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ORIGINAL ARTICLE

The Integrative Cycle of Pharmacological Learning (CIAF): description and validation of a pedagogical model for health pharmacology teaching

El Ciclo Integrativo de Aprendizaje Farmacológico (CIAF): descripción y validación de un modelo pedagógico para la enseñanza de farmacología en salud

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Abstract The teaching of Pharmacokinetics and Pharmacodynamics is a cornerstone of safe clinical reasoning in health professional training. However, the predominance of traditional expository models and the absence of contextualized pedagogical strategies produce persistent cognitive gaps in students. To describe the development process and theoretical-methodological foundations of the Integrative Cycle of Pharmacological Learning (CIAF), an original pedagogical model developed over a three-year period of teaching innovation in the Angolan context. Qualitative-descriptive research using a Design-Based Research approach, conducted in a higher health education context in Angola, between 2023 and 2026, with 873 students from Nursing and Nutrition programs. The CIAF is structured in five sequential and interdependent phases: Cognitive Diagnosis, Guided Planning, Scientific Visualization, Active Learning, and Intelligent Assessment. Its implementation produced a reduction in the final failure rate from 14.1 to 3.6% and in the initial diagnostic failure rate from 42 to 21% over three consecutive academic years. The CIAF demonstrated efficacy, replicability, and contextual adaptability to the needs of pharmacology teaching in the Portuguese-speaking African context, with potential for transfer to other health sciences disciplines.

Keywords active learning, artificial intelligence, educational model, health education, pedagogical innovation, pharmacokinetics.

Resumen La enseñanza de Farmacocinética y Farmacodinámica es uno de los pilares del razonamiento clínico seguro en la formación en salud. Sin embargo, el predominio de modelos expositivos tradicionales y la ausencia de intervenciones contextualizadas en el aula generan de manera continua brechas cognitivas desalineadas en los estudiantes. Describir el proceso integrativo y las bases conceptuales teórico-metodológicas del CIAF, que constituye un modelo de enseñanza propio concebido a lo largo de tres años, en el contexto angolano de innovación educacional, a partir de esta estrategia de aula. Investigación cualitativa-descriptiva, basada en diseño (Design-Based Research), desarrollada en el contexto de la educación superior en salud en Angola (2023-2026), con 873 estudiantes de los programas de Enfermería y Nutrición. El CIAF posee componentes secuenciales e interdependientes organizados en cinco fases: Diagnóstico Cognitivo, Planificación Orientada, Visualización Científica, Aprendizaje Activo y Evaluación Inteligente. Se obtuvo una reducción de la tasa final de reprobación del 14,1 al 3,6%, y de la tasa de fracaso en el diagnóstico inicial del 42 al 21% a lo largo de tres años académicos consecutivos. El CIAF demostró ser un modelo educacional exitoso en el África lusófona, transferible a otras disciplinas del área de la salud y adaptado al contexto para la enseñanza de farmacología.

Palabras clave aprendizaje activo, inteligencia artificial, modelo educacional, enseñanza en salud, innovación pedagógica, farmacocinética.

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PUBLIS EDITORIAL

Introduction

The education of health professionals in the pharmacological sciences represents one of the greatest pedagogical challenges in contemporary higher education (Omar & Barwick, 2026). Pharmacokinetics and pharmacodynamics, disciplines that underpin therapeutic rationality and patient safety, require students to integrate physiological, biochemical, mathematical, and clinical knowledge, a capacity that is rarely developed through traditional lecture-based methodologies (Rang et al., 2020).

The World Health Organization (2024) estimates that approximately 50% of medication prescriptions and administrations worldwide involve some degree of irrational use, frequently associated with educational gaps in pharmacokinetic principles. This finding gives the teaching of this discipline a dimension that extends beyond the academic sphere: it is a matter of public safety and institutional responsibility in the education of future professionals.

In the Angolan context, where higher education in the health sciences is undergoing rapid expansion, the challenges are particularly significant. The heterogeneity of the student population, with classrooms comprising individuals ranging from 19 to 53 years of age and presenting diverse educational backgrounds, gaps in foundational knowledge in the exact and biological sciences, and the prevalence of teacher-centered pedagogical models systematically result in passive and decontextualized learning. Ausubel (2000) refers to this approach as rote or mechanical learning, in contrast to meaningful learning, which is an essential condition for the development of safe clinical reasoning.

The international literature consistently documents the benefits of active methodologies, pedagogical personalization, and the integration of educational technologies in health sciences education (Hattie, 2009; Mayer, 2009; Tomlinson, 2014). Nevertheless, the transfer of this evidence to Portuguese-speaking African contexts remains limited, both because of the scarcity of locally tested models and the lack of publications documenting systematically organized experiences within this geographical and linguistic setting.

It is within this context that the Ciclo Integrativo de Aprendizaje Farmacológico (CIAF), or Integrative Pharmacological Learning Cycle, emerged. The CIAF is an original pedagogical model developed and empirically validated over three consecutive academic years (2023–2026). It integrates cognitive assessment, personalized instruction, technology-mediated scientific visualization using Artificial Intelligence (AI), active methodologies, and continuous formative assessment.

