Advances in Medical Education and Practice

Dovepress
open access to scientific and medical research

Open Access Full Text Article

REVIEW

The Role of Education in Nanomedicine as a Current Need for Academic Programs Related to the Healthcare Field: A Scoping Review

Juan-David Huertas[1], Yuli-Viviana Fuentes[2,3], Julio-Cesar Garcia[2,3], Rosa-Helena Bustos[2,3]

[1]PGY-2 at the Clinical Pharmacology, Faculty of Medicine, Universidad de La Sabana, Chía, Colombia; [2]Department of Pharmacology, Evidence-Based Therapeutics Group, Faculty of Medicine, Universidad de La Sabana, Chía, Colombia; [3]Clínica Universidad de La Sabana, Chía, Colombia

Correspondence: Rosa-Helena Bustos, Department of Pharmacology, Evidence-Based Therapeutics Group, Faculty of Medicine, Universidad de La Sabana, Chía, Colombia, Tel/Fax +576018615555, Email rosa.bustos@unisabana.edu.co

Introduction: Clinical research has recently focused on developing diagnostic and therapeutic alternatives through nanomedicine, and it has become essential for both current and coming healthcare professionals, especially medical residents, to know about it to face actual challenges in the setup of their professional practice.

Approach: This scoping review was conducted to show the relevance of nanomedicine in the formation of medical residents and to determine the educational strategies proposed worldwide for their teaching.

Results: 12 records met the inclusion and exclusion criteria, including information related to the importance of teaching nanotechnology, possible educational approaches, or the best action strategies for incorporating said teaching.

Discussion: Multiple studies showed the need for students in health-related programs to be trained and instructed in topics related to nanotechnology. Still, the students' perceptions highlight how inadequate or non-existent such education in this field is. Although a few studies have proposed strategies and approaches for incorporating nanotechnology in academic programs in different areas, it is still necessary to establish educational standards so that the training of future professionals will be uniform and of high quality. The concerned educational institutions' directives must try to ensure that their in-training staff receives an updated, full, and excellency education.

Keywords: nanotechnology, nanomedicine, teaching medicine, medical education

Introduction

According to the National Institutes of Health of the United States (NIH), the term nanotechnology is defined as "the understanding and control of matter at dimensions between approximately 1 and 100 nanometers (nm), where unique phenomena enable novel applications". [1] The term nanotechnology involves the development, characterization and production of structures at the nanometer scale, with broad importance in surface area.[2] Likewise, within the broader conception of this concept, nanotechnology is part of the convergent technologies where life sciences, physical sciences and engineering come together.[3]

It is considered an applied science whose objective is to manipulate matter at its most fundamental level to generate solutions to problems in different areas, such as engineering, computer science, and even medicine. In this sense and considering the possible close relationship between nanotechnology and health care, the term nanomedicine is given way, designated by the European Science Foundation as "the science and technology to detect, treat and prevent diseases, as well as relieve pain, preserve and improve human health, using tools and molecular knowledge of the human body".[4]

The importance of nanotechnology in the field of health sciences lies in the fact that biological systems are of nano-order magnitude at the cellular level, so using materials at the nanometric scale allows in many cases the interaction with the origin and the core of a particular biological phenomenon.[5] Many of the first nanotechnology applications have been carried out by the pharmaceutical industry and these have been related to creating new drugs with significantly superior

Received: 19 July 2023
Accepted: 8 December 2023
Published: 27 January 2024

efficacy and safety profiles.[6] However, nanomedicine promises to revolutionize medical care not only through drug development at the nanoscale but also through diagnostics tools and innovative devices that will promote the evolution of health care and benefit the general population.[7]

Clinical research has recently focused on developing diagnostic and therapeutic alternatives through nanomedicine.[8] In addition, the expectations of the general population about the potential that this area has in advancing health sciences are growing. Physicians face the real challenge of understanding and working towards these expectations, which is why it has become essential for both current and coming doctors to grasp and have essential knowledge of nanomedicine to face actual demands and challenges in the setup of their professional practice.[9]

Nevertheless, although the rise of nanotechnology started several years ago, education within medical schools in this field is still very weak and limited. In addition, this knowledge gap is not only limited to undergraduate students but also extends to residents in physician specialties. It is important to highlight that medical specialists have a widespread understanding of a specific area, so it is essential that training personnel be updated on the latest clinical discoveries and technologies.[10]

As far as one can tell, the apprenticeship of medical residents (MR) in nanomedicine is completely necessary. Even so, it is challenging to incorporate ways of instructing this subject, especially their inclusion in the academic curriculum of medical residency programs. The real defiance arises from the lack of experience and knowledge about what the focus is, the ideal educational plan of action for its teaching, and the best way to incorporate training spaces that allow the learning of MR in this issue. Although it is a difficult task, has must join efforts for the comprehensive education of the present and future MR.[11]

The main purpose of this scoping review is not just to show the value of nanomedicine and its relevance in the formation of MR, but also, to determine the approach and the educational strategies that have been so far proposed worldwide for their teaching and some paths for their inclusion in the curriculum of physician specialties programs.

Methods

Protocol and Registration

The protocol for this scoping review was included as a section in the whole protocol of the investigational project "Nanobiosensor platform for therapeutic drug monitoring (TDM) as a strategy in minimizing antimicrobial resistance".

This project was developed by the Therapeutic Evidence investigation group and the protocol was approved by the General Directorate of Research for Clínica Universidad de la Sabana, Bogotá, Colombia (session number 53 of September 6, 2022). The corresponding section of the protocol to the scoping review in mention was aligned with frameworks proposed by the Preferred Reporting Items for Systematic Reviews and Meta-analysis Extension for Scoping Reviews (PRISMA-ScR).[12]

Protocol and Registration

The broad research question was "What are the current literature findings regarding the importance and the best way to implement educational plans for teaching nanomedicine in the academic curriculum of programs in the health field such as medical residencies?

The specific questions were: (i) What is the value of nanomedicine and its relevance in the training of MR? (ii) What are the approaches and educational strategies that have been proposed worldwide for the teaching of nanomedicine in MR? (iii) What are the need and the best way to incorporate training spaces on nanomedicine in the curricula of medical residency programs?

Identifying Relevant Studies

Efficacy

The inclusion criteria were studies of any methodological design that responded to the broad research question and/or some or all the specific questions. No exclusion criteria were considered. The studies were included if they investigated the embracement of teaching nanotechnology or nanomedicine in the curriculum of undergraduate and graduate educative programs in the health area, ideally in the medical residency programs. All study designs were included to ensure that the full breadth of literature was captured.

Search

The search strategy was conducted across PubMed®, Latin American and Caribbean Health Sciences Literature (LILACS®) and Scopus® for articles published from January 2010 to January 2022. For the search in PubMed were used the Medical Subject Headings (MeSH) and the search query was: ("Education, medical" [MeSH Terms] OR "Internship and Residency" [MeSH Terms] OR "Curriculum" [MeSH Terms] OR "Education" [MeSH Terms]) AND ("Nanotechnology" [MeSH Terms] OR "Nanomedicine" [MeSH Terms]). In the case of LILACS were used the Health Sciences Descriptors (DeCS) and the search query was: (Educación Médica OR Medicina OR Internado y Residencia OR Curriculum OR Educación [Palabras]) AND (Nanotecnología OR Nanomedicina [Palabras]). At last, in Embase were used keywords and index terms, and the search query was: (Nanotechnology OR Nanomedicine) AND (Education OR Curriculum OR Medical OR Internship OR Residency).

Study Selection

The results from the search were uploaded into Rayyan® (a web platform for scoping reviews) and duplicates were identified and removed. The title and abstracts of articles were screened by three independent reviewers. The same reviewers obtained and assessed the full text of identified papers. Any discrepancies were discussed and resolved through consensus.

Collection and Processing

The articles that met all the inclusion criteria were add-in, organized, and divided according to 3 different approaches. The first approach included those articles that argued the importance and necessity of teaching nanotechnology or nanomedicine to students in the health area, ideally MR. The second included those articles that proposed a possible educational approach and the necessary topics related to nanotechnology or nanomedicine that should be included in their teaching. Finally, the last one included those articles that proposed the ideal way, as well as action strategies for the incorporation of said teaching.

Risk of Bias

The selected articles will be evaluated for their quality through the STROBE checklist adapted to cross-sectional studies.[13] The Risk of bias will be calculated through NEWCASTLE - OTTAWA QUALITY ASSESSMENT SCALE adapted for cross sectional studies.[14,15]

Results

Study Characteristics

After the search in the databases, 238 citations were identified, of which 29 records were duplicates and therefore were eliminated. A total of 170 articles were screened, 12 records met inclusion and exclusion criteria, and were finally included in the current review.

They were from USA, the Commonwealth of Dominica, Jordan, Iraq, Singapore, China, Korea, Switzerland, Denmark, Portugal, and the UK. The largest proportion of studies were from the USA (n = 7). The flow of studies is presented as a PRISMA flowchart (Figure 1).

Of the 12 articles included, eight referred to nanotechnology in undergraduate majors, and the remaining five discuss it in postgraduate programs (Supplementary Table 1).

Regarding the articles related to undergraduate majors, three of them were focused on pharmacy programs, two on medicine programs, one on biology programs, and two on general undergraduate majors.

In respect of the 4 articles related to postgraduate programs, three looked at medical residencies, two focused on dermatology and one on internal medicine, and the remaining article was related to Master's in Pharmacy.

Regarding the risk of bias, of the 12 articles selected, 5 are cross-sectional observational design studies and 7 articles are a narrative review (non-systematic). In this way, risk of bias was assessed only in the 5 cross-sectional observational design studies. Of the 5 studies evaluated, 4 showed a high score for risk of bias control and all had a high-quality rating with the STROBE scale (Supplementary Tables 2 and 3).

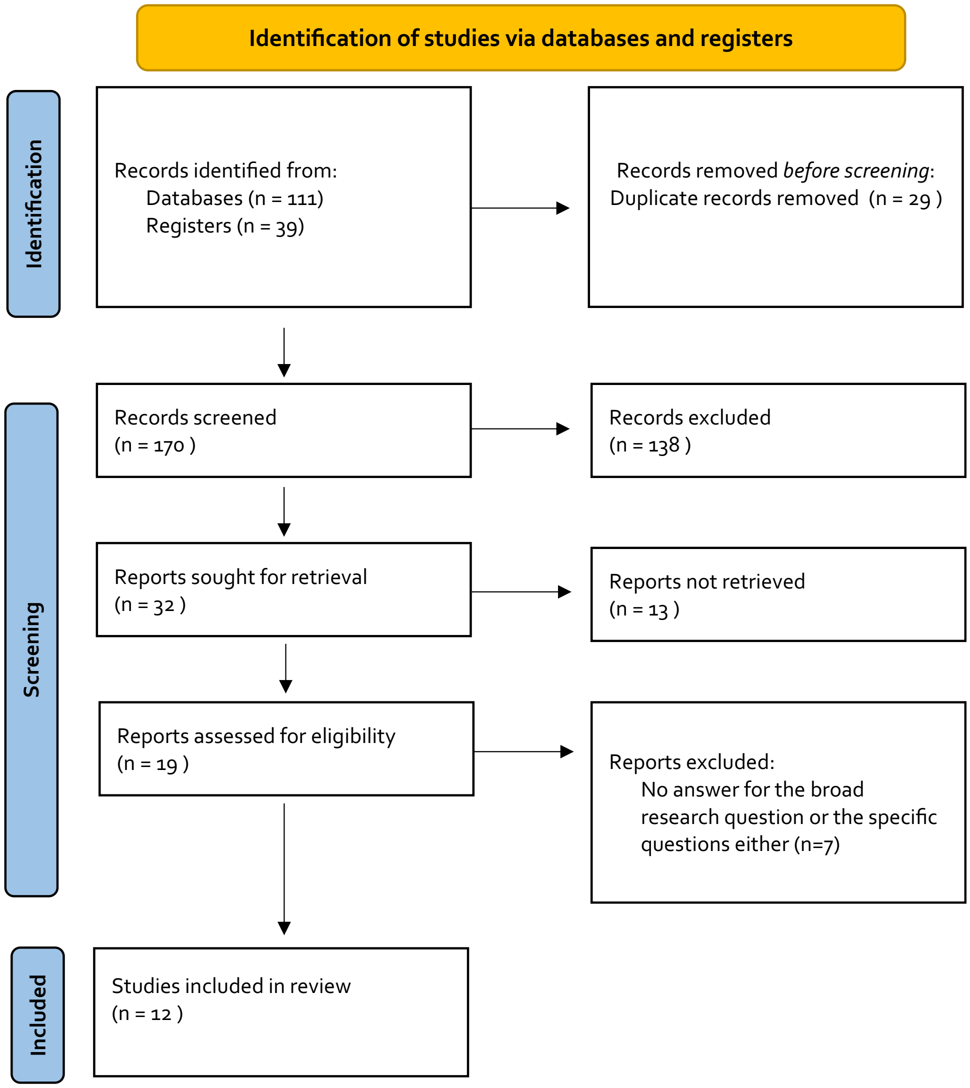

Figure 1 Flowchart of studies selected.
Notes: Adapted from Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. Creative Commons.[16]

Results by Study Approach

Approach 1: articles that argued the importance and necessity of teaching nanotechnology or nanomedicine to students in the health area, ideally MR.

