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Pharmacomathematics: Charting the Road to Health; The Fundamental Role of Mathematics in the Health Sciences

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Abstract*– In the dynamic context of current healthcare, the role of mathematics stands out as essential for scientific advancement in disease treatment. This study investigates the integration and perception of mathematical competencies in the curriculum of health science students, with particular attention to the emerging discipline of pharmaco-mathematics. A survey was conducted among 416 students of medicine, nursing, dentistry, and pharmaceutical biochemistry across four Ecuadorian academic institutions to assess their appreciation of the relevance of mathematics in their professional education. Findings reveal a significant association between academic progress and the perception of competence in pharmacological models and their clinical application. This analysis underscores the need for a deeper integration of mathematical competencies in healthcare education programs, aiming to equip future professionals with the critical skills required to address the challenges inherent in contemporary healthcare.

***Keywords* Mathematical pharmacology · Model identifiability · Model development · Receptors Drug-disposition · Dose-response- time analysis**

I. Introduction

In the rapidly evolving realm of medicine and healthcare, where each discovery may signify the difference between life and death, mathematics emerges as a fundamental and indispensable pillar. From the conception of personalized treatments to the optimization of hospital processes, health sciences increasingly rely on mathematical principles to advance the understanding and treatment of diseases [1-7].

In recent years, there has been a growing interest in the utilization of mathematical tools to better comprehend pharmacological processes. The integration of mathematical concepts into the study of pharmacokinetic and pharmacodynamic models has enabled addressing the inherent complexity in the interaction between drugs and biological organisms [8-13].

The necessity to integrate mathematics into the curricula of healthcare professions becomes increasingly evident as medicine progresses towards more personalized and data-driven approaches. Future healthcare professionals must be equipped not only with a profound knowledge of anatomy and physiology but also with skills to interpret and critically analyze medical data [12,14,15].

Furthermore, it has been evidenced that mathematical knowledge can facilitate the interpretation of complex data sets, which is crucial in the research and development of effective pharmacological treatments. The inclusion of courses in statistics, biostatistics, and data analysis in the curricula of healthcare programs will not only prepare students to confront the challenges of modern clinical practice but also foster a deeper understanding of the scientific basis of medicine. By understanding how to apply mathematical principles in the healthcare context, future healthcare professionals will be able to make more informed and evidence-based decisions [12,16,17,18].

As we move towards a healthcare paradigm increasingly centered on the patient and data-driven, higher educational institutions must recognize and address this need to ensure that healthcare professionals are adequately prepared to confront the challenges of the 21st century [6,7].

The interrelation between medicine and mathematics extends beyond mere statistical modeling and encompasses the biophysical implications related to human physiology and pathophysiology. The application of mathematical principles in the medical field not only forms the basis of advanced analytical models but also drives the development of data mining optimization, visualization methods, and algorithmization [19,20].

The integration of mathematics into the medical context presents inherent complexity, as it involves an interaction between medicine and mathematics that spans a variety of variables and a dynamic bidirectional relationship. This process demands both creativity and skills to establish links between different areas of scientific knowledge, thereby fostering a transdisciplinary approach [21].

This mathematically precise approach has led to the emergence of a new paradigm in computational medicine and healthcare that utilizes a variety of mathematical tools. Pharmacokinetics and pharmacodynamics modeling, included in mathematical pharmacology along with analysis and machine learning, help address increasingly complex medical problems. This approach starts with data management, proceeds to hypercomplexity analysis, and culminates in the implementation of artificial intelligence systems and digital ecosystems in healthcare [22,23].

However, there still exists a gap in our understanding of how exactly mathematical knowledge influences the comprehension and application of pharmacological principles, especially among students in health-related academic programs. It has not been established to what extent the mastery of specific mathematical concepts correlates with better performance in understanding pharmacological models and their application in real clinical contexts. Likewise, the extent to which students' academic advancement may modulate this relationship between mathematical knowledge and pharmacological understanding has not been thoroughly explored.

