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Research on the Integration of Scientific Research Practice into the Teaching of Bioinformatics Course

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Abstract:

Bioinformatics, as an emerging discipline, plays a significant role in cultivating scientific research abilities among medical undergraduates. The bioinformatics curriculum aligns with the requirements of the new era for developing research capabilities in medical undergraduates, serving as a practical tool for medical research and expanding students' research skills. However, current bioinformatics education faces certain shortcomings, such as imbalanced course hours and content, lack of synchronization between theory and practice, students' misconceptions, insufficient teaching materials, and the absence of online teaching resources. By incorporating research practices such as database exploration, software analysis comparison, and data simulation, teachers can further enhance the quality of bioinformatics instruction. This approach enables students to deepen their understanding of learned knowledge during research projects and apply this knowledge in practice. Scientific practice helps students improve their independent design skills, scientific research literacy, and understanding of experimental procedures. It addresses the shortcomings of routine laboratory courses, while also fostering students' critical thinking abilities and interest in scientific research.

Keywords:

Bioinformatics

Scientific research practice

Course teaching

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1. Introduction

With the development of modern information and technology, disciplines such as molecular biology and bioinformatics have emerged. Bioinformatics applies knowledge from various disciplines including mathematics, biology, physics, information science, and computer science to the collection, sorting, analysis, statistics, and storage of biological information. The utilization of these results to identify biological patterns has propelled the continuous advancement of medicine and the pharmaceutical industry. Bioinformatics, characterized by its rapid updating, is well-suited to adapt to the evolving landscape of modern technological research. "China's Education Modernization 2035" outlines eight fundamental principles: morality priority, comprehensive development, inclusivity, lifelong learning, individualized teaching, integration of knowledge and action, integrated development, and collaborative construction and sharing. For biomedical undergraduates, participation in scientific research practices is a crucial aspect of university education, serving as an excellent pathway to enhance their innovative cognitive abilities. As technological advancements, socioeconomic developments, and educational modernization progress, numerous educators focus on enhancing undergraduates' scientific research practices and innovative capabilities. Numerous studies have demonstrated that integrating scientific research practices into teaching designs and involving students in project implementation can effectively improve their hands-on practical abilities, deepen their understanding of course content, and cultivate their comprehensive qualities.

By integrating the thinking patterns, viewpoints, conclusions, and analytical methods from scientific research into theoretical teaching, undergraduate instructors can transform research outcomes into educational content, thereby achieving an effective combination of research and teaching. This approach aligns with the new era's requirements for cultivating undergraduates with strong professional practical abilities and high scientific research literacy. Student participation in scientific research is not only a vital component of university education but also a favorable path for enhancing their innovative cognitive abilities. The basic knowledge acquired in the classroom is often not sufficient for fully grasping practical results, highlighting the increasing importance of integrating scientific research with practical teaching.

2. The necessity of Bioinformatics courses in cultivating medical undergraduates' scientific research abilities

2.1. Bioinformatics courses in cultivating medical undergraduates' scientific research abilities

As scientific and technological innovations continue to evolve, the biomedical industry is poised for significant growth. As one of the pillar industries in China's high-quality economic development strategy, the demand for talent in the biomedical sector is increasing year by year. To keep pace with the rapidly changing talent needs in the medical field and stay abreast of advancements in medical science and technology, it is urgent to cultivate comprehensive medical students. Medical students are expected not only to master medical expertise and clinical experience but also to develop scientific research innovation awareness and capabilities. Under the guidance of teachers, medical students can foster a strong sense of scientific research innovation, cultivate innovative thinking, actively participate in scientific research projects, and enhance their experimental research abilities from the undergraduate level onward.

Early exposure to scientific research benefits the comprehensive development of undergraduates, particularly when schools encourage students to participate in innovation and entrepreneurship projects, fostering their interest in scientific research through practical experiences. However, conducting scientific experiments can be challenging for medical students due to their heavy academic workloads and the demand for professional knowledge in their future careers. This often leads to limited time for scientific research, making it difficult to complete experiments timely and to a high standard. Consequently, students may find it hard to derive enjoyment from scientific research, develop an interest in it, or sustain their involvement in subsequent research work.