In this approach were classified four articles, all were cross-sectional studies and they performed surveys to evaluate the perception, knowledge, and attitude of different implicated actors depending on the focus of the study.

In Jordan, a study was carried out to assess the level of nanotechnology awareness among pharmacy students. The study was conducted at ten out of nineteen faculties of pharmacy in Jordanian universities and targeted 500 students and deans of the faculties. The student's perceptions, sources of information, and attitudes toward the perceived risks and safety of nanotechnology were assessed using questionnaires. The questionnaire to pharmacy students and deans of the faculties, which showed that 55.3% of the students had poor knowledge, 21.2% did not have any knowledge, 21.6% had good knowledge, and just 1.9% had good knowledge about nanotechnology and its applications. All the deans confirmed the absence of a specific practical or theoretical course to teach nanotechnology, but they explained that the concepts are taught within other courses. Besides, only 43% of the students mentioned that they studied nanotechnology as part of one or more courses while 57% said they did not study it in any university course. However, 90.3% of the students stated a desire to know more about.[17]

Otherwise, the Staten Island University Hospital, a tertiary care teaching hospital in New York, appraised the perception and attitude about nanomedicine of seventy MR of internal medicine. Most of the participants reported not having adequate access to information related to nanomedicine, notwithstanding, the 60% of the students showed a positive attitude towards this field, particularly in their application to diagnose and treat patients.[11]

Besides, a similar study was done among dermatology trainees, dermatology investigators, and dermatology faculty in US academic medical centers, using an online survey that was sent to 100 members of the dermatology community. This study was applied to dermatology trainees, dermatology investigators, and dermatology faculty in USA academic medical centers. 69.57% of the surveyed had not previously attended any educational activity on nanotechnology, 78.26% agreed that more education in this field is needed, and 68.87% considered it should be incorporated into the residency training curriculum.[18]

At last, the University of Al-Qadissiyah, College of Education in Iraq looked at how much nanotechnology was included in the content of subjects in the Department of Biology College of Education. The researchers built a standard verifying validity by presenting to a group of arbitrator's specialists in the methods of teaching Biology. In this way was analyzed the content of those subjects during the academic year between 2018–2019. The expert's opinions found that the subjects of this department were weak in their inclusion of nanotechnology issues. So, in this order of ideas, many observational studies have evaluated and shown students' perceptions, knowledge, and attitude toward nanotechnology and/or nanomedicine.[19]

Approach 2: articles that proposed a possible educational approach and the necessary topics related to nanotechnology or nanomedicine that should be included in their teaching.

In this approach four articles were classified too, most of them were narrative revisions but some publications also included expert consensus and other forms of opinion statements.

In Portugal, were analyzed the incorporation of nanotechnology in the curricula of Integrated Master's in Pharmaceutical Sciences programs. Also, a nanotechnology inclusion in curriculum (NIC) index was developed and used to rank each institution. NIC was proposed as a potential tool for the inclusion of nanotechnology in distinct educational programs.[20]

The Division of Dermatopathology at the University of Connecticut re-evaluated the dermatology residency curriculum to incorporate molecular diagnostics and personalized medicine training into the core competencies. They proposed a basic curriculum template for how to begin approaching these topics, a template that could be used by other dermatology residencies to get the inclusion of Nanotechnology in their syllabus. This study shows that the medical residency curriculums be longitudinal and incorporate didactic, clinical, and laboratory instruction elements. Specifically for the dermatology residency program, they recommended that the curriculum must be designed to teach a variety of research and training backgrounds and provide a solid, standardized basic knowledge in genetics and molecular medicine. Also, each subsequent year of training should be more specific, and all years of training should focus on the moral, ethical, interpersonal, and social implications. Finally, the article highlights the six core competencies defined by the Accreditation Council for Graduate Medical Education (ACGME) that must be followed for the right inclusion in nanotechnology/nanomedicine: patient care, medical knowledge, practice-based learning and improvement, interpersonal and communication skills, professionalism, and systems-based practice. These instructions could help guide other residency programs to offer similar initiatives based on goals, expertise, and available resources.[21]