Therefore, in this research, we aim to address these uncertainties by experimentally examining the impact of mathematical knowledge on the comprehension of pharmacokinetic and pharmacodynamic models, as well as on the application of pharmacological principles, specifically in the context of patients. We have designed a study involving students from different semesters of health-related academic programs at four university institutions.

II. METHODOLOGY

A. Study Population

At the outset of the study, a review of the curricula of the participating university institutions was conducted, specifically in the disciplines of medicine, nursing, dentistry, and pharmaceutical biochemistry. Based on these data, contact was established with the teachers responsible for subjects that incorporate mathematics as a fundamental element or tool in their content.

As a result of this process, four priority indicators were identified, focusing on the use of mathematical models and calculations in the pharmacological domain. The survey results prioritized topics emphasizing the use of mathematical models and calculations. Thus, four indicators were obtained: Calculation of drug doses, interpretation of plasma concentration-time graphs, application of pharmacokinetic models to anticipate drug absorption, distribution, metabolism, and elimination processes in the body following administration, and use of mathematical models in pharmacodynamics to predict drug interaction with cellular receptors and resulting biological effects in the body.

Based on the mentioned indicators, a survey was conducted on students of health-related careers at various Higher Education Institutions, from June 2023 to January 2024. The study population consisted of 500 students (416 students completed the entire survey) from medicine, dentistry, nursing, and pharmaceutical biochemistry, spanning from the first to the tenth semester, as per the case of universities and careers.

B. Study Design

A quantitative observational and cross-sectional study was conducted to gather data on students' perceptions of the importance of studying mathematics in their healthcare careers. Participants were selected through random sampling.

C. Data Collection Instrument

The questionnaire design was based on previous literature reviews and consultations with experts in the field of health education and mathematics. Expert teachers in the various professional areas of health sciences in medicine, nursing, dentistry, and biochemistry, and pharmacy were interviewed. Closed-ended questions were designed to evaluate various aspects of students' perceptions, including the importance of mathematics in their professional formation, specific areas of healthcare where they perceive mathematics as most relevant, and perceived difficulties in studying mathematics. This questionnaire consisted of 11 structured questions. The first section gathered sociodemographic information, including variables such as age, gender, and the level of study the student was pursuing. The second section of the questionnaire included an item requesting participants to rate their perception of the essential mathematical analytical skills in the field of health sciences and their importance, categorizing them on a 3-point Likert scale. Likewise, the third part of the questionnaire required participants to respond to multiple-choice questions aimed at evaluating their perceptions about the application of numerical competencies in subjects developed as professionalizing such as microbiology, pharmacology, statistics, and public health, among others and concluded with the topics presented on the use in dosage calculation, interpretation of plasma concentration-time graphs, application of pharmacokinetic models to anticipate drug absorption, distribution, metabolism, and elimination processes in the body following administration, and use of mathematical models in pharmacodynamics to predict drug interaction with cellular receptors and resulting biological effects in the body.

Before the study's commencement, the instrument underwent evaluation by a subject specialist, followed by a pilot study with a random sample of 30 students to obtain feedback on its effectiveness. After incorporating necessary adjustments based on the pilot study results, the final version of the questionnaire was distributed among the planned research participants. A reliability analysis was conducted using SPSS software to calculate the Cronbach's alpha coefficient, with a threshold value of 0.70 suggesting the adequacy of the questionnaires for the study. It is important to note that the data collected during the pilot study were not included in the final analysis.

D. Data Collection Procedure

To collect the data, an instrument was designed and created using Microsoft Forms. Students were invited to respond via a web browser from a mobile device or computer. Out of the 500 students contacted, 416 responded to the instrument, representing 83.2% of the total. It is noteworthy that all procedures followed ethical standards by the Declaration of Helsinki (updated in 2013).

The instrument sent focused on two main domains: 1) students' perception of the usefulness of mathematics and its applicability during classes taught by faculty, and 2) the type of activities carried out during the academic period, their implementation, and frequency. Responses were presented on a Likert scale ranging from "Strongly Disagree" to "Strongly Agree," with values graded from 1 to 3, respectively.