Bioinformatics, based on big data, continues to demonstrate its charm as a cutting-edge discipline with the emergence of precision medicine. It enables students to better identify scientific research goals, guides them in conducting in-depth studies on disease mechanisms, and serves as a bridge between basic research and clinical healthcare. Bioinformatics courses can assist students in finding their areas of interest, streamlining experimental processes, undertaking relevant scientific research projects, gaining a deeper understanding of disease pathogenesis, and overcoming technical limitations encountered in the laboratory. This practical application deepens students' understanding and retention of professional knowledge, thereby enhancing their scientific research literacy and innovative capabilities.

2.2. Bioinformatics knowledge is a practical tool for medical research

Currently, the biomedical field has generated a vast amount of data, and data analysis has become a new research hotspot. Disease diagnosis and treatment have shifted from the cellular level to the molecular level. By studying nucleic acid sequences and protein sequences, bioinformatics can identify disease gene mutation sites, guiding the development of treatments targeting diseases caused by mutated genes. Through learning bioinformatics, students can cultivate their ability to analyze and solve specific biological problems. Walter Gilbert once stated that medical research begins with theory and is validated through experiments after all genes have been analyzed. Therefore, analyzing existing data to validate theories is an advantage that enables the rapid development of bioinformatics. As future scientific research participants, medical undergraduates should have early exposure to bioinformatics and master analytical techniques, making it possible to effectively integrate clinical practice with scientific research.

2.3. Bioinformatics courses can expand students' scientific research capabilities

Medical undergraduate courses already include specialized subjects such as cell biology, biochemistry and molecular biology, pathology, physiology, histology and embryology, epidemiology, and medical genetics, as well as compulsory courses like English and computer science for university students. These courses require students to have a solid foundation of professional knowledge, familiarity with basic biological theories, a strong ability to screen clinically relevant data, the ability to quickly identify disease mutation sites, analyze the obtained information, and study the mechanisms of disease occurrence and development. Medical students, who learn to utilize bioinformatics knowledge and techniques for experimental research and publishing papers during their undergraduate studies will be more competitive than students from other majors. Mastering bioinformatics-related knowledge and skills allows students to conduct more advanced scientific research, exercise their scientific thinking, enhance their research capabilities, and publish more outstanding achievements. Strengthening the development of medical-related cases and research topics in the era of big data can cultivate medical undergraduates' ability to integrate clinical and research thinking early on, meeting the development needs of modern medical research.

3. Deficiencies in Bioinformatics teaching

3.1. Imbalance between class hours and content

Bioinformatics requires students to master a lot of basic biological knowledge. When arranging bioinformatics courses, medical universities often prioritize basic medical courses, resulting in compressed class hours for bioinformatics. With a limited amount of time and a vast amount of knowledge to cover, students may find it difficult to digest what they have learned. The conflict between limited class hours and extensive content deserves attention.

3.2. Asynchrony between theory and practice

The study of bioinformatics requires a combination of theory and practice. Mere theoretical knowledge cannot satisfy the teaching requirements of bioinformatics. Interleaving theory and practical courses, and applying the theoretical knowledge learned in a short time to practice, is a teaching method accepted by most students. However, in reality, bioinformatics courses still need to be adjusted based on different schools, majors, and the scheduling of other courses, which sometimes makes it difficult to achieve simultaneous progress in theory and practice.

3.3. Students' misunderstandings

Feedback from students after taking bioinformatics courses shows that most students still perceive bioinformatics as merely a research tool discipline that relies on computers to process nucleic acid or protein fragments to collect information and data. If students do not participate in scientific experiments, they will not have the opportunity to experience the efficiency brought by bioinformatics technology, nor will they be able to correctly understand the bioinformatics course. Medical school biology majors tend to focus more on teaching medical professional knowledge and less on basic bioinformatics concepts, resulting in students only being able to use pre-existing sequences and models to create cluster diagrams when teaching knowledge about evolutionary tree construction. They may not understand where the sequences come from, the concepts of similarity and homology, or the difference between orthologs and paralogs.

3.4. Scarcity of Bioinformatics textbooks

Bioinformatics involves multiple research fields and covers a wide range of knowledge. Teaching materials are diverse, and different textbooks have different content emphases. Most of them are intertwined with other disciplines and differ in language and compilation. The scarcity of bioinformatics textbooks makes it difficult for medical schools to find relevant textbooks, akin to searching for an oasis in the desert.