Finally in this section, a publication provides recommendations for the judicious incorporation of nanomedicine topics into the Doctor of Pharmacy curriculum based on emerging pharmaceutical and clinical science applications. This publication focuses on the PharmD programs as well, it considers, for example, that key concepts of nano-size surface effects and quantum mechanical effects should be introduced early within pharmaceutics topics, emphasizing the behavior of the material at the nanoscale and how it correlates with the physicochemical properties of the final nano-pharmaceutical formulation. Besides, nano-scale drug qualities can be compared to conventional ones in the biopharmaceutics and pharmacokinetics curriculum in terms of drug delivery methods, localized and systemic tissue absorption/permeability, biodistribution, and pharmacokinetics profiles. Furthermore, clinical knowledge framework activities should construct basic nanomedicine information and highlight its clinical applicability with the aid of learning objectives and clinical case studies.[22]

Also, a commentary article provides an overview of nanomedicine education within the selection of pharmacy programs globally and describes different approaches to incorporating nanomedicine science in pharmacy programs around the world. The expansion of pharmacy education in the growing field of nanomedicine evaluates the educational content in different countries (Switzerland, Singapore, UK, USA, and China) of pharmacy programs that already include this topic in their syllabus. For example, The National University of Singapore (NUS) offers their Pharmacy and Pharmaceutical Sciences students a course that provides the knowledge required to understand nanotechnology at a deeper level and emphasizes the advantages and disadvantages of novel drug delivery strategies. In addition, the authors describe an emerging trend in pharmacy education that involves offering optional track programs with targeted elective courses that create a foundation for subspecialty knowledge. To complement the core curriculum's discussion of nanomedicine, elective courses, and collaborative practical experiences for interested students should be made available that are centered on the development and clinical usage of medical products based on nanotechnology. At last, faculties could create several extracurricular activities to combine fundamental research nanomedicine concepts with clinical decision-making. These could include early interprofessional education, collaboration, and innovation that is unrelated to patient care, seminar series with an emphasis on medical technology, or groups that provide professional services like student chapters of the Industry Pharmacist Organization (IPhO). On the other hand, the article describes the following ideal learning outcomes of a graduate module in nanotechnology: (I) to acquire knowledge and critically examine the innovative approaches taken by pharmaceutical industries and scientists to develop efficient drug delivery systems and/or diagnostic devices. (II) to present a selected topic and share own knowledge on nanomedicine through small group discussions and (III) to be able to summarize key information and data from the literature in a concise, relevant, and conducive manner.[23]

Approach 3: articles that proposed the ideal way, as well as action strategies for the incorporation of said teaching.

In this approach four articles were classified, most of them were narrative revisions but some publications also included expert consensus and other forms of opinion statements.

The New Jersey Institute of Technology describes the structure and development of a multidisciplinary, cross-campus educational program that integrates nanotechnology into the undergraduate curricula of all majors in science and engineering. This proposal gives interesting key points for the inclusion of nanomedicine and the modification of the curriculums.[24]

As the formula for success, they emphasize the following key ideas:

- Nanotechnology education must be multidisciplinary and interdisciplinary: nanometric entities and the nanoscale mechanisms expand beyond the bounds of conventional academic curriculums, so they are not restricted to one or a few disciplines.
- Nanotechnology is by default a field with a robust research component: the creation of nanotechnology courses for students must consider the hampered by a body of knowledge that is continually changing.
- The curriculums are not particularly flexible: students often have relatively rigid syllabi that do not provide much opportunity for electives. Therefore, the creation of new programs must be compatible with those already in use or postponed until the moment the curricula allow.

Nanotechnology research must be strong: on their campus, more than 30 academic members from several departments are conducting research in nanotechnology. Personal studying nanotechnology has access to a wide range of research options.[24]

A consensus of experts in which connoisseurs from all over the world participated, discussed the need to develop a standard curriculum that would allow the integration of nanotechnology concepts. The debate was centered on the effectiveness of integrating nanotechnology concepts into existing coursework versus creating new courses for nanotechnology. Finally, they built general recommendations for design curriculums that present common learning goals in the nanotechnology field.[25]

In this order of ideas, a consensus of an educational panel emits the 5 recommendations.[25]

