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Abstract: Background: Nanotechnology has emerged as a promising field of study, aiming to revolutionize healthcare through the innovative development of drugs, diagnostic tools, and medical devices. As a result, healthcare professionals in training are constantly faced with the challenge of understanding and applying these emerging technologies. The objective of this study is to determine the factors to consider for including the teaching of nanotechnological tools in medical specialty postgraduate programs. **Methods:** A study based on the Nominal Group Technique (NGT) was conducted to identify the factors that promote and hinder the implementation of nanotechnology in certain postgraduate programs where nanotechnology is employed, such as Internal Medicine, Critical Care Medicine, Family Medicine, and Clinical Pharmacology at the School of Medicine of Universidad de La Sabana. A framework analysis was used to analyze the collected data. **Results:** Based on the two research questions, several aspects were identified for the inclusion of nanotechnology in the medical practice of specialties. Key challenges include lack of knowledge and resource availability, misinformation, and lack of knowledge, as well as paradigmatic analysis as the main obstacles to the use of nanotechnology. **Conclusions:** The findings provide a first-time study on nanotechnology curricula within medical specialty programs in Colombia, with potential extrapolation to similar situations in other medical schools.

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1. Introduction

The current era is witnessing a profound scientific revolution, markedly diverging from the First Industrial Revolution's focus on large-scale projects such as expansive operating rooms and skyscrapers. Today, the emphasis lies in developing smaller, more precise, and highly utilitarian tools. Nanotechnology epitomizes this shift, involving the design and manipulation of objects ranging from 1 to 100 nanometers—dimensions so minute they are one-hundredth the thickness of a sheet of paper [1,2].

As a result, contemporary medicine is undergoing an unprecedented phase of innovation. The convergence of various scientific disciplines is pushing the boundaries of disease diagnosis, treatment, early detection, and prevention. Within this context, nanotechnology has emerged as a pivotal force, substantially transforming clinical practice and medical education in institutions worldwide, both in the West and the East, that have integrated it into their medical-surgical curricula [3-5]. The concept of 'nanomedicine' represents a paradigm shift, offering novel insights into the translation of advanced medical technologies from the laboratory to clinical practice.

The COVID-19 pandemic underscored the value of nanomedicine by accelerating the development of more effective diagnostic tools, therapeutic strategies, and vaccine delivery systems [6,7]. This global health crisis has emphasized the urgent need for modern medical education to incorporate innovative technologies [3-5]. Integrating nanotechnology into medical education not only enhances students' understanding of disease diagnosis and treatment but also fosters practical skills in utilizing advanced medical technologies.

Nanotechnology has impacted various medical domains, including drug delivery systems [8,9] and medical imaging [7,10]. In drug delivery, nanotechnology has facilitated the development of systems that interact at cellular and molecular levels, improving therapeutic efficacy while minimizing side effects. Moreover, its focus on quality by design stresses the need to ensure both the efficacy and safety of treatments with minimal immune reactivity [8].

In medical imaging, nanotechnology has revolutionized current technologies by enhancing image contrast and specificity, enabling more accurate and earlier disease diagnoses through advanced imaging agents [10].Nanotechnology also presents significant opportunities in preventing nosocomial infections and improving public health outcomes through faster diagnostics and timely responses to critical patient conditions [7]. Research on antimicrobial nanoparticles is pioneering new strategies to combat hospital-acquired and opportunistic infections [3,7,8].

However, the advancement of nanotechnology also raises ethical and regulatory challenges. The potential toxicity of nanoparticles and their impact on human health and the environment are growing concerns. Establishing appropriate regulatory frameworks and safety standards is crucial to ensuring the safe and sustainable application of nanotechnology in medicine [2,7].

In the realm of precision and personalized medicine, nanotechnology plays an essential role in biomarker discovery, improving diagnostic accuracy, and optimizing individualized treatments, including advanced technologies such as CRISPR [2,7,11,12]. Incorporating nanotechnology into postgraduate medical-surgical education programs is crucial for preparing healthcare professionals to fully leverage these innovations [6]. This integration presents a unique opportunity to train medical personnel in scientific innovation and cutting-edge technology, deepening their understanding of the field while cultivating practical skills in the application of advanced medical tools.

By mastering both the foundational principles of nanomedicine and the practical use of diagnostic and therapeutic technologies, healthcare professionals trained in this field will be better equipped to meet future challenges. Therefore, incorporating nanotechnology into medical education is essential for equipping healthcare professionals with the skills and knowledge to lead in modern medicine, which increasingly influences diverse specialties and informs clinical decision-making in light of future innovations [13-16].