This article aimed to describe the development process and the theoretical and methodological foundations of the CIAF, documenting its five-phase structure, the theoretical frameworks that support it, and the quantitative results observed throughout the three-year implementation period. Its purpose is to provide a replicable model for pharmacology and health sciences educators working in similar contexts.

Methodology

This study adopted a Design-Based Research (DBR) approach, a methodological framework developed to investigate educational interventions in real-world contexts and characterized by iteration, the integration of research and practice, and an orientation toward generating transferable principles (The Design-Based Research Collective, 2003). DBR combines scientific rigor with sensitivity to practical contexts, making it particularly suitable for developing and validating innovative pedagogical models under ecologically valid conditions.

The study was conducted through three iterative cycles corresponding to the 2023–2024, 2024–2025, and 2025–2026 academic years at a Faculty of Medical and Health Sciences in Cuito, Angola. A total of 873 students enrolled in Nursing and Nutrition programs participated in the study, with 361, 292, and 220 students in each respective academic year. Participants were divided into three age groups: 18–29 years, 30–39 years, and 40–55 years. During each cycle, the pedagogical model was implemented, evaluated, and refined based on the data collected, following a continuous improvement process that constitutes the methodological essence of DBR.

Quantitative data were obtained from two sources: the institutional academic management system for the 2023–2024 and 2024–2025 academic years, and the physical course records for 2025–2026. Data collection instruments included a standardized initial diagnostic test administered on the first day of each academic year; regular and supplementary assessments conducted according to the institutional academic calendar; and records of attendance and students' age and gender profiles.

Data analysis followed a mixed-methods approach. Descriptive statistics were used to analyze the quantitative data, including pass rates, failure rates, and diagnostic test failure rates by academic year and age group. Interpretive qualitative analysis was used to document the pedagogical decisions made during each cycle and the process through which the model was refined. Triangulation of the quantitative and qualitative dimensions strengthened the conclusions and made it possible to distinguish the effects of the model from those associated with the demographic characteristics of the groups.

The study was conducted in accordance with the ethical principles governing educational research. Data are presented exclusively in aggregate form to preserve student anonymity, and the reported results refer to the collective performance of each group rather than to identifiable individual assessments.

Results and discussion

The Integrative Pharmacological Learning Cycle (CIAF) (Table 1) is a pedagogical model structured into five sequential and interdependent phases, which form an intentional, adaptive, and student-centered learning cycle. The term "cycle" reflects the model's iterative nature: the data generated in Phase 5—Intelligent Assessment—feed back into Phase 1—Cognitive Diagnosis—of the subsequent cycle, creating a continuous improvement system that self-regulates according to the actual profile of each group.

Phase 1—Cognitive Diagnosis: This phase constitutes the essential starting point of the cycle. Before any pedagogical intervention, a standardized diagnostic test is administered to assess students' mastery of the conceptual prerequisites: Cell Biology, Organic Chemistry, Anatomy, and Physiology. The results directly inform Phase 2, ensuring that personalization is based on evidence rather than assumptions. Over the three-year period, the diagnostic failure rate decreased from 42 to 21%, documenting the model's progressive effect on students' initial level of preparedness.

Phase 2—Guided Planning: Based on the diagnostic results, students are classified into three competency levels—basic, intermediate, and advanced—and differentiated learning pathways are developed. This approach is directly aligned with concept of differentiated instruction (Tomlinson, 2014): personalization is not a luxury but a measurable pedagogical necessity. In practice, differentiation is reflected in the selection of reading materials, the level of complexity of clinical cases, and the pace of progression through the course content.

Phase 3—Scientific Visualization: The inherently invisible and dynamic nature of ADME processes constitutes the main cognitive obstacle in pharmacokinetics education. Phase 3 addresses this challenge through the use of AI-mediated visual resources, including dynamic infographics created with ChatGPT and Microsoft Copilot; instructor-developed educational videos with synthesized narration; interactive concentration–time curve simulators, such as WebPKS and the PK Visualization Tool; hyperrealistic images of physiological processes; and content organization through NotebookLM. Mayer (2009) demonstrated that the intentional combination of text and images produces significantly greater learning gains than verbal instruction alone.

Phase 4—Active Learning: During this phase, students engage with real or simulated clinical cases that require the integrated application of the knowledge acquired in the previous phases. The strategies employed include problem-based learning (PBL), therapeutic role-play, structured clinical debates involving collaborative problem-solving, and gamification activities incorporating applied pharmacokinetics. According to Bonwell and Eison (1991), active learning promotes greater retention, engagement, and transfer of knowledge to practical contexts, a premise supported by the performance data observed throughout the three-year period.

Phase 5—Intelligent Assessment: Assessment within the CIAF is intended primarily to improve learning rather than to classify students (Black & Wiliam, 1998). The instruments used include adaptive quizzes with immediate feedback, administered through Google Forms and ArchiMeds; AI-mediated progress analysis; and structured verbal synthesis activities in which students explain and integrate the content learned. The data generated during this phase inform the diagnosis of the subsequent cycle, thereby providing the CIAF with its adaptive dimension.