The first one, "Inspire Students To Envision What Is or Could Be Possible" is: It must find innovative ways to demonstrate how nanoscience and nanotechnology affect our world and improve it. There may be a stronger emphasis on nanotechnology applications in the courses or practical laboratory exercises related to the principles covered in class. Getting students' attention is the first step in developing effective teaching strategies.[25] The second one, "Promote Role Models Who Impact Society": Despite the potential of nanotechnology applications, it is even more crucial to give pupils role models to inspire them to achieve comparable heights. The third one, "Encourage Global Collaboration": Students should do scientific study in many cultural contexts as part of their educational experience and be exposed to other perspectives, backgrounds, and methodologies. Research and development in nanotechnology are genuinely international. Students who are exposed to these trends early on will be more informed about employment options and will have ideas about how to collaborate in cross-disciplinary teams and across cultures.[25]

The fourth one, "Support Early Exposure Inside and Outside of the Laboratory": Nanotechnology teaching can be pursued through a variety of methods, including formal education, practical training, manufacturing, and entrepreneurship. A long-term strategy that not only teams individual students with cross-disciplinary knowledge but also produces students with complementary skill sets who can work together in teams to address the complex problems facing society will be necessary for the successful implementation of nanotechnology education and training programs across the entire sector. The fifth one, "Communication Across Fields": one of the greatest assets of the nanoscience and nanotechnology communities is that they have taught one another how to communicate across disciplines, as well as how to examine and use one another's methods and to solve the major concerns of many other professions.[25]

On the other hand, the article Which Nanobasics Should Be Taught in Medical Schools? Explains why it is critical for medical education to include instruction in nanotechnology, nanomedicine, nanotoxicology, and nanoethics and suggests basic concepts educators can use to infuse curricula with this content. They analyzed multiple approaches that could be embodied to optimally integrate the nanotechnology content into the medical school curriculum. Nanotechnology could be a stand-alone course that includes a discussion of the underlying scientific principles governing physiochemical behavior at the nanoscale, the use of nanotechnology in imaging, drug creation, and certain clinical specialties, as well as nanotoxicology and the dangers of nanomedicine. On the other hand, nanotechnology instruction could be included in courses in clinical pathology, immunology, cancer, and pharmacology. The scope and size of nanotechnology, peculiarities of nanomaterials, targeted delivery methods, processes of nano drug delivery, and interactions of nanomaterials with the host might all be covered in Clinical Pharmacology curriculum.[5]

Coursework in pathology may include nano diagnostics and nanotoxicology, while courses in immunology and infectious diseases might cover the immunological response to vaccination and vaccines made of nanoparticles as well as the interactions between innate immunity, nanotechnology, and materials science. Finally, ethics classes may go into nanotoxicology, patient adverse effects from nano therapy, potential environmental dangers, and cost-benefit evaluations.[5]

Finally, Sweeney et al come up with five key nanomedicine concepts, with brief suggestions regarding how they might be incorporated into the existing general medical curriculum. Those concepts are presented as a potential guide in terms of how they effectively might be incorporated systematically and coherently into the med-school syllabus. Ultimately, a relevant article proposed key nanomedicine concepts and suggests the way to their incorporation into the general medical curriculum. The five key concepts are: Size and scale, Interaction of nanomaterials with biological systems and design of nanomedicines, Mechanisms of drug delivery, Nanodiagnostics, and Potential ethical issues. The text describes all the contents and pedagogic strategies for their successful inclusion.[4]

Discussion

Advances in nanomedicine, personalized medicine and medicine have demonstrated the usefulness of nanotechnology, which has been integrated into the diagnosis, treatment, prevention and therapy of patients. On the other hand, nanomedicine is being used in the treatment of multiple diseases, which is individually adapted to each type of patient according to their pharmacogenetic and pharmacokinetic profile.[26] In this sense, the different tools on which nanomedicine is based from the point of view of nanotechnology become relevant. Nanotechnology has been one of the fastest-growing fields in recent years, and as mentioned above, its relevance in healthcare is becoming increasingly important.

https://doi.org/10.2147/AMEP.S431359
DovePress

However, healthcare professionals who are directly involved with the use of nanomedicine, in most cases, do not have sufficient and robust training in this field, or even worse, do not have training at all. Multiple cross-sectional studies have shown that students enrolled in undergraduate and postgraduate programs in pharmacy, medicine, and biology, although they are conscious of the importance and relevance of nanotechnology or/and nanomedicine, have little exposure to it in their educational programs.[11,17–20]

The common finding is that no matter the major or the educational area, an important percentage of the students have a poor understanding of nanotechnology, their attitude is positive toward it, and most of them believed that they need more training and education in this field. The need for a curriculum change, which includes courses dedicated to teaching nanotechnology and its applications and reflects an interdisciplinary nature, was a common finding too.(Supplementary Tables 3 and 4)

The lack of knowledge not only of the concept of nanotechnology, but also of the multiple implications that this convergent technology has in the clinical area, means that medicine or medical specialties programs do not dedicate part of their curricula to teaching it.[5] On the other hand, there is not much literature on how to incorporate the teaching of nanotechnology in different medical programs. Discussions have been found on the possible implications that nanotechnology has on drug delivery systems, for example, in the use of liposome formulations compared to free drugs and how nanomedicine benefits improvements in drug therapy. Furthermore, other aspects such as ethics in pricing, patents and incentives in pharmaceutical development are part of the topics that must be addressed within medicine programs.[27]

Interestingly, it is important to highlight the research grant opportunities in the area of nanotechnology, as well as innovation programs and centers.[28] The National Nanotechnology Initiative (NNI), mentions in its Supplement to the President's 2023 Budget, that program component area (PCA) funding promotes fundamental research with 45%, followed by Applications, Devices & Systems, Infrastructure & Instrumentation and Education & Workforce Development with 35%, 15% and 1% respectively. For this latest PCA, continued innovation in nanotechnology depends on STEM talent and people highly qualified in nanotechnology education.[29] In the case of medicine and medical specialties programs, teaching topics in the area of nanotechnology will allow expanding and increasing the capabilities of inserting this biomedical knowledge, such as the use of nanoparticles for safe drug release, use of nanomaterials for the design of diagnostic devices, in tissue engineering and cellular treatments, improvement of chronic diseases, among others.[30] We propose some possible courses on nanotechnology that can be included in the curriculum (Supplementary Table 4) and an example of a Syllabus that is being established at the University of La Sabana, Colombia (Supplementary Material 1).

In addition to what was found in the selected studies, the academic disciplines in which they are trained in the area of nanotechnology in some universities in The United States of America (USA), there are a greater number of areas of biomedicine at the doctoral and undergraduate level. postdoc[28]

Finally, the fifth theme of the NNI mentions that the ethical, legal and social implications, as well as the training of qualified workers in the area of nanotechnology, requires an interdisciplinary perspective and training in this area is only possible if we link this knowledge from training programs in the area of biomedicine.[31]

Conclusion

It is evident that multiple surveys have shown the need for students in health area programs, including MR, to be trained and instructed in topics related to nanotechnology. However, the students' perceptions of how inadequate or nonexistent such education in this field is, are also evident. Although multiple studies and investigations have increased the contents and strategies for incorporating nanotechnology in academic programs of different areas, it is still necessary to establish educational standards so that the training of future professionals will be uniform and of high quality. The concerned educational institutions' directives must make an effort to ensure that their in-training staff receives an updated, full, and excellency education.

Acknowledgments

The authors would like to acknowledge the enormous support of the Universidad de La Sabana.

Funding

This research was funded by Universidad de La Sabana MED-303-2021.

Disclosure

The authors report no conflicts of interest in this work.

References

1. National Nanotechnology Initiative. What is so special about "Nano"?; 2023. Available from: https://www.nano.gov/about-nanotechnology/what-is-so-special-about-nano. Accessed March 3, 2023.
2. Busquets R, Mbundi L. Chapter One - Concepts of Nanotechnology. In: *Emerging Nanotechnologies in Food Science*. Boston: Elsevier; 2017:1–9.
3. Rocco M, Bainbridge W, Tonn B, Whitesides G. *Convergence of Knowledge, Technology and Society.* Switzerland: Springer Cham; 2017.
4. Sweeney AE. Nanomedicine concepts in the general medical curriculum: initiating a discussion. *Int J Nanomed*. 2015;10:7319–7331. doi:10.2147/IJN.S96480
5. Sunshine JC, Paller AS. Which nanobasics should be taught in medical schools? *AMA J Ethics*. 2019;21(4):E337–346. doi:10.1001/amajethics.2019.337
6. Gómez López A. Nanomedicina y su impacto en la práctica médica. *Repertorio de Medicina y Cirugía*. 2017;26(3):129–130. doi:10.1016/j.reper.2017.06.003
7. Wong KK, Liu XL. Nanomedicine: a primer for surgeons. *Pediatr Surg Int*. 2012;28(10):943–951. doi:10.1007/s00383-012-3162-y
8. Castillo FE. Retos de este siglo: nanotecnología y salud; 2012.
9. Nance E. Careers in nanomedicine and drug delivery. *Adv Drug Deliv Rev.* 2019;144:180–189. doi:10.1016/j.addr.2019.06.009
10. Vélez J, Vélez J. The eminent need for an academic program in universities to teach nanomedicine. *Int J Nanomed*. 2011;6:1733–1738. doi:10.2147/IJN.S21133
11. Nassani N, El-Douaihy Y, Khotsyna Y, Shwe T, El-Sayegh S. Knowledge, perceptions, and attitudes of medical residents towards nanomedicine: defining the gap. *Med Sci Educ*. 2020;30(1):179–186. doi:10.1007/s40670-019-00837-8
12. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med*. 2018;169(7):467–473. doi:10.7326/M18-0850
13. STROBE. STROBE Checklist: cohort, case-control, and cross-sectional studies (combined); 2023. Available from: https://www.strobe-statement.org/checklists/. Accessed October 15, 2023.
14. Ribeiro CM, Beserra BTS, Silva NG, et al. Exposure to endocrine-disrupting chemicals and anthropometric measures of obesity: a systematic review and meta-analysis. *BMJ Open*. 2020;10(6):e033509. doi:10.1136/bmjopen-2019-033509
15. Wells GA, Shea B, O'Connell D, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses; 2021. Available from: https://www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed October 13, 2023.
16. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.
17. Al-Nemrawi NK, AbuAlSamen MM, Alzoubi KH. Awareness about nanotechnology and its applications in drug industry among pharmacy students. *Curr Pharm Teach Learn*. 2020;12(3):274–280. doi:10.1016/j.cptl.2019.12.003
18. Friedman A, Nasir A. Nanotechnology and dermatology education in the United States: data from a pilot survey. *J Drugs Dermatol*. 2011;10(9):1037–1041.
19. Mazin Thamer Shanef MA. Nanotechnology issues included in the subjects of the department of biology in the colleges of education. *Indian J Med Forensic Med Toxicol*. 2020;14(2):692–697.
20. Das Neves J. Nanotechnology inclusion in pharmaceutical sciences education in Portugal. *Am J Pharm Educ*. 2018;82(9):6403. doi:10.5688/ajpe6403
21. LaChance A, Murphy MJ. Keeping up with the times: revising the dermatology residency curriculum in the era of molecular diagnostics and personalized medicine. *Int J Dermatol*. 2014;53(11):1377–1382. doi:10.1111/ijd.12621
22. Weissig V, Elbayoumi T, Flühmann B, Barton A. The growing field of nanomedicine and its relevance to pharmacy curricula. *Am J Pharm Educ*. 2021;85(8):8331. doi:10.5688/ajpe8331
23. Barton AE, Borchard G, Wacker MG, et al. Need for expansion of pharmacy education globally for the growing field of nanomedicine. *Pharmacy.* 2022;10(1). doi:10.3390/pharmacy10010017
24. Perez-Castillejos R. Nanotechnology in education: taking multidisciplinary nanotechnology into the classroom. Paper presented at: 2015 41st Annual Northeast Biomedical Engineering Conference (NEBEC); 2015.
25. Jackman JA, Cho DJ, Lee J, et al. Nanotechnology education for the global world: training the leaders of tomorrow. *ACS Nano*. 2016;10(6):5595–5599. doi:10.1021/acsnano.6b03872
26. Alghamdi MA, Fallica AN, Virzì N, Kesharwani P, Pittalà V, Greish K. The promise of nanotechnology in personalized medicine. *J Pers Med*. 2022;12(5):673. doi:10.3390/jpm12050673
27. Moore R. Nanomedicine: rethinking medical training. *Med Device Technol*. 2008;19(1):52–53.
28. Kim KY. Research training and academic disciplines at the convergence of nanotechnology and biomedicine in the United States. *Nat Biotechnol*. 2007;25(3):359–361. doi:10.1038/nbt0307-359
29. National Nanotechnology Initiative. The national nanotechnology initiative supplement to the president's 2023 budget; 2023. Available from: https://www.nano.gov/2023BudgetSupplement. Accessed October 12, 2023.
30. Haleem A, Javaid M, Singh RP, Rab S, Suman R. Applications of nanotechnology in medical field: a brief review. *Global Health J*. 2023;7(2):70–77. doi:10.1016/j.glohj.2023.02.008
31. Council NR. *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative*. Washington, DC: The National Academies Press; 2002.