By advancing understanding of cutting-edge medical technologies and fostering the practical skills necessary for their clinical application, nanotechnology is paving the way for a new era in healthcare, where precision, efficacy, and innovation serve as the cornerstones of patient care [2,3,17,18]. This article aims to identify, through nominal group technique focus groups, the factors considered essential by residents in medical-surgical specialties at our institution for implementing nanotechnology education within the medical curriculum and to assess key aspects of its impact on daily professional practice and medical education.

2. Materials and Methods

A qualitative study was conducted using the adapted Nominal Group Technique (NGT) [19,20], which could help identify the most important aspects of the challenge of implementing nanotechnology in the curricula of medical specialties. The study was carried out at the Universidad de La Sabana, Chía, Colombia, and was approved by Research Ethics Committee of Universidad de La Sabana (protocol 01 18 May 2021)

2.1. Participants

The participants for the NGT were residents of medical-surgical specialties at Universidad de La Sabana. Recruitment was conducted through an invitation notice for voluntary participation in the study (Figure1S). A total of 12 residents participated (4 from internal medicine, 4 from family medicine, 4 from clinical pharmacology).

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2.2. Data Collection

The NGT was conducted in three phases:

Phase I: The objectives of the NGT were shared with participants before starting the activity. The multiple purposes of the technique were explained, as it provides participants with the opportunity to begin thinking about their contributions to the topics discussed. A discussion about these topics followed. Additionally, participants were given time to ask clarifying questions about their role, their participation, and what would be expected of them [20].

Phase II: The purpose of the meeting and the value of participants' contributions were emphasized, as well as the voluntary and anonymous nature of their participation. Participants provided written informed consent before the focus group session began (Supplementary material 1). The information was anonymized and treated according to ethical principles of confidentiality. All participants agreed to be recorded during the NGT session.

Targeted questions were formulated following a thorough literature review and consultations with specialists in addiction treatment and nominal group technique methodologies. The questions were designed to address two key decision points in the treatment process:

Question 1 (Q1): “In your medical specialty residency, what are the factors that promote the use of nanotechnology?”

Question 2 (Q2): “In your medical specialty residency, what are the factors you believe hinder the implementation of nanotechnology?”

The participants were asked to write their ideas in silence for about 10 minutes. Subsequently, a turn-by-turn idea collection was carried out, where the moderator wrote each point mentioned on a whiteboard, allowing the entire group to see the growing list of ideas and be stimulated to think of additional ones.

This method of data collection served multiple purposes: it freed the facilitator from influencing group opinions, protected the anonymity of those presenting ideas, and focused on the idea rather than the author. This approach helped to address anchoring bias, a bias where participants attempt to align their responses with the group's opinion, and also minimized social desirability bias, where respondents attempt to provide answers that present themselves in a socially favorable manner.

Afterward, forms were collected, and the participants' comments on the listed elements were transcribed. The facilitator ensured that the information was complete and clearly explained to all participants. If there were questions about what was written, participants clarified the meaning. The session continued with the structured discussion of ideas for a limited time, followed by additional rounds of questions and idea generation until responses were saturated. Finally, a selection and ranking of ideas (voting) was conducted.

In some cases, a brief clarification dialogue took place [19]. This step ensured that participants understood the meaning of each idea, allowing individuals to make informed decisions when ranking their priorities [21]. The moderator ensured that dominant participants did not unduly influence the group.

Phase III (Analysis): In the third phase, participants were asked to silently rank the top five ideas (5 = highest priority and 1 = lowest priority). Votes were tallied, and ideas were ranked [22]. A final discussion was held to determine if the group supported the top-ranked priorities. The nominal group session was audio-recorded and transcribed verbatim to aid in understanding and retaining participants' considerations.

Our findings were reported in accordance with the RATS guidelines for qualitative research, which evaluate the relevance of the study question, appropriateness of the qualitative method, transparency of procedures, and soundness of the interpretive approach [23].

3. Results

A total of 12 residents from 4 medical specialties participated in the NGT. Based on the questions asked, three key elements were highlighted: a) Aspects to consider for the inclusion of nanotechnology in medical-surgical education (MSE); b) Mechanisms for introducing nanotechnology into MSE; c) Competitive advantages of incorporating nanotechnology into MSE.

Before starting with the questions, basic aspects and concepts of nanotechnology were discussed to provide context for the questions. The concept of nanotechnology, although seemingly simple, proved to be a difficult term to define and was mostly based on the idea of scale.

Some the relates to Q1 and Q2 are presented in Table 1. Each resident had 3 votes for each of the established categories. The categories that received the most votes and predominated were knowledge and its application and availability of resources.

