

Lei Xu, Yanan Ren, Ying Ma and Feng Shen*

Biomedical engineering teaching: challenges and the NICE strategy

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Abstract

Objectives: The objective is to present the NICE strategy's effectiveness in providing a well-rounded learning experience for biomedical engineering students, preparing them for future careers.

Methods: The NICE strategy uses multiple methods. For “new frontier,” students study recent research with the assistance of artificial intelligence tools. “Integrity” is taught through case studies of both successful scientists and fraud cases. “Critical and creative thinking” is fostered by analyzing creative ideas and generating novel solutions. “Engagement” is achieved by involving clinical doctors and industry in teaching and students' product development projects.

Results: Students gain up-to-date knowledge, a strong sense of integrity, enhanced critical and creative thinking skills, and practical experience. They can better understand emerging technologies, make ethical decisions, think independently, and are more familiar with product development processes.

Conclusions: The NICE strategy comprehensively equips biomedical engineering students with knowledge, skills, and ethical awareness. It effectively bridges the gap between academia and industry, ensuring students' success in future academic research and industrial work.

Keywords: college teaching; interdisciplinary; biomedical engineering student; teaching models

Introduction

Over the past decade, biomedical engineering has witnessed remarkable growth, driven by the continuous pursuit of developing innovative engineering tools and biological methodologies to address the evolving demands of the medical field. Distinguished from traditional disciplines like physics, chemistry, biology, and mechanical engineering, biomedical engineering is characterized by its highly interdisciplinary nature [1, 2]. It actively seeks practical solutions that can be seamlessly translated into clinical applications, thereby directly impacting patient care and medical advancements [3, 4]. The combined effects of an aging global population, the far-reaching consequences of the COVID-19 pandemic, and the advent of novel treatment modalities have collectively created an urgent need for more sophisticated diagnostic tools [5–7]. This demand not only underscores the importance of biomedical engineering but also highlights the challenges faced in educating the next generation of professionals in this field.

Challenges in biomedical engineering teaching

Curriculum gap: fundamental vs. advanced knowledge

Current biomedical engineering curricula often place a strong emphasis on fundamental principles, which is undoubtedly essential for building a solid academic foundation. However, there is a conspicuous lack of courses dedicated to advanced materials and emerging technologies. In recent years, the field has been revolutionized by breakthroughs such as AI-driven protein folding prediction [8], the development of miRNA-based therapies [9], the rapid emergence of mRNA vaccines [10], and the CRISPR gene-editing technology [11]. Additionally, digital polymerase chain reaction (digital PCR) [12], nanopore sequencing [13], and single-cell analysis technologies [14] have been successfully commercialized. Teaching these cutting-edge advancements using traditional textbooks is a formidable task. Yet, for students, whether they aspire to pursue advanced research in graduate school or enter the biomedical

*Corresponding author: **Feng Shen**, School of Biomedical Engineering, Shanghai Jiao Tong University, Shanghai 200230, China; and Zhengzhou Industrial Technology Research Institute of Shanghai Jiao Tong University, Zhengzhou 450016, Henan, China, E-mail: feng.shen@sjtu.edu.cn.

<https://orcid.org/0000-0002-4709-330X>

Lei Xu and Yanan Ren, School of Biomedical Engineering, Shanghai Jiao Tong University, Shanghai, China

Ying Ma, Center for Teaching and Learning Development, Shanghai Jiao Tong University, Shanghai, China

industry, being well-versed in these state-of-the-art technologies is crucial. It equips them with the knowledge and skills necessary to contribute meaningfully to the field.

Ethical and integrity considerations

A significant proportion of biