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IMMUNOLOGY IN MEDICINE: BRIDGING THE GAP BETWEEN THEORY AND CLINICAL PRACTICE[i]

Abdelkader Ouhtit[ii],
Anouar Aidoun,
El Mostafa Amiri,
Rajae Zerhane,
Rachid Janati-Idrissi
École Normale Supérieure (ENS),
Faculty of Sciences,
Abdelmalek Essaadi University,
Tetouan, Morocco

Abstract:
Immunology is a fundamental discipline in medical education, but is often perceived as challenging due to its complex concepts and cognitive demands. This study explores future physicians' perceptions of immunology, the difficulties they encounter, their use of educational resources, and the impact of immunology on their career choices. To accomplish this, we adopted a mixed approach by conducting two studies: a quantitative study to gather students' perceptions of immunology and a qualitative study analyzing the immunology course content for second-year medical students. The results reveal that while most students (88.8%) view immunology as essential or very essential to their medical training, and 59.3% report that immunology influences their choice of medical specialization, 55.5% of our sample feel underprepared to apply immunological concepts in clinical contexts. These findings underscore the need to modernize immunology education in medical faculties by incorporating interactive tools, emphasizing clinical applications, and addressing the cognitive challenges posed by the discipline.

Keywords: immunology; medical students; educational resources; career orientation

Résumé :
L'immunologie est une discipline fondamentale dans la formation médicale, mais elle est souvent perçue comme difficile en raison de la complexité de ses concepts et de ses exigences cognitives. Cette étude explore les perceptions des futurs médecins à l'égard de l'immunologie, les difficultés qu'ils rencontrent, leur utilisation des ressources

[i] L'IMMUNOLOGIE EN MÉDECINE : COMBLER LE FOSSÉ ENTRE LA THÉORIE ET LA PRATIQUE CLINIQUE

[ii] Correspondence: email abdelkader.ouhtit@etu.uae.ac.ma

pédagogiques, ainsi que l'impact de cette discipline sur leurs choix de carrière. Pour ce faire, nous avons adopté une approche mixte en menant deux études : une étude quantitative recueillant les perceptions des étudiants sur l'immunologie, et une étude qualitative analysant le contenu du cours d'immunologie destiné aux étudiants en deuxième année de médecine. Les résultats révèlent que, bien que la majorité des étudiants (88,8 %) considèrent l'immunologie comme essentielle ou très essentielle à leur formation médicale et que 59,3 % déclarent que cette discipline influence leur choix de spécialisation, 55,5 % de notre échantillon se sentent insuffisamment préparés à appliquer les concepts immunologiques en contexte clinique. Ces constats soulignent la nécessité de moderniser l'enseignement de l'immunologie dans les facultés de médecine en intégrant des outils interactifs, en mettant l'accent sur les applications cliniques et en tenant compte des défis cognitifs que pose cette discipline.

Mots-clés : immunologie ; étudiants en médecine ; ressources pédagogiques ; orientation professionnelle

1. Introduction

Immunology is one of the most central and dynamic fields in contemporary biological and biomedical sciences. According to Pradeu (2005, 2020), it forms a critical link between fundamental biology and medicine. Over the 20th century, its role has evolved significantly, gaining prominence in both biological research and societal applications. Contemporary and future medical challenges, such as combating AIDS and treating cancer, are closely tied to immunological advancements (Pradeu, 2005, 2020). Similarly, Janeway (2001) emphasizes immunology's pivotal role in understanding and managing infectious, autoimmune, allergic, and cancerous diseases (Ca, 2001). Progress in recognizing autoimmune diseases and addressing host-graft reactions has further underscored the importance of immunology for clinicians (Gell & Coombs, 1963).

The COVID-19 pandemic further demonstrated the societal significance of immunology, highlighting its impact beyond scientific realms. Immunological terms like "virus," "vaccine," "booster," "herd immunity," "lockdown," and "pandemic" became part of everyday discourse (Belhaj, 2020). Socially, new behaviors such as mask-wearing, social distancing, and vaccination campaigns emerged, while economically, the global vaccine market generated $141 billion in revenue in 2022 (WHO, 2023), surpassing Morocco's GDP for the same period (HCP, 2023). Consequently, immunology has become a staple of life sciences education, from middle school to advanced biomedical studies.

Despite its importance, immunology education faces several challenges. Rumelhard (1990) identifies the complexity of immunology as a major obstacle, requiring a systemic and interdisciplinary approach to understand concepts like regulation, systems, networks, and memory (Rumelhard, 1990). Beyond fostering critical thinking, analytical skills, and practical abilities (Bailin, 2002), immunology is essential for developing personalized treatments and immunotherapies such as monoclonal

antibodies, CAR-T cell therapies, and co-signaling inhibitors central to cancer and chronic infection treatments (Olive, 2020).