Figure 1 represents the representative percentage for each of the designated categories for questions Q1 and Q2. The categories related to lack of knowledge and resource availability received the highest votes for question Q1. For the second question, misinformation and lack of knowledge, as well as paradigmatic analysis, were identified as relevant obstacles to the implementation of nanotechnology among residents.

Table 1. Some narratives from the participants, categories, and thematic analysis in response to questions Q1 and Q2.

Participant's voices	Categories	Thematic analysis	Votes
Question 1			
"I have heard very little about nanotechnology, especially as it applies to medicine, but I believe that what is fundamental here is that it is part of what is known as translational medicine. From basic medicine to applied medicine, to surveillance, which is what we are doing right now, and I think this point is vital for the transition to what we now know as personalized medicine, which I believe is the future."	Quality Construction of Knowledge and its application	Relevance of Nanotechnology in Specialist Medical Training	17
"Actually, I had never heard of nanotechnology until we were sent the articles."		Teaching expertise	
"I believe that what the article mentioned is very, very close to our reality. Both professors, whether at the undergraduate or graduate level, lack knowledge about nanotechnology, even though it is used in everyday life. What they propose is that we need environments where people can learn about the basis of nanotechnology and what it can achieve. This way, individuals can start to create or innovate things where I can gradually begin to apply it, aiming to develop different avenues—whether for treatment, diagnosis, or other applications—that can be implemented."			
"I also mentioned that, since we are more clinical in this field, the time allocated for assistance activities may sometimes overshadow these types of activities, and I believe that could also be a limitation. Furthermore, many times, budget constraints at the different faculties significantly limit research in these areas, so I think that should also be taken into account."	Resource Availability		9
"In diabetes, nanotechnology is also being used for early diagnosis and timely treatments. If you have knowledge of what exists, then great, you can use it. But in my view, I don't just want to know that it exists and use it; I want to know how I can help my patients in other ways. If I	Cost-effectiveness of implementation		4

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can conduct more research on this, then I would really like to know. *I believe that in both undergraduate and graduate programs, we can provide this range of possibilities for doctors so they can decide. For example, they might choose to be clinical and only know about it, applying it as needed. Alternatively, they could also gain an understanding of how it works, which allows them to approach it in a better way and maximize the benefits of that process.* *So, in reality, both points are valid. If someone just wants to use it because it exists, that's fine."*			
"There are certainly doctors who are not very interested in the applicability of this; they simply want the knowledge to practice professionally based on what they learned. However, I believe in the importance of this topic in education, starting from undergraduate studies, to provide tools for doctors. *We are doctors, but we are also researchers, and we can each choose our own path and decide how we want to shape our professional focus and profile. I think it's very useful for medical schools to provide these tools and this education so that in the future, all these resources can support each individual's approach, especially since we don't fully understand the concept yet."*	Policies for implementation		4
"It's important to emphasize multidisciplinarity and change it to interdisciplinarity. We cannot remain isolated; honestly, I am not particularly interested in understanding those machines or in engineering and mathematics. However, it is essential to understand that there are processes that exist. Just as some people learn in different ways—through kinesthetic channels or more visual ones—there are others who need to understand things differently."	Interdisciplinary and interprofessional Teamwork		2
Total			36
Question 2			
"Perhaps this is something that will be the next step, and in a few years, everyone will know about it."	Misinformation and Lack of Knowledge	Need for Nanoeducators	27
"People lack knowledge about nanotechnology, even though it is used in everyday life. What they propose is to create environments where people can understand the basis of nanotechnology and the potential it holds. This way, individuals can start to create or innovate things that they can gradually apply to develop different avenues—whether for treatment, diagnosis, or other applications—that can be implemented."		Nano-Literacy	
"Well, I had also seen it more in subspecialties, for example, in gastroenterology and other specialties where there is ongoing work based on nanotechnology. In subspecialties like pathology, it wasn't something we perceived as being so close."		Challenges for Educators	