E. Data Analysis

Statistical analysis was conducted by presenting all data in the form of mean ± standard deviation of the mean (SD) and evaluated using SPSS 26.0 statistical software. To compare between groups that meet normal distribution and homogeneity of variance, an independent sample t-test was conducted. In the case of data meeting normal distribution but not homogeneity of variance, Welch's t-test was used. On the other hand, for groups not meeting normal distribution, the Wilcoxon rank-sum test was applied. A value of $p < 0.05$ was considered statistically significant. It is important to highlight that responses were collected anonymously, and no personal or confidential information of the respondents was manipulated or recorded.

F. Ethical Considerations

This study was conducted following the ethical principles of scientific research. The confidentiality of the collected data was ensured, and informed consent was obtained from all participants before they participated in the study.

III. RESULTS

The sample consisted of a total of 500 students from healthcare careers: in medicine, nursing, dentistry, biochemistry, and pharmacy, across four universities in Ecuador, of which 416 responded to the survey. Their sociodemographic data are reflected in Table I.

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TABLE I
SOCIO-DEMOGRAPHIC DATA

Variable	N	Mean	Median
Gender			
Male	134		
Female	282		
Age	416	21.65	21

The average age of the students was 21.65 years, with a median of 21 and a mode of 20 years. Regarding academic level, 233 (56%) students were in the first to third semester, 61 (14.6%) students were in the fourth to sixth semester, and 122 (29.4%) students were in the seventh to tenth semester. The distribution by gender showed a predominance of females (282 females; 67.78%) compared to male students (134 males; 32.22%).

Upon analyzing the data obtained from the questions regarding the applications of mathematics in the selected topics from interviews with teachers from various healthcare science careers, results are evidenced in relative frequencies, expressed in Figures 1 to 4.

Following an analysis of the curricula of the participating institutions, it was observed that, in three universities, the careers of medicine, nursing, and dentistry do not include a separate mathematics course in their curriculum. Instead, mathematical concepts are integrated transversely into subjects such as biostatistics, biochemistry, and pharmacology. However, in the fourth university, a specific mathematics course is identified in these careers.

On the other hand, in the biochemistry and pharmacy careers, differences were found in the curricula among institutions. While one university describes two levels of mathematics and two of physical chemistry that serve as a basis for pharmacology subjects, the presence of a single level of mathematics is evident in other institutions.

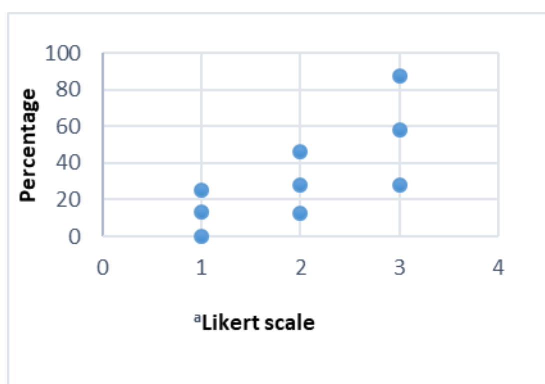

Fig. 1 Calculation of medication doses

[a] Scale 1. Disagree 2. Partially agree 3. Completely agree.

Analyzing the data presented in Figure 1, related to the first indicator, as students progress in their studies, there is a significant increase in the perception of competence in medication dosage calculation. The group of students from the 7th to 10th semester shows a clear trend towards total agreement (87.2%), suggesting that these students feel much more confident and competent in this skill compared to the groups from the 1st to 3rd and 4th to 6th semesters.

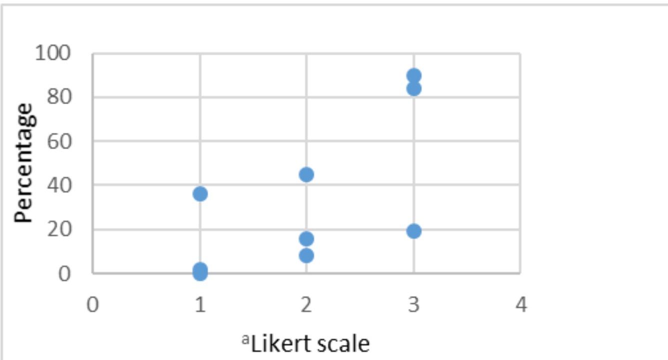

Fig. 2 Interpretation of plasma concentration-time graphs

[a] Scale 1. Disagree 2. Partially agree 3. Completely agree.