Given its relevance, understanding future physicians' perceptions and knowledge of immunology is crucial. Deonna (2006) notes that individual perceptions depend on how one views their environment (Deonna, 2006). This study focuses on immunology education for future physicians, introduced during their second year of medical school. For example, second-year students undertake a 73-hour module covering bacteriology, virology, and immunology (FMPT, 2023).

Immunity has long been associated with disease resistance, orchestrated by the immune system's coordinated responses (Silverstein, 2009). Abbas (2015) highlights that immunology examines these mechanisms and their roles in health (Abbas, 2015). Concepts such as innate and adaptive immunity, vaccines, inflammation, allergy, tumor immunotherapy, transplantation, and autoimmunity are integral to infectious diseases, pathology, clinical trials, and public health (Haidaris & Frelinger, 2019). Immunology bridges foundational medical knowledge and clinical practice (Peakman & Vergani, 2009). Mastery of immunological concepts enables future physicians to understand defense mechanisms, diagnose immune-related pathologies, develop prevention strategies, and optimize infectious and autoimmune disease management. Kolopp-Sarda (2008) stresses that such knowledge is vital for managing complex scenarios like graft rejection and developing tailored therapeutic approaches in transplantation (Kolopp-Sarda, 2008). However, immunology's interdisciplinary vocabulary poses significant challenges for students. Additional obstacles include pedagogical approaches, didactic materials, and the cognitive load associated with the discipline, which influence student motivation. Ryan (2000) asserts that learning requires the learner's cognitive, emotional, and behavioral engagement (Ryan & Deci, 2000).

The current state of research concerning the teaching of immunology in Moroccan medical faculties, focusing on pedagogical strategies, student perceptions, and the challenges encountered in explaining immunological concepts. To achieve this aim, the work was guided by the following research questions:

1) What are the difficulties hindering the teaching of immunology in Moroccan medical faculties?
2) What are the main pedagogical strategies used to address immunological topics?
3) What are the perceptions of medical students regarding immunology?

We hypothesize that the current immunology curriculum influences student motivation and their future career choices as medical practitioners.

2. Material and Methods

2.1 Research Design

This study employed a mixed-methods approach, combining qualitative and quantitative methods to analyze the presentation of immunology in the second-year medical immunology course and to identify students' perceptions of the discipline. Two distinct

studies were conducted: a questionnaire for students and a content analysis of the immunology course.

2.2 Research Population

Students: The first study involved 81 students (second- and third-year medical students). The inclusion of these groups is justified by the introduction of immunology in the second year of the medical faculty. In the third year, students begin clinical rotations in hospitals, where they can apply their immunology knowledge in real-world scenarios, providing an opportunity to assess the impact of theoretical teaching on clinical practice. Of the participants, 70.4% were women, and 66.7% were in their third year of medical studies.

Table 1: Distribution by Gender and Year of Study in Medicine

	Gender		Year of study in medicine	
	♀	♂	2nd Year	3rd Year
%	70.4	29.6	33.3	66.7

2.2.1 Immunology Course

The second study involved a content analysis of the immunology course provided to second-year medical students. The course materials were accessed via the Faculty of Medicine and Pharmacy of Tangier's Drive link for the 2023-2024 academic year.

2.3 Instruments

2.3.1 Student Questionnaire

A questionnaire was designed to evaluate students' perceptions of immunological concepts. Of the 100 students invited, 81 responded. They were informed of the study's objectives and assured of the anonymity of their responses. The questionnaire, based on a Likert scale, covered four areas: general information, knowledge of immunology, perceptions of immunology, use of resources and educational tools, and career orientation and perspectives.

2.3.2 Immunology Course Analysis Grid

To evaluate the presentation of immunology in the course for second-year medical students, a simplified analysis grid was developed based on a validated model by Roegiers (Gérard & Roegiers, 2009). The analysis focused on four criteria: the accuracy of immunological concepts, the connection between immunology and health, prevention and health promotion, and cultural and social sensitivity.

2.4 Validity and Reliability Tests

2.4.1 Student Questionnaire

The questionnaire underwent peer validation to assess its content. It was reviewed by five high school life sciences teachers to evaluate the clarity and precision of the questions. Based on their feedback, some questions were revised. To assess reliability (internal consistency), Cronbach's alpha test was applied. The results (calculated using

SPSS software) indicated satisfactory data collection instrument homogeneity ($\alpha \approx 0.77$), showing that the questionnaire items were well-correlated.