"In total, the specialties that form the basic sciences are super important for countries to achieve better adherence. Now, they are bringing the concept into universities, so if we can incorporate it at some point into our research, that would be great."			
"We often don't realize how we sometimes start to adjust our understanding of what should be because we are presented with benefits and shown very promising results. It's almost like brainwashing, as they tell us that this new thing is the best of the best. That's why we need to be very critical. As young people, we often fall into this trap of being influenced too easily."	Paradigmatic Paralysis	Resistance to change	10
This is one factor, reassurance, which is independent of the approval of technology by regulatory entities."	Structure and Reassurance of the Health System		7
"The articulation of the curriculum in the practical environment, utilizing technological resources to educate in practice spaces." *"Comparatively, I would add two things directed at the university, which is the one managing my academic curriculum. The university has the capacity—or how should I put it?—the academic arm to guide these projects.* *Yes, and if the university were to have a greater presence in my practice area, it would be easier to implement nanotechnology as a basic concept, not just for you but for everyone. I mean, I thought of it as directed towards us, the ICU staff."*	Curriculum Articulation in Practice		6
"So that they can have, as you've mentioned, I'm not sure if you can implement these concepts and introduce them into training programs, both in basic information for undergraduate studies. *Creating spaces such as discussions and open talks initially would ensure that the basic concepts are included within a program as minimum common requirements. Additionally, there should be opportunities for anyone who wants to delve deeper into the topic."*	Approval of the Nanotechnology System		5
"But how much does the industry, beyond just pharmaceuticals, particularly in industrial sales, influence us not only to learn about it but also to use it"	Influence of Industry		3
"We can address that point as well. Yes, as you mentioned from experiences, it could also become compact, which could hinder the process. How many clinical trials are needed to prove that nanotechnology is effective? For example, I won't look into anything else because I already know that mechanical ventilation driven by neural impulses works. On the other hand,	Conflict of Interest		2

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evidence-based medicine is influenced by what the pharmaceutical companies present."			
"I believe that the problem here is related to that, but the disaster is a factor in the sense that I'm not sure if it relates to access to technology on that front."	Critical Judgment		1
Total			60

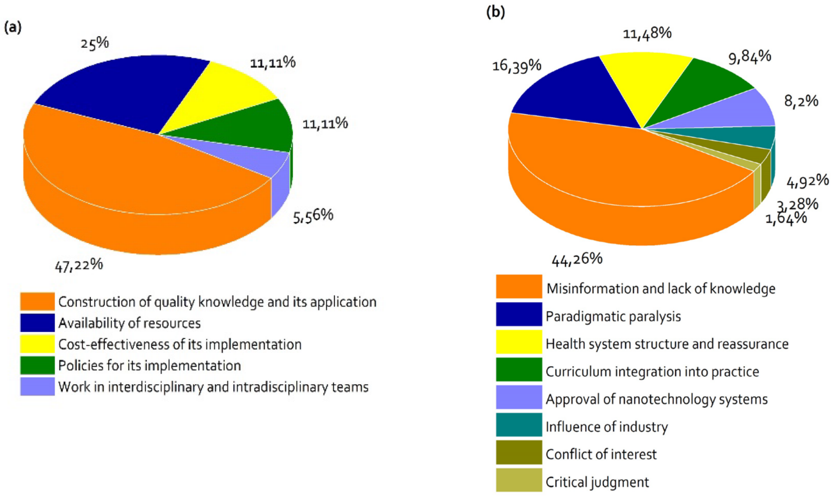

Figure 1. Percentage diagram of the analyzed categories from participants' responses to Q1 (a) and Q2 (b) using the Nominal Group Technique (NGT).

The categories analyzed for each of the responses using NGT provide valuable insights into the challenges and obstacles in the implementation of nanotechnology in medical specialty curricula.

4. Discussion

This section presents an analysis of the significance of the results obtained from the NGT activity, focusing on the main challenges faced by medical specialty residents in implementing nanotechnology in their curricula, as well as the key aspects for promoting the use of nanotechnology. The analysis is subdivided according to the questions posed.

Question 1 (Q1)

4.1. Category 1: Quality Construction of Knowledge and Its Application

This category considers relevant aspects of the processes developed from undergraduate studies, emphasizing that a solid foundation in basic sciences is essential for understanding where nanotechnology fits.

Currently, nanotechnology is seen as the next "industrial revolution" of the modern era. Therefore, to ensure that research, development, and social implications of this topic have the desired impact, it is important to promote continuing education courses that address its risks, benefits, limitations, as well as its ethical and social impact [24]. Hence, the advances and potential developments in the field of nanotechnology pose challenges for the academic world, both in teaching and learning and in the ongoing training of new generations.

This impact presents a challenge to the academic community, as it requires fostering in students the knowledge, understanding, and skills necessary to engage with and provide leadership in the emerging world of nanotechnology. This is particularly important given the technological revolution society is currently immersed in, and the numerous potentials of nanotechnology in consumer goods, electronics, computing, medicine, pharmacology, biotechnology, energy, environment, portable devices, and more [25].

In the medical field, nanotechnology has broad applications as nanomedicine. Certain nanoparticles have potential uses in new instruments, imaging and diagnostic methodologies, specific medical products, pharmaceuticals, biomedical implants, and tissue engineering [9]. Today, highly toxic treatments can be administered more safely using nanotechnology, such as chemotherapeutic drugs for cancer. Moreover, portable devices can detect critical changes in vital signs, cancerous cell conditions, and infections occurring within the body [17]. These technologies will provide physicians with much better direct access to critical data regarding the causes of life signs or disease changes, due to the technological presence at the source of the issue. Biomedicine can also be used for therapies through predictive analytics and artificial intelligence [25]. In the discussion held during the plenary session of the NGT, the importance of nanotechnology in medical education was emphasized. It was concluded that nanotechnology should be incorporated transversally across the medical curriculum, as the knowledge gained progressively throughout a professional's education enables the consolidation of this process during later postgraduate stages. This has been outlined in the formation of the MEDICUS curricular model, where the most ideal integration could represent a combination of both horizontal and vertical integration, merging learning across time and disciplines [26]. This model was previously described as "spiral integration," a concept that suggests learning and understanding a subject improve through continuous review and repetition, approaching material from different perspectives and levels of complexity. This approach recognizes that students can benefit from revisiting key concepts multiple times throughout each phase of their educational development. In spiral learning, topics are initially presented at a basic level and then revisited and expanded upon in successive iterations, allowing students to deepen their understanding as they progress. This method fosters more robust and long-lasting learning by engaging students in the practical application of their knowledge and connecting new concepts to prior knowledge [27].

In this regard, the curriculum involves "learning basic and clinical sciences over time and through subject matter." Utilizing the spiral model as the ideal goal, it is proposed that an "integrated curriculum" be defined as the delivery of transdisciplinary information fully synchronized between fundamental and applied sciences across all years of a medical school curriculum.

4.1.1. Subcategory: Relevance of Nanotechnology in Specialist Medical Training

The teaching of Basic Biomedical Sciences faces significant challenges in ensuring its relevance to medical training. A solid understanding of basic sciences is a prerequisite for successfully completing medical education. Therefore, it is essential to improve the quality of teaching and ensure the applicability of basic sciences [28]. In this context, concerns have been raised about students' preparation when they enter clinical settings and their ability to apply basic sciences to professional practice.

It has been described that fundamental knowledge of basic sciences serves as an important determinant of diagnostic success, as numerous modern devices and methods used for diagnosis and treatment are based on these principles. However, there is significant variation in students' basic scientific knowledge at the beginning of medical education [29]. Insufficient knowledge in basic sciences may lead to a lack of understanding of fundamental biochemical, physiological, and pathophysiological principles, and possibly to student attrition [30]. Despite the general consensus on the value of these subjects in medical practice, students often arrive in clinical training settings with what many consider an insufficient level of preparation. This limits their ability to transfer or apply the knowledge they have acquired about nanotechnology.

4.1.2. Subcategory 2: Teaching Expertise

Participants emphasized the responsibility of educators to enhance the learning of scientific concepts and foster the development of skills that enable the evaluation of information, critical reflection, and the adoption of positions related to the development of nanotechnology in healthcare. These processes prepare physicians to navigate their profession and raise awareness of the complex relationships between science, technology, society, and the environment. This approach allows them to explain broad concepts that facilitate the understanding of emerging technologies and their

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limitations, as well as explore potential solutions to health-related problems, considering the context of their implementation, ethical implications, and eventual clinical translation.

Nanotechnology offers a powerful educational tool to inspire and captivate students' minds, igniting their curiosity in STEM (Science, Technology, Engineering, and Mathematics) disciplines. By incorporating nanotechnology into educational curricula, educators can spark interest and support accessible and inclusive learning environments, fostering critical thinking and preparing the next generation of innovators for the challenges and opportunities of a technologically advanced future. By harnessing the transformative potential of nanotechnology, we move closer to a future where equal opportunities for quality STEM education are extended to all students, fostering a diverse and empowered generation ready to contribute to the human-centered revolution of Society 5.0 [31].

4.2. Category 2: Resource Availability

This category highlights aspects such as knowledge of the country's requirements and needs; strategies outlined in national and regional development plans; multidisciplinary and cross-sectional research; the presence of industries linked to universities that establish agreements to develop research processes [32]. Likewise, it is crucial to strengthen scientific, technological, and business capacity within a dynamic legal and institutional framework aligned with the market. This includes promoting the formation of consortia and leveraging resources to generate innovative processes that meet market demands [33].

4.3. Category 3: Cost-effectiveness of Implementation

In this section, the group discusses how the advancements in nanotechnology may be contingent upon the progress of the knowledge society and the policies that different governments apply based on a set of priorities determined by the political and social forces within each country. This is particularly relevant in light of the current socio-political-economic context of our country. In this regard, most developed countries face skyrocketing healthcare costs. Population aging, rising prices for medications and treatments, and inefficient use of medical services are partly responsible for the continuous cost increases.