The results of this evaluation in the second indicator, shown in Figure 2, reveal a significant trend in the perception of competence among different academic levels in interpreting plasma concentration-time graphs. It is evident that as students progress in their education, from the first to the last semesters, they experience a considerable increase in their confidence and ability to interpret these graphs, as demonstrated by the increasing percentage of students who 'Completely Agree' with this competence, which is evidenced by the 89.6% obtained at the end of their career. This trend highlights the critical importance of acquiring the ability to interpret plasma concentration-time graphs throughout the academic formation in health sciences.

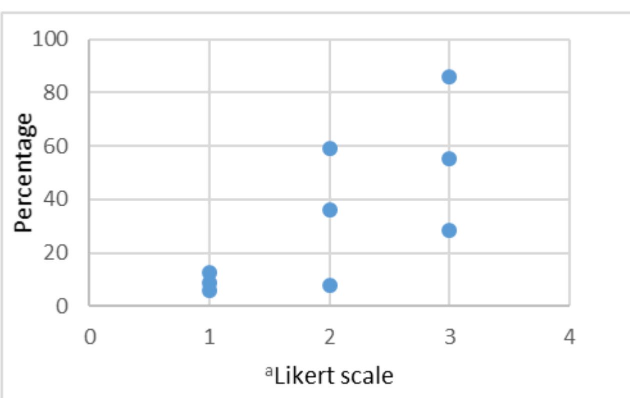

Fig. 3 Application of pharmacokinetic models to anticipate the processes of drug absorption, distribution, metabolism, and elimination in the body following administration.

[a] Scale 1. Disagree 2. Partially agree 3. Completely agree.

Regarding the third indicator, the collected data reveal significant variations in students' responses regarding the increasing perception of the importance of using mathematical models to anticipate drug absorption, distribution, metabolism, and elimination processes in the body. According to the data shown in Figure 3, for the group of students from the first to third semester, 12.5% indicated insufficient perception, 59.3% demonstrated a moderate perception, and 28.2% showed a high perception. For the group of students from the fourth to sixth semester, 8.6% indicated insufficient perception, 35.9% demonstrated a moderate perception, and 55.5% showed a high perception. Finally, the group of students from the seventh to tenth semester exhibited a significant improvement in perception, with 6% indicating insufficient perception, 7.8% demonstrating a moderate perception, and 86.2% showing a high perception.

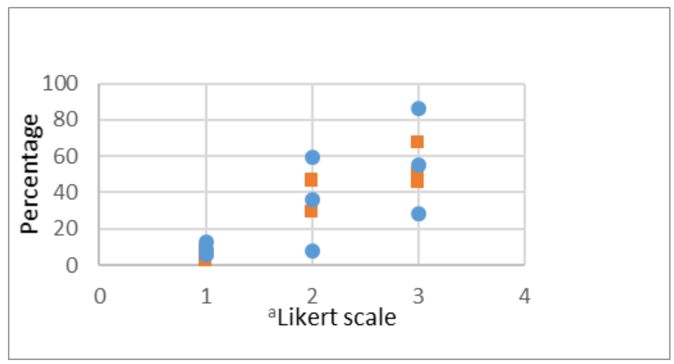

Fig. 4 Use of mathematical models in pharmacodynamics to predict drug interaction with cellular receptors and the resulting biological effects in the body.

[a] Scale 1. Disagree 2. Partially agree 3. Completely agree.