3.5. Lack of online bioinformatics teaching

Currently, most schools in China still primarily conduct traditional classroom teaching. Online teaching was gradually adopted after the COVID-19 pandemic began in 2020, but this online instruction still focuses on theoretical knowledge. Students have limited access to virtual platforms for online experiments, and they cannot follow the teacher's hands-on operations. There are still many difficulties in implementing online teaching.

4. Measures to improve bioinformatics course teaching in medical schools

4.1. Design of an embedded teaching and training program architecture for scientific research practice among medical undergraduates

The cultivation of scientific research practice and innovation abilities among medical undergraduates should be integrated with teaching, student-centered, and combine classroom integration, scientific research, and practice. The goal is to develop students' innovative thinking and enhance their innovative practical abilities. The objective is to achieve a development model that integrates discipline construction, teaching and research, and talent cultivation, resulting in a talent training system that prioritizes moral education and emphasizes ability. The architecture of the embedded teaching and training program for scientific research practice among medical undergraduates is shown in **Figure 1**.

4.2. Extracting medically relevant content from teaching materials

Bioinformatics covers multiple disciplines, not just medicine. Due to the different weighting of medical professional courses and bioinformatics courses, it is important to select teaching content reasonably within the limited time available for bioinformatics. This includes principles and applications of molecular databases,

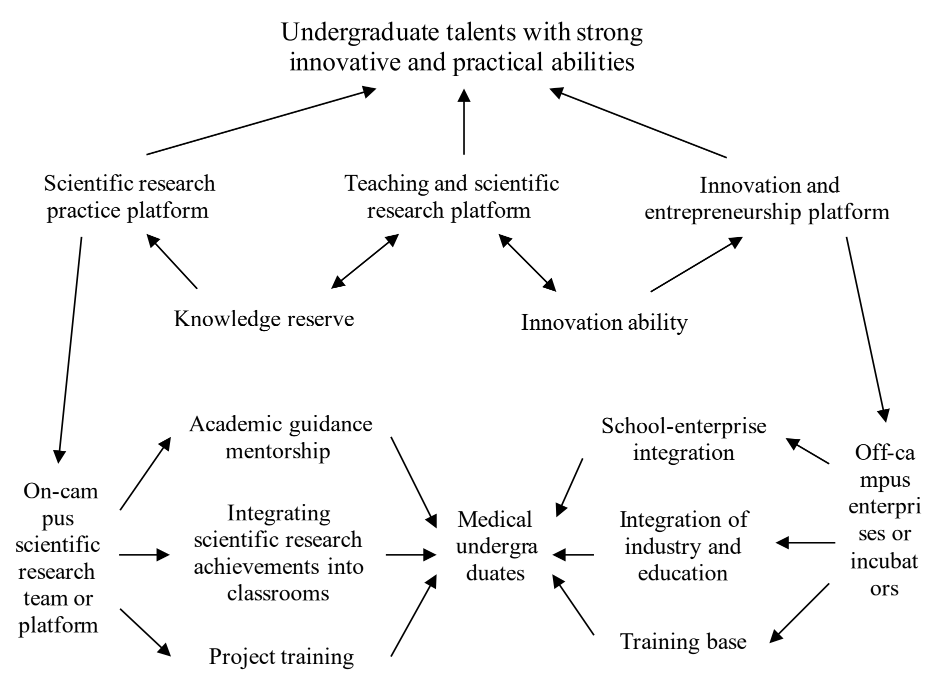

Figure 1. Embedded teaching and training system architecture for scientific research practice of medical undergraduates.

construction and use of computer models, methods and applications of algorithm optimization, etc. The teaching content should be comprehensive and focused. When teaching medical students, courses can be aligned with clinical problems, addressing issues found in clinical and scientific research experiments. Bioinformatics can be used to open up new perspectives and discover new methods in medicine. In addition, computer programming or mathematical computations can also be appropriately included as teaching content.

In medical schools, the teaching content of bioinformatics can include principles of genomics, proteomics, high-throughput sequencing, and gene chips. Detailed explanations can be provided on the selection and use of databases such as GEO, TCGA, ICGC, and MSK-IMPACT. Relying on professional basic knowledge, students can learn about the extraction and analysis of genomic sequence information, simulation of biological macromolecule structures and drug design, protein function prediction, etc. Relevant scientific research experiments can be conducted to help students consolidate their professional knowledge and cultivate their interest and innovation ability in scientific research.