The data reveal a consistent pattern of improvement (Table 2): the final failure rate decreased from 14.1 to 3.6%, representing a relative reduction of 74.5% over the three-year period. The overall pass rate reached 96.4% in the 2025–2026 academic year, despite an increase in the proportion of students aged 40–55 years—historically the most challenging group in regular assessments—from 3.2 to 5.5% of the total cohort. This finding demonstrates the robustness and adaptability of the model in addressing the actual diversity of the student population.

Table 1. Structure of the Integrative Pharmacological Learning Cycle (CIAF)

Phase	Designation	Theoretical Foundation	Instruments/Strategies
1	Cognitive diagnosis	Ausubel (2000): meaningful learning	Standardized diagnostic test; analysis of students' age and academic profiles
2	Guided planning	Tomlinson (2014): differentiated instruction	Competency-level grouping; differentiated learning pathways; personalized reading lists
3	Scientific visualization	Mayer (2009): multimedia learning	AI tools (ChatGPT, Copilot, and NotebookLM); infographics; instructor-created videos; ADME simulators
4	Active learning	Freire (1996); Bonwell and Eison (1991)	Clinical cases; problem-based learning (PBL); therapeutic role-play; structured clinical debates
5	Intelligent assessment	Black and Wiliam (1998): assessment for learning	Adaptive quizzes; automated feedback; student-led verbal synthesis

Table 2. Evolution of academic performance by academic year (2023–2026)

Academic Year	Regular pass rate	Overall pass rate	Final failure rate / Change (pp)
2023–2024 (n = 361)	75.9	85.9	14.1 / —
2024–2025 (n = 292)	83.9	94.2	5.8 / +8.3 pp
2025–2026 (n = 220)	54.5	96.4	3.6 / +2.2 pp

pp = percentage points.

Source: Institutional academic management system and physical course records.

A particularly significant result is the evolution of performance in the initial diagnostic assessment, as documented in Table 3.

Table 3. Evolution of the failure rate in the initial diagnostic assessment (2023–2026)

Academic year	Initial diagnostic failure rate	Change
2023–2024	42	—
2024–2025	34	−8 pp
2025–2026	21	−13 pp

Source: Course diagnostic assessment records.

The 21-percentage-point reduction in the initial diagnostic failure rate suggests a positive feedback effect of the model: as the CIAF was implemented and its strategies were disseminated among faculty members, students entered the course progressively better prepared. This spillover effect, which extends beyond the classroom and influences earlier stages of training, represents one of the most relevant and unexpected findings of the study, with implications for institutional curriculum management.

A distinctive feature of the CIAF is the gradual and intentional integration of educational technologies throughout the three years of implementation. During the first year (2023–2024), the interventions focused on pedagogical personalization and the adoption of static visual resources. In the second year (2024–2025), systematically organized external ICT resources were introduced, including Khan Academy, Osmosis, internationally recognized educational videos, and digital simulators of pharmacokinetic curves. In the third year (2025–2026), AI became a central pedagogical tool: ChatGPT was used to create infographics and personalized clinical cases; NotebookLM supported content synthesis and organization; Microsoft Copilot facilitated real-time scientific research; and AI-based video and image generators were used to produce original teaching materials aligned with the specific difficulties identified through the diagnostic assessment.

This progression was not arbitrary; it was guided by the continuous assessment of students' needs and the systematic evaluation of the impact of each technology introduced. The result was a qualitative transformation of the teaching materials, which became more visual, contextualized, and substantially more motivating—factors that Mayer (2009) identifies as essential to the effectiveness of multimedia learning.

Conclusions

This article described the development and theoretical-methodological foundations of the Integrative Pharmacological Learning Cycle (CIAF), an original pedagogical model implemented over three consecutive academic years with 873 health sciences students in Angola. The results indicate that the CIAF is an effective, adaptable, and potentially replicable response to the challenges of teaching pharmacology in heterogeneous student populations, as reflected in the reduction of the final failure rate from 14.1 to 3.6%. Its main contributions include the integration of diagnosis, personalization, scientific visualization, active learning, and formative assessment into a continuous cycle; the practical incorporation of artificial intelligence into pharmacology education; and the development of a model that may be transferred to other health sciences disciplines and comparable educational contexts. Although the absence of a control group and the non-experimental design limit causal interpretation, future experimental or quasi-experimental studies could assess its effectiveness in other institutions. Overall, the CIAF does not seek to replace teachers but to strengthen their pedagogical practice by making abstract concepts more understandable, clinically relevant, and actively constructed by students.

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Conflicts of interest

The authors declares that she has no conflict of interest.

Author contributions

Daryanis Guilbeaux: Conceptualization, formal analysis, research, methodology, writing the original draft, writing, review and editing.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Statement on the use of AI

The author acknowledges the use of generative AI and AI-assisted technologies to improve the readability and clarity of the article.