The analysis of the results regarding the fourth indicator, shown in Figure 4, which addresses students' perception of the usefulness of mathematical models in pharmacodynamics to predict drug interaction with cellular receptors and biological effects in the body, reveals significant differences between the different student groups. In the group of students from the 1st to 3rd semester, 8.4% disagree with the usefulness of such models. However, it is notable that 46.3% partially agree, while 45.3% completely agree. On the other hand, in the group of students from the 4th to 6th semester, only 2.3% disagree, with 46.8% partially agreeing, and a significant 50.9% expressing complete agreement. Finally, in the group of students from the 7th to 10th semester, only 3% disagreed, while 29.5% partially agree. However, it is evident that the majority, with 67.5%, completely agree. These findings suggest a trend towards an increase in positive perception regarding the usefulness of mathematical models in pharmacodynamics as students progress in their academic formation.

IV. DISCUSSION

In this study, we examined the impact of mathematical knowledge on the comprehension of pharmacokinetic and pharmacodynamic models, as well as the application of pharmacological principles in the context of patients, among students from different semesters of academic programs related to the field of health in four universities in Ecuador. The sample included a total of 500 students, of which 416 actively participated in the study by providing complete responses to the survey. The results revealed significant variations in the comprehension of pharmacokinetic, pharmacodynamic models, and the practical application of pharmacological concepts, according to the academic advancement level of the students. Overall, gradual progress in conceptual understanding was observed, demonstrating a solid foundation in mathematical analysis and logic as students progressed in their studies, with notable improvement among those in more advanced semesters.

To our knowledge, this is the first study to converge mathematical modeling and pharmacology, contributing to an emerging field: pharmacomathematics. This interdisciplinary approach, pioneering in nature, seeks to unveil new perspectives for a detailed understanding of the therapeutic effects and mechanisms of action of pharmacological agents within the context of health sciences. Mathematics, universally recognized as a system of representation facilitating environmental perception, should occupy a fundamental place in the academic curriculum of health-related careers. This is because it provides clear support for understanding highly complex processes such as pharmacokinetics and pharmacodynamics. Beyond traditional studies focused on numbers, shapes, and patterns, mathematics offers fundamental tools for various disciplines, including health sciences, the focus of this research. This discipline not only fosters the development of logical and systematic capacity but also the ability to address and solve a variety of problems effectively. Success in this area will play a crucial role in opening new opportunities in both higher education and research.

Stratified analysis of the surveys revealed an association between student opinions and progress in their academic training, demonstrating a positive approach to the use of methodologies in the early semesters of the program. These findings indicate that 82.63% of the students in our study agree with previous research highlighting basic science students' preference for case applicability in their learning. Conversely, it is acknowledged that health science students show a favorable perception of mathematics by demonstrating its applicability in case studies, underscoring the importance of direct interaction that these careers have with patients in the development of their clinical skills. These results offer an effective strategy to improve the quality of health education and professional development of students, ensuring optimal care for patients through the enhancement of medical evidence and the application of mathematical and statistical concepts in the evaluation and discrimination of information.

The obtained results revealed significant variations in the comprehension of pharmacokinetic, pharmacodynamic models, and the practical application of pharmacological concepts, according to the academic advancement level of the students. Thus, we can affirm that the percentage of students considering the study unnecessary decreases from 10.45% in the initial levels to 4.5% in the 7th to 10th semesters. According to the mentioned percentages, we can conclude that as time progresses in the health science career, there is gradual progress in the understanding of these concepts, indicating a solid foundation in mathematical analysis and logic as students advance in their studies, with improvement noted in students in more advanced semesters. These findings support the importance of integrating mathematical knowledge into the education of health science students and provide valuable insights for the development of curricula that promote a more detailed and practical understanding of pharmacological principles.

Particularly, it was observed that students of biochemistry and pharmacy had a more solid initial understanding of pharmacokinetic and pharmacodynamic models compared to students of medicine, nursing, and dentistry. This finding could be attributed to the nature of their previous training in areas related to pharmacology and chemistry, due to a greater emphasis on mathematics in their curriculum, which provided them with a solid foundation for understanding the mathematical concepts involved in pharmacokinetic and pharmacodynamic models.