2.4.2 Immunology Course Analysis Grid

To ensure consistent analysis, the analysis grid was designed based on a tested and validated model by Roegiers.

2.5 Data Analysis

Quantitative and qualitative data were analyzed descriptively according to the questionnaire sections or the analysis grid, considering two criteria: frequency and specificity of responses. Data analysis was performed using SPSS software (IBM SPSS Statistics 28.0, Windows) and Excel (Microsoft Office Professional 2021, Windows).

3. Results

3.1 Analysis of the Immunology Course Content

Table 2 highlights that the immunology course is well-structured, with logical progression and effective illustrations, but it lacks clear learning objectives and summaries to consolidate knowledge. While the scientific language is appropriate, some sections are overly dense and less accessible due to the absence of practical examples. Modern concepts like immunotherapy are addressed, but the content could be further updated to include current controversies.

Table 2: Analysis of the Second-Year Medical Immunology Course

Criteria	Strengths	Weaknesses
Structure and Pedagogical Organization	- The course follows a logical and progressive structure, from fundamental basics. - Chapters are well-defined, facilitating navigation and review. - Diagrams and illustrations enhance the understanding of complex concepts.	- Learning objectives are not explicitly outlined at the beginning of each chapter. - The lack of summaries or key points at the end of chapters may hinder knowledge consolidation.
Clarity and Accessibility	- The scientific language is precise and suited to the students' academic level. - Complex terms are explained in detail (e.g., PRRs, MAMPs, MHC).	- Some sections are dense and require significant effort from students to comprehend. - Few practical examples or analogies to make concepts more accessible.
Scientific Update	- The course references recent works and modern concepts (e.g., immunotherapy, microbiota). - Contemporary approaches like mRNA vaccination and superantigens are mentioned.	- Recent developments (e.g., advances in immunotherapy or digital immunology) could be more extensively integrated. - Lacks discussion of current immunological controversies (e.g., vaccine hesitancy).
Engagement and Interaction	- Numerous illustrations and graphics provide visual interaction with the content.	- Few interactive activities or thought-provoking questions to engage students in active learning. - Absence of multimedia elements or digital platforms to complement the course.

Clinical and Interdisciplinary Integration	- Good coverage of immune mechanisms and their roles in diseases (cancers, infections, allergies).	- Limited integration with other medical disciplines (pathology, pharmacology). - Lack of concrete clinical case examples or pathological correlations.
Adaptability and Universality	- Fundamental concepts are universal and applicable in various medical contexts.	- Limited adaptations to the regional or cultural specificities of the student population (e.g., endemic diseases or local socio-economic contexts). - Absence of content on personalized medicine or approaches specific to vulnerable populations.

3.2 Medical Students' Perceptions of Immunology

3.2.3 Level of Knowledge in Immunology

Data from Figure 1 reveals that 48.1% of participants rate their knowledge of immunological concepts as moderate, while 40.7% consider themselves to have good mastery. Only 11.1% rate their knowledge level as low.

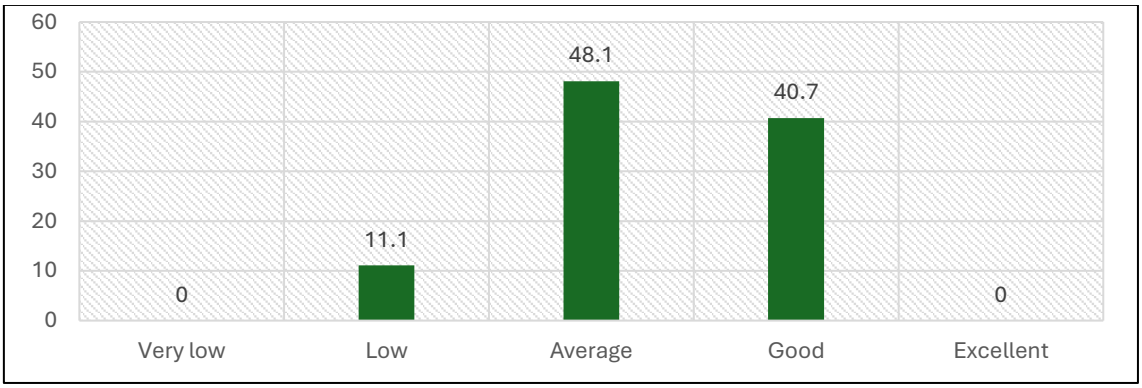

Figure 1: How Would You Rate Your Current Knowledge in Immunology?

3.2.4 Obstacles to Learning Immunology

Figure 2 highlights that the primary challenge in studying immunology is the complexity of its concepts, cited by 51.9% of respondents. Additional factors include high cognitive load (37%) and evaluation methods (7.4%). Only 3.7% of participants reported no difficulties in learning this subject.