4.3. Integrating clinically relevant cases into teaching

Bioinformatics requires not only theoretical knowledge but also practical experience. Teachers can include cases in their lesson plans and use these cases to interact with students during class, guiding them to think independently, discuss in groups, and solve medical clinical problems. To pique students' interest in the introductory section of the bioinformatics course, teachers can share the latest domestic and international scientific research achievements, in addition to introducing relevant concepts and application areas.

When teaching chapters, teachers can first present a case in class to capture students' attention, then explain the case process, including scheme design, research methods, results and conclusions, and discussion and analysis. Next, students can be organized to discuss the case independently, and raise questions, and the teacher can provide answers. Finally, after-class exercises can be assigned, providing a database operation guide, and requiring students to complete the exercises in groups and submit experimental result reports. This encourages students to actively seek solutions, shifting from passively accepting example methods to actively learning solution methods, which exercises their independent thinking ability and cultivates team collaboration skills. Teachers can then grade the group's after-class assignments based on their completeness.

By following the cases provided by the teacher, students can understand which step of scientific research experiments a certain knowledge point of bioinformatics is applied to, which can guide their learning path and improve their learning effectiveness. When medical undergraduates are initially exposed to scientific research experiments, teachers should fully consider the students' knowledge scope and acceptance ability when selecting teaching cases. The cases should cover the teaching knowledge outline while also being scientific and novel, keeping up with the development requirements of the new era, and allowing students to continue to develop in the direction of scientific research.

Clinical research utilizes bioinformatics to analyze and calculate clinical data, search for disease gene mutation sites, sort out the causes of diseases, screen gene targets for disease diagnosis and treatment, and provide a theoretical basis and direction for optimizing clinical treatment plans. By exposing students to clinical research cases early on, they can accumulate experience for future scientific research. Attention can be paid to public health events released by the World Health Organization, and relevant cases can be incorporated into the teaching classroom, such as the previous COVID-19 pandemic. Bioinformatics can be used to analyze pathogen antigens, determine the crystal structure of the main protease of SARS-CoV-2, analyze its genomic sequence, and clarify its origin and homology with other viruses. Additionally, bioinformatics analysis can be conducted for tumor diseases, screening which genes in the tumor genome are involved in tumor formation or development, identifying new oncogenes or tumor suppressor genes, and optimizing methods for early diagnosis and treatment of tumors. These cases already have established research models, which can better cultivate students' application abilities.

4.4. Connecting teaching with the forefront of medicine and conducting relevant clinical research topics

As a leading discipline in medical research, bioinformatics should focus on its future development. Relying on teachers' knowledge capacity and technical proficiency, attention can be paid to discipline development trends, and teaching methods and content can be optimized. The allocation of teachers in the teaching and research section should be scientific and reasonable, including not only professors with rich teaching experience to deliver introductory lectures but also doctors at the forefront of scientific research to explain medical technology methods and research hotspots to students. This allows students to progress from being introduced to the subject to independently performing relevant operations. Simultaneously, young teachers who have studied abroad at internationally renowned universities can be invited to teach, or those who have returned from overseas studies can share cutting-edge techniques from abroad, expanding the teaching horizons of the course and improving the teaching level of the bioinformatics discipline.

Bioinformatics advocates the use of practical applications to support teaching, encouraging teachers to lead students in participating in cutting-edge clinical research and applying bioinformatics in practical teaching. Some medical schools implement a one-on-one guidance model, where a mentor is responsible for guiding a student in utilizing bioinformatics-related databases to screen clinical information and perform clinical data analysis using relevant techniques, ultimately completing clinical research topics at the forefront of the field. By harnessing the frontier advantages of bioinformatics, this approach promotes an integrated teaching model of education, learning, and research, cultivates scientific research talents in the medical field, and advances the development of education. Additionally, teachers should encourage students to focus on the latest scientific research developments, enrich their disciplinary knowledge reserves, raise questions or issues, and cultivate their sense of self-innovation.

5. Conclusion

With the advent of the information age, the research directions available to medical undergraduates under big data are more extensive. Students can think independently and carry out innovative research projects to cultivate their innovative thinking. Building a teaching system for medical bioinformatics courses, strengthening clinical case analysis, and increasing clinical-related research topics cultivate a combination of clinical and scientific research thinking for medical undergraduates, aligning with the requirements of modern medical scientific research development. By studying bioinformatics, undergraduate students in clinical medicine can cultivate their clinical and scientific research abilities, promoting their future career development.

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Disclosure statement

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