On the other hand, students of medicine, nursing, and dentistry, although showing a more limited initial comprehension, experienced significant growth in their pharmacomathematical competence throughout their education. This suggests that, despite starting from a less solid base, these students were able to develop relevant mathematical skills to understand and apply pharmacokinetic and pharmacodynamic models in the context of their clinical practice.

Mathematical analysis of pharmacological models is increasingly important for drug development. Greater emphasis on mechanistic models has greatly improved our qualitative understanding of complex biological systems, providing essential modular elements of the processes involved in a wide range of physiological systems, including drug-target interaction models. Another pharmacomathematical model is the basis of signal transduction across the cell membrane, these models demonstrate complex and interesting kinetics that are directly related to the action of drugs.

Mathematics in this context is a tool of precision medicine, providing answers to the inherent complexities of human diseases, where symptoms can vary from person to person. Traditionally, treatments have been developed based on what works for large groups of patients, without considering the details of individual cases. However, precision medicine through pharmacomathematics seeks to change this paradigm and focus healthcare on a personalized approach that considers the uniqueness of each patient. In this sense, researchers and healthcare professionals are using mathematical and statistical tools to analyze and understand large amounts of clinical data, to adapt treatments more accurately to the individual needs of each patient. Mathematics thus emerges as a key element on the path towards a more precise and personalized medicine.

We have as reference the incorporation of mathematical and statistical models in medical areas such as cardiology and oncology, which mark notable progress towards a more specific and individually adapted medicine. In cardiology, these models allow a detailed analysis of cardiac function and early detection of abnormalities, thus facilitating the adaptation of treatments without the need for invasive interventions. On the other hand, in oncology, mathematical models offer crucial information about the effectiveness of management and tumor evolution, supporting clinical decisions and improving patient outcomes. This application of modeling provides a valuable tool for precise diagnostics, treatment evaluations, and selection of therapies tailored to the individual needs of each patient. The integration of mathematical concepts into the education of healthcare professionals will lay a solid foundation for a deep understanding of fundamental aspects such as pharmacokinetics and pharmacodynamics in the medical field.

The results obtained from surveys conducted on students at different academic levels reveal a trend towards a greater understanding of mathematical concepts as students progress in their education. This suggests the effectiveness of progressive and adapted teaching that allows students to acquire and apply this knowledge effectively in their future clinical practice. In this way, in a dosage calculation indicator, we managed to obtain 100% of students aware and empowered to use mathematical concepts for medication dosage personalization.

Practical implications derived from the analysis include the need to update curricula, offer continuous education for healthcare professionals, promote interdisciplinary collaboration, and raise public awareness about the importance of mathematics in health sciences, with a visionary focus on pharmacomathematics and precision medicine.

A limitation of our study lies in the self-reported nature of the data collected through surveys, which could introduce response biases and affect the validity of the results. Additionally, the sample may not be fully representative of the student population in health-related careers in Ecuador, which could limit the generalization of our findings. Future research could address these limitations using mixed methods and a more diverse and representative sample.

V. CONCLUSIONS

In conclusion, our study contributes to the understanding of how students in health-related fields acquire and apply mathematical knowledge in the context of pharmacomathematics. These findings suggest implications for the design of educational programs and the formulation of teaching strategies that promote effective mastery of mathematical skills in the health domain.

The practical implications derived from the analysis propose the need to update curricula, provide ongoing training for healthcare professionals, foster interdisciplinary collaboration, and raise public awareness about the importance of mathematics in healthcare. These measures could significantly contribute to the advancement of health sciences.

This is relevant not only for designing educational programs that promote a deep mastery of mathematical skills necessary for effective clinical practice but also for understanding the progression of mathematical competence in students pursuing health-related careers.

Therefore, the premise is established that mathematics plays a role in health sciences, serving as a component in advancing the understanding and treatment of diseases. This initial focus sets the groundwork for further investigative analysis, highlighting the relevance of mathematics in the healthcare field. The authors wish to express their gratitude to the teachers for their collaboration, as well as to the students who participated in the study.

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