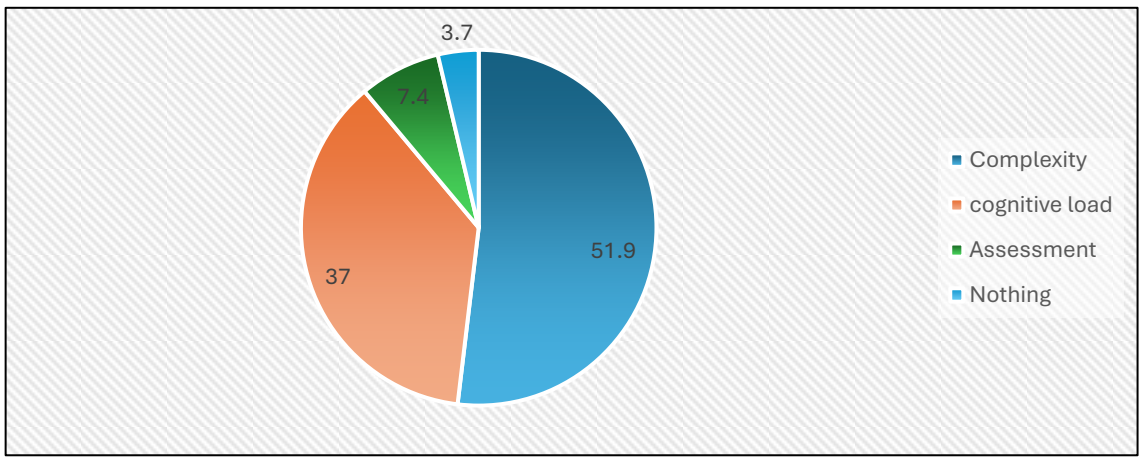

Figure 2: Aspects of Immunology Courses that Are Stressful

3.2.5 Use of Resources and Educational Tools

According to Figure 3, students utilize a variety of resources for studying immunology, with preferences distributed as follows:

- Lecture notes: 66.7%,
- Online videos (e.g., YouTube, Khan Academy): 40.7%,
- Specialized books and educational apps: 11.1%,
- Interactive simulations: 7.4%,
- Artificial intelligence (IA) tools (e.g., ChatGPT): 3.7%.

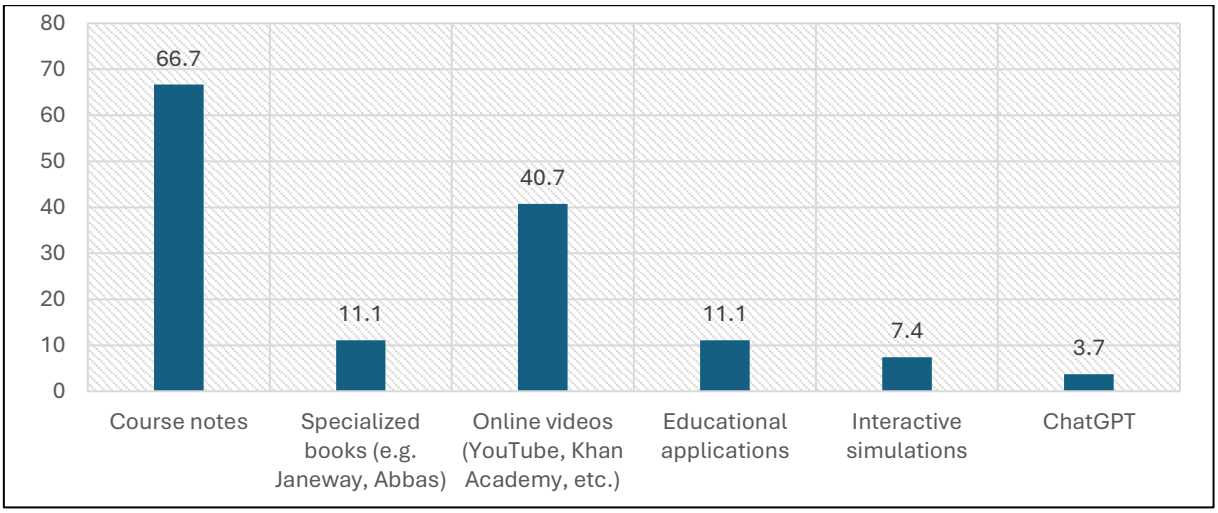

Figure 3: Resources Used to Study Immunology

3.2.6 Teaching Approaches in Immunology

Figure 4 indicates that immunology is primarily taught through lectures. Other approaches, such as project-based learning, differentiated instruction, flipped classrooms, problem-solving methodologies, and collaborative learning, are nearly absent.