The rise in healthcare spending exerts growing pressure to improve the efficiency of public health services, which should encourage policymakers and health administrators to promote more efficient healthcare. This clearly demonstrates the need for efficient allocation of healthcare resources to contain the growth of healthcare spending while ensuring that new drugs and treatments, such as highly effective nanomedicines, are made available at reasonable costs [34].

4.4. Category 4: Policies for Implementation

This section emphasizes several relevant aspects, including the fact that the country still lacks a critical mass of professionals such as economists, administrators, and lawyers who can fully support processes related to technology surveillance, competitive intelligence, market access, national regulations, and international agreements. These professionals are essential for promoting nanotechnology as a valuable resource in medical education [35]. In Colombia, nanotechnology is primarily focused on research and scientific applications, with limited emphasis on its impact on quality of life and technological or industrial development [36].

4.5. Category 5: Interdisciplinary and Interprofessional Teamwork

A notable point in this category is the deficient culture of alliance and cooperation among health professionals to form groups that, through nanotechnology, can achieve local or regional advancements [37]. It is important to establish all possible networks, alliances, and clusters or bioregions to build a critical mass of professionals in key areas for the development of nanotechnology, including resource management, marketing, and business management [38].

Question 2 (Q2)

4.6. Category 1: Misinformation and Lack of Knowledge

Students in the NGT reported that the main gap preventing nanotechnology from being integrated into their education is a lack of information. As nanotechnology continues to grow, there is an increasing need to educate a new generation of technicians, scientists, doctors, entrepreneurs, policymakers, regulators, and communicators who are knowledgeable about this emerging field. Additionally, advances in nanotechnology have occurred at an unprecedented rate, making it imperative to find the most effective ways to teach essential concepts and processes involved in nanoscience.

It is critical to ensure that students have opportunities to work directly with established nanotechnology research centers (local, regional, national, international) to gain practical experience and engage in nanotechnology as part of their education as 21st-century physicians.

4.6.1. Subcategory: Need for Nanoeducators

The nominal group members highlighted the importance of having specialized professors in appropriate disciplines who can teach nanotechnology courses and create direct connections between industry and research centers. This would improve the quality of available information, help their research achieve the desired impact, and enable adaptation to a rapidly changing world. Another key point emphasized was the need to train educators in nanoeducation, as the new academic scenarios demand unique learning paces that require changes in the teaching role, enhancing instructional content quality, simulation tools, and a broad knowledge of the main applications and potentials of nanotechnology. These educational dimensions are essential for Scientific and Technological Literacy.

4.6.2. Subcategory: Nano-Literacy

Participants in the nominal group stressed the importance of having expert educators in nanotechnology whose professional development is aligned with the educational level (undergraduate, postgraduate, continuing education). This alignment ensures effective knowledge transfer using the most effective strategies to foster self-efficacy in teaching nanoscale science. Educators must have basic tools and knowledge to achieve nano-literacy. It is crucial for everyone to update, deepen, or specialize in specific areas of knowledge and acquire new cognitive and procedural skills, making teaching and learning a continuous, lifelong process.

New proposals are being generated for collective knowledge building, promoting spaces where teachers explore students' conceptions, mental models, communication skills, and social imaginaries. This environment fosters motivation among both parties and strengthens various teaching-learning processes. Therefore, it is essential for educators to know and apply the necessary tools to implement this approach with their students. Instructional design plays a key role in ensuring these processes have the intended impact. This approach makes educational practices tangible by understanding, interpreting, and systematizing the diversity and complexity of the teaching profession. It also creates a community of practice where students provide feedback, self-regulate, reassess their progress and challenges, and seize opportunities for improvement by enhancing motivation, innovation, and interdisciplinarity in the implementation of nanotechnology.

4.6.3. Subcategory: Challenges for Educators

This subcategory emphasizes the need to integrate nanotechnology into medical curricula, aiming to incorporate it into existing courses. This will require re-evaluating basic competencies to achieve excellence in patient care, developing innovative methods for teaching and assessing new skills and competencies for future doctors, and designing frameworks for disseminating social and ethical (SEI) aspects surrounding the public distribution of nanometric applications. Educational programs are innovating rapidly, presenting a narrow window of opportunity to shape these new programs to reflect best practices in nanotechnology education and its application to real-world problems [39].

It should be noted that most medical professors receive training in a discipline different from nanoscience, and as a result, there is a need for professional development to learn more about advancements in this field. This would foster a process of nano-literacy, ensuring a faculty well-

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prepared in the curriculum, content, and pedagogical strategies required to teach nanotechnology, which, in turn, promotes innovation and facilitates engagement with centers that support their research. Therefore, it is essential to employ effective strategies to deliver quality education. Familiarity with the various technological devices and platforms, integrated with pedagogical, didactic, and evaluative knowledge, is imperative to provide a highly meaningful, impactful, and inclusive learning experience.

Under this scenario, the goal of education should not be limited to the transmission of knowledge. Instead, it should extend to enabling students to select, evaluate, interpret, classify, and use knowledge in ways that develop cognitive functions such as planning, reflection, creativity, depth, and the identification and resolution of problems [40,41].

4.7. Category 2: Paradigmatic Paralysis

Participants in the nominal group affirmed that there is significant paradigmatic paralysis, understood as supposedly unquestionable truths that are anchored in time and space and defended or justified whenever a member raises any doubt. These beliefs are the result of mental schemas that prevent the assimilation of new knowledge, obstructing change as a strategy for distinction and differentiation [42]. From this perspective, paradigmatic paralysis hinders the creation of sustainable value in administrative acts and decisions, and it detracts from the institutional vision and mission. In the case of nanotechnology, it slows down the processes necessary for integrating nanotechnology into the training of medical specialists.

Therefore, it is crucial to foster an institutional philosophy grounded in new paradigms where empowerment, a sense of belonging, and motivation are the tools that allow for taking risks when implementing new research and resource management approaches. Mechanisms must be created for students to acquire skills that enable the development and understanding of advancements in nanotechnology [43]. The initial strategy to overcome this paradigmatic paralysis is to think and do something different every day, permeating the medical career with new technological trends and innovations. Additionally, various organizational and management processes must be accelerated to promote research and the implementation of nanotechnology. Furthermore, it is important to develop strategies that enhance adaptability to change, foster teamwork, identify the technological needs of the environment, and rapidly carry out the necessary processes to develop or acquire the appropriate technology and adapt it to specific processes or products.

4.7.1. Subcategory: Resistance to Change

Resistance to change, understood as an observable behavior in response to the discomfort or challenge teachers feel due to the introduction of new ideas, methods, or devices, is an inevitable constant in educational organizations. In this sense, nanotechnology is considered a cutting-edge research field, which may present some challenges even in an academic setting; some professors prefer to teach more familiar courses to apply their knowledge in the classroom effectively. New content can sometimes hinder acceptance and the willingness to use it in the classroom. Therefore, medical schools must begin implementing changes in their curricular systems and incorporate nanoscience courses.

Educational systems, as dynamic organizations whose mission is to respond to the population's educational needs, must assume that change is inevitable, and consequently, so is resistance to it. A study is needed to identify strategies and incentive pathways from institutional managers, as successful changes are only possible when resistance to change is properly managed. Regardless of how effective the change may be, professors and the rest of the university community must be motivated to innovate. Creating this motivation is the responsibility of those leading the processes [44].

For an organization to overcome resistance to change, individuals at all levels must be involved in the process [45]. Similarly, some individuals reject the educational importance of nanoscience, believing there is no room for a new medical curriculum addressing this topic [39].

4.8. Category 3: Structure and Reassurance of the Health System

This category highlights the benefits for patients, doctors, and the health system, emphasizing the appropriate management of medications, time savings, rational therapeutic changes, and cost reduction. It focuses on improving access to medications, enhancing quality and patient impact, and reducing costs. However, the current political context in the country, shaped by the government's proposed ordinary law, implies changes that impact the health insurance system. This may slow down the development of improved versions of diagnostics, treatments, prevention, and proactive healthcare measures related to nanotechnology [46].

4.9. Category 4: Curriculum Articulation in Practice

Participants in the NGT emphasize the use of technological resources to educate within practice spaces. They also highlight the significant impact of curricular coherence in practice sites, aligning with the current MEDICUS curricular reform [26], which is evident in the framework of the Entrustable Professional Activities (EPAs) standards. These allow the evaluation of competencies in the workplace, as well as the 4C/ID instructional model (4C/ID model), which organizes educational material so that students' progress logically and coherently through concepts and skills. This model is pioneering in our country. Through the development of various teaching proposals for nanotechnology in medical education or postgraduate training, dynamic, flexible, participatory, and motivating educational processes are generated. These processes identify challenges and opportunities to consolidate innovation and research processes, while building educational strategies that guarantee quality education and training for students. This approach seeks to minimize the gap in nanoeducation and its implementation.

