (9). In the cognitive domain, the results show an improvement in content comprehension. Studies by Qingming Wu et al. have demonstrated that simulations allow for the integration of theory and practice through interactive environments, facilitating knowledge acquisition and retention in medical students. Their findings demonstrate that current reviews highlight that virtual and high-fidelity simulations promote meaningful learning by dynamically representing complex physiological processes (10).

Regarding the procedural domain, the results show a positive impact on the application of knowledge. Evidence provided by Chukwuka et al. recently indicates that simulation improves the acquisition of clinical skills and decision-making by allowing repeated practice in safe and controlled environments (11). Furthermore, there are reports that this type of training increases student confidence and reduces errors in real-life scenarios. The attitudinal domain showed high levels of motivation and interest in the subject. Contemporary studies, such as those conducted by Qingming Wu, indicate that simulation-based technologies, especially those incorporating virtual reality, generate immersive experiences that increase student engagement and promote active participation in learning (10). As for the metacognitive domain, although the results were positive, less intensity was observed compared to other domains. Cordeiro identified and measured metacognitive events during the three simulation phases, highlighting that debriefing is the critical moment where students demonstrate greater awareness of their difficulties and self-regulation processes (12). While simulation promotes reflection and critical thinking, its impact on self-regulated learning depends largely on the incorporation of strategies such as structured debriefing and formative feedback.

Furthermore, social and collaborative skills demonstrated a favorable perception in student interactions. Recent research underscores that social and collaborative skills have moved beyond being considered a "soft skill" to become a cornerstone of medical education, driven by the need for more resilient healthcare systems. Studies such as that conducted by Tiller and Ortiz validated clinical simulation as the ideal environment for developing collaborative skills. The results show significant improvements in empathy, emotional intelligence, and effective communication (13). These findings confirm that simulation fosters collaborative learning by replicating clinical scenarios that require communication, teamwork, and joint decision-making.

Taken together, these findings confirm that simulations not only impact the acquisition of knowledge, but also the development of practical skills, attitudes, and social competencies, making it a comprehensive strategy for current medical education.

This study has some limitations: first, it did not include indicators such as grades or practical assessments, which would allow for comparison of the results. Another limitation is that the sample was limited to a specific cohort of students, restricting the generalizability of the findings to other contexts and the performance of multivariate analyses such as factor analysis or principal component analysis. Finally, the absence of a control group and the single-point-of-event assessment limit the interpretation of the intervention's long-term impact. Future research could incorporate complementary quantitative indicators and larger samples to explore the structural interaction between the dimensions of meaningful learning. Despite these limitations, the results provide relevant evidence on the value of interactive simulations in medical education, highlighting their potential as a pedagogical tool to promote meaningful learning in real-world training contexts.

5. Conclusions

- The implementation of interactive simulations in the teaching of Human Physiology at the University of Gambia proved to be an effective teaching strategy to promote meaningful learning.
- A positive impact was evident in all dimensions evaluated, with the indicators, content comprehension, development of practical skills, motivation, social interaction and self-regulation of learning standing out.

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