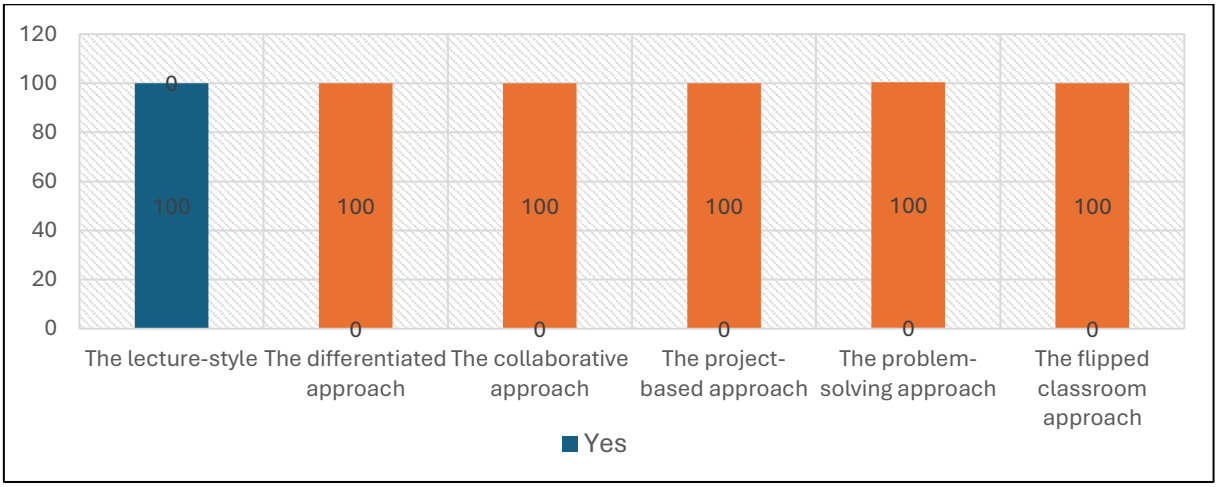

Figure 4: Pedagogical Approaches Adopted in Immunology Teaching

3.2.7 Workload

Figure 5 shows that only 11.1% of participants perceive the immunology workload as light. For 59.3%, the workload is moderate, while 29.6% consider it heavy or very heavy.

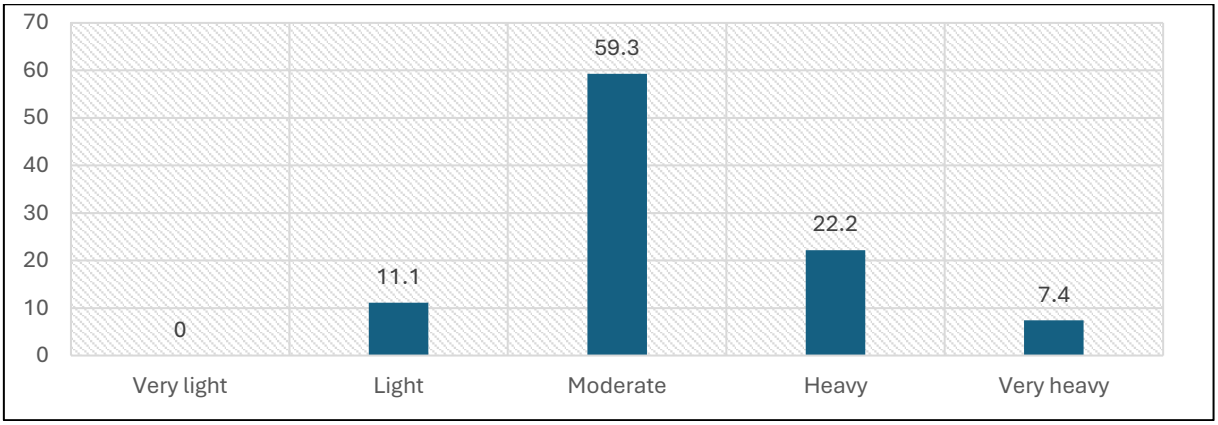

Figure 5: Perception of Workload in Immunology

3.2.8 Importance of Immunology in Medical Training

According to Figure 6, 59.2% of respondents view immunology as very essential to their medical training, and 29.6% deem it essential. Conversely, 11.1% find it of little or no importance.