4.10. Category 5: Approval of the Nanotechnology System

Healthcare is undergoing a paradigm shift in the diagnosis and management of diseases, focusing on bringing personalized medicine and care to those who need it. In this sense, pure sciences have found allies in nanoscience, nanotechnology, and other converging and disruptive technologies to take on this demanding task. This convergence can generate unprecedented solutions in healthcare through the use of electrochemical nanobiosensors to monitor pathogens and multiparametric biomarkers at different molecular levels, allowing for the personalized assessment of an individual's health status [47].

In this context, smart diagnostics play a crucial role in Healthcare 4.0. Progress can be made from smart data to diagnostic devices capable of analyzing big data, benefiting from the Internet of Things, machine learning, deep learning, and smartphones, among other cutting-edge converging and disruptive technologies. These are promising for personalized medicine, though there are many challenges to implementing this new and revolutionary technology on a large scale in global health systems. Therefore, it is essential to direct technology towards more efficient and accessible diagnostic and therapeutic solutions [48].

Additionally, several challenges remain in discovering, developing, manufacturing, and delivering novel diagnostics and therapies compatible with this new paradigm. For instance, precision medicine should offer a new foundation to help reduce patient risks, timelines, and costs for future clinical trials. While the efficacy and broad utility of these technologies have been demonstrated step by step, their implementation still depends on cost-benefit considerations.

4.11. Category 6: Influence of Industry

Participants in the nominal group pointed out that the nanotechnology industry offers its products to the market, and if there is insufficient knowledge about these products, it becomes an arduous task to discern which ones to use. This highlights the lack of understanding in this area. Furthermore, for some participants, this topic is deemed irrelevant, as they are only interested in the practical implementation of nanotechnology.

4.12. Category 7: Conflict of Interest

Nanotechnology is helping to exploit the initial measurement point, optimize data, and build an information exchange network, to name just a few of its main possibilities. These innovative tools have the potential to rapidly generate biomedical data and create opportunities not only for diagnostics but also for prevention, control, treatment, surveillance, and disease management. This makes it necessary to steer technology toward more efficient and accessible diagnostic and therapeutic solutions.

In the future, precision medicine is expected to revolutionize healthcare by providing enormous opportunities to assess disease risk and predict treatment responses, while simultaneously understanding an individual's health status and making medical care decisions. Similarly, Translational Medicine seeks to turn molecular knowledge into practical, specific diagnostics and therapies, applying interdisciplinary biomedical research to improve the health of both patients and society. It brings together physicians, scientists, bioengineers, biostatisticians, epidemiologists, patent and regulatory experts, as well as patients.

4.13. Category 8: Critical Judgment

Some participants believe that critical judgment is necessary when implementing nanotechnology. Therefore, applying basic science concepts and principles to the biomedical field drives the development of innovative detection and diagnostic tools, new treatments, or novel approaches to combating diseases and investigating their mechanisms. However, it is essential that healthcare professionals are aware of the risks and scientific uncertainties associated with these technologies, which should be, as far as possible, widely known, debated, and questioned. Thus, it is necessary to analyze specific aspects of this interdisciplinary field, which is of great importance to modern society, considering the new concepts, implications, responsibilities, and risks it entails.

5. Conclusions

Nanotechnology has been heralded as the next "industrial revolution," making it critical to establish clear educational objectives to foster success in research, development, and societal engagement. Immediate action is required to integrate nanotechnology education, as delays could hinder scientific progress by limiting the number of qualified researchers and informed consumers. It is essential to develop policies that support new standards, curricula, teacher training, and informal education related to nanoscale science. Moreover, designing interdisciplinary courses and medical programs that integrate nanotechnology is vital. The field faces several educational challenges, including the need for learning standards, curricular materials, and teacher training in nanoeducation, as well as the expansion of informal science education. Finally, healthcare professionals must engage in lifelong learning through continuing education and professional development programs, particularly in nanoscience, to ensure they can critically assess and implement nanotechnology in their medical practice.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: Graphic Invitation to Medical Specialty Residents for Participation in NGT; Supplementary material 1: Informed Consent for focus group.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, R.-H.B., and J.-C.G.; methodology, R.-H.B., J.-C.G., M.M.D.-L., and J.-F-G.-R.;.; formal analysis, R.-H.B., J.-C.G., M.M.D.-L., and J.-F-G.-R.; investigation, R.-H.B., J.-C.G., M.M.D.-L., and J.-F-G.-R.; resources, R.-H.B., and J.-C.G; data curation, R.-H.B., J.-C.G., M.M.D.-L.; writing—original draft preparation, R.-H.B., J.-C.G., M.M.D.-L.; writing—review and editing, R.-H.B.; visualization, R.-H.B; supervision, R.-H.B., and J.-C.G.; project administration, R.-H.B; funding acquisition, R.-H.B., and J.-C.G. All authors have read and agreed to the published version of the manuscript.".

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