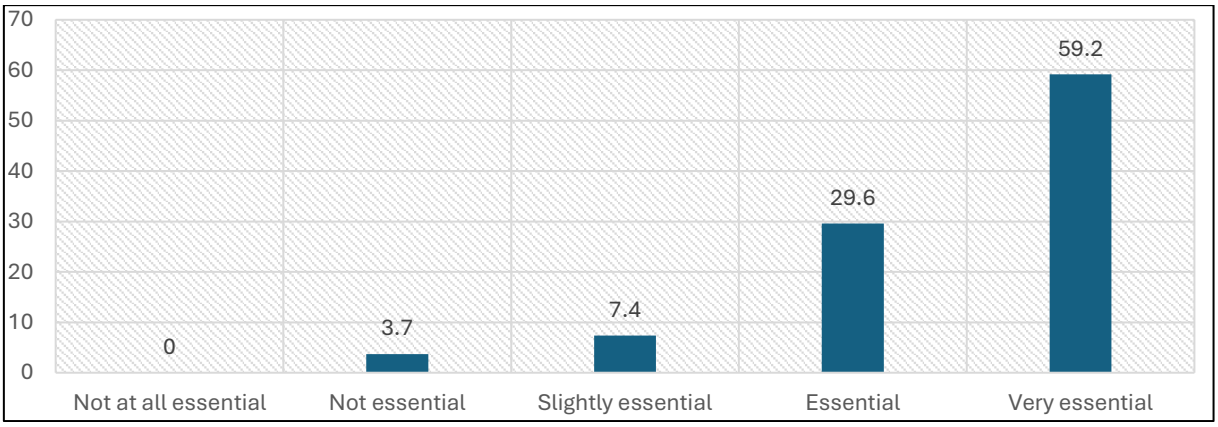

Figure 6: Is immunology Essential for Medical Education?

3.2.9 Preparedness for Clinical Application

Figure 7 reveals that 44.4% of medical students feel well or adequately prepared to apply immunological concepts in clinical practice. However, 55.5% feel they are poorly or not at all prepared for such applications.

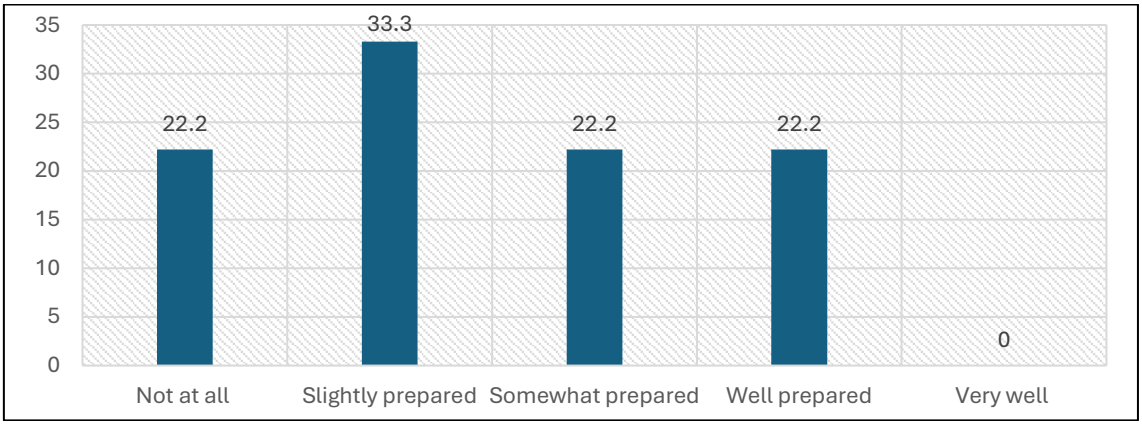

Figure 7: Prepared to Apply Immunology in Practice?

3.2.10 Influence of Immunology on Specialization Choices

As shown in Figure 8, 59.3% of future physicians believe immunology will influence their choice of medical specialization, while 40.7% do not see it impacting their decision.

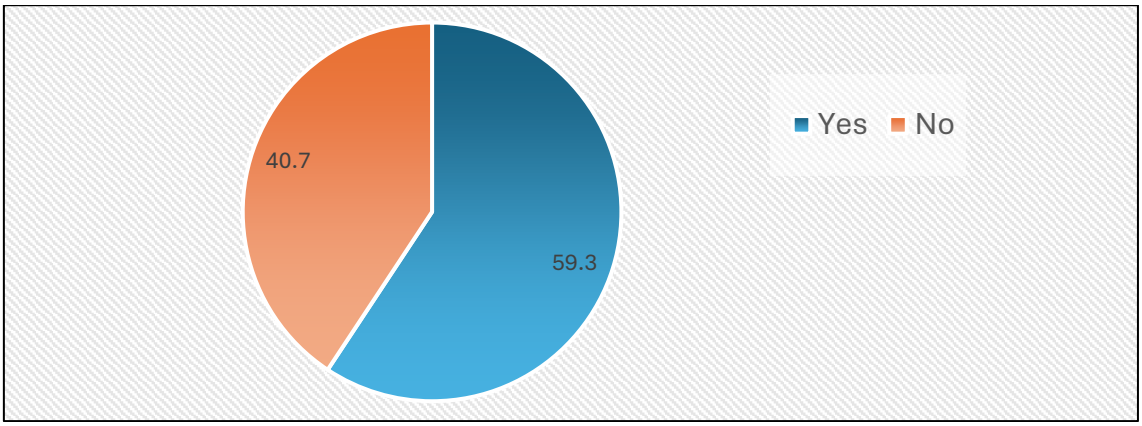

Figure 8: Does Immunology Influence Choice of Specialty?

3.2.11 Career Interests in Immunology

Among those who believe immunology will affect their specialization, the primary fields of interest (Figure 9) are:

- Immunology research: 33.3%,
- Immunotherapy: 29.6%,
- Vaccinology: 25.9%,
- Clinical immunology: 22.2%,
- Immunology teaching: 11.1%.

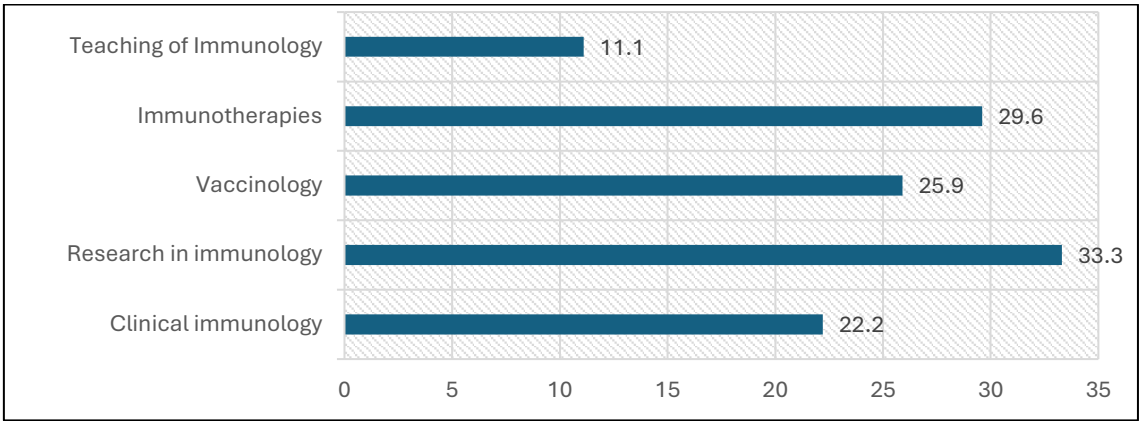

Figure 9: Areas of Immunology for Future Career

4. Discussion

4.1 A Lack of Practical Clinical Examples in Immunology Courses

Immunology is deeply intertwined with medicine, offering insights into mechanisms underpinning infectious diseases, cancer, transplantation, allergies, and autoimmune disorders (Paul, 2012). Pioneers such as Louis Pasteur and Robert Koch laid the groundwork for linking diseases to microbes (Moulin, 1983), while the first Nobel Prize in Physiology or Medicine (1901) honored von Behring's work on diphtheria serotherapy (Kantha, 1991).

Despite this close relationship, the immunology course analyzed, delivered through traditional lectures shows significant gaps. While it is well-structured and comprehensive, with detailed illustrations, it lacks critical elements for effective clinical integration. These include:

- **Concrete clinical cases**: Essential for connecting theory to practice.
- **Interdisciplinary links**: Limited connections with other medical fields, such as pathology and pharmacology.
- **Practical examples**: Scarcity of real-world scenarios to solidify understanding.

The content remains largely focused on theoretical knowledge, with minimal emphasis on historical context or interactive pedagogical approaches. This passive learning model can diminish motivation and engagement among medical students.

In similar contexts, Stranford (2020) emphasized the importance of active learning strategies in immunology education. These approaches not only enhance student motivation and comprehension but also better prepare them for clinical practice by fostering critical problem-solving skills (Stranford, 2020). Similarly, a study at Lanzhou University explored the flipped classroom model for immunology education. Findings showed significant improvements in student motivation, self-directed learning, and problem-solving abilities (Ma, 2018). These insights suggest that integrating active learning methodologies, such as case-based learning, interdisciplinary collaboration, and the use of digital tools, could enhance the effectiveness of immunology courses in preparing future physicians.

4.2 Immunology: Essential but Challenging to Apply Clinically

Our findings reveal that nearly 90% of medical students self-assess their immunology knowledge positively, with 48.1% rating their knowledge as average and 40.7% as good. Additionally, almost 90% of respondents consider immunology essential or very essential to their medical training. However, all participants reported difficulties in learning immunology, primarily due to the complexity of its concepts and the high cognitive load of the subject. Furthermore, nearly half of the students feel unprepared to apply immunological concepts in clinical practice. This aligns with Rumelhart's (1990) assertion that immunology is a complex subject with transdisciplinary concepts such as regulation, systems, networks, individuality, self vs. non-self, and memory, which can be examined from biological, chemical, physical, and philosophical perspectives (Rumelhard, 1990). Bernard (2006) emphasizes that immunology's complexity is evident at both structural and functional levels (Bernard, 2006). Similarly, Thomas (2015) highlights the multi-scale organization of the immune system, ranging from organ-level interactions to molecular mechanisms, as a significant challenge for learners (Thomas-Vaslin, 2015). These complexities present obstacles that students must overcome to progress in their learning (Bourgeois & Chapelle, 2015).

The prevalent use of lecture-based teaching methods contributes to these difficulties. Lectures, often delivered in large auditoriums with over 300 students, limit opportunities for discussion and interaction. Bruter (2008) notes that lectures foster student passivity, lack interactivity, and fail to accommodate diverse learning needs, resulting in high cognitive loads and unequal assimilation (Bruter, 2008).

While teachers incorporate digital resources such as PDF notes, the impact of ICT (Information and Communication Technology) remains minimal due to the traditional pedagogical approaches employed. Research highlights the positive impact of ICT (Karsenti & Collin, 2013; Vescio, 2008) and AI (Terwiesch, 2023) on teaching and learning, but these technologies must be integrated into active and innovative teaching methods to be effective (Lebrun, 2007). Medical students have adapted by supplementing lecture notes with online videos, educational apps, interactive simulations, and even AI tools, suggesting a readiness to embrace modern tools to enhance their learning.

Regarding career aspirations, over half of the respondents believe immunology will influence their specialization choice, with key interests in immunology research, immunotherapy, vaccinology, and clinical immunology. The clinical importance of immunology has long been recognized. Gell (1963) emphasized its applications in diagnosing bacterial, viral, and parasitic infections using serology and skin tests, as well as its central role in managing allergies and autoimmune diseases such as asthma and rheumatoid arthritis (Gell & Coombs, 1963).

5. Conclusion

This study underscores the need to adapt immunology teaching methods to better address medical students' needs. While the current course provides a solid foundation, improvements are needed in the following areas:

- **Innovative Teaching Methods**: Incorporating active learning strategies such as flipped classrooms, problem-based learning, and interactive discussions.
- **Practical Learning**: Integrating clinical cases to bridge theoretical knowledge with real-world applications.
- **Cognitive Load Management**: Simplifying complex concepts with analogies, examples, and modular teaching.
- **Personalized Support**: Offering tailored guidance to students struggling with specific topics.
- **Enhanced Resources**: Leveraging multimedia tools, interactive simulations, and AI to make learning more engaging.

By implementing these recommendations, medical faculties can better prepare students for the clinical application of immunological concepts and inspire interest in this critical field.

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Conflict of Interest Statement
The authors declare that they have no conflict of interest related to this study. The research was conducted independently, without any financial or institutional influence that could have affected the objectivity or integrity of the findings.

About the Author(s)
Abdelkader Ouhtit is currently a doctoral candidate preparing a PhD in the Didactics of Science. He also works as a supervisor of Life and Earth Sciences in high schools. His research interests include science education, digital learning tools, and the integration of ICT in teaching scientific disciplines.
ORCID: https://orcid.org/0009-0000-1051-4433
Anouar Aidoun is a Professor of Didactics of Science at the École Normale Supérieure (ENS) of Tetouan. His academic interests focus on pedagogical innovation, science curriculum development, and teaching practices in secondary and higher education.
ORCID: https://orcid.org/0009-0001-5183-9178
El Mostafa Amiri is a Professor of Didactics of Science at ENS of Tetouan. His work is centered around teacher training, curriculum design, and the epistemology of science education.
Rajae Zerhane is a Professor of Immunology at ENS of Tetouan. Her teaching and research focus on immunological mechanisms, science communication in health education, and interdisciplinary approaches in medical education.
ORCID: https://orcid.org/0000-0002-7100-0273
Rachid Janati-Idrissi is a Professor of Biochemistry at ENS of Tetouan. His academic work includes research in biochemical processes, as well as didactic approaches for teaching biochemistry and related sciences.
ORCID: https://orcid.org/0000-0002-6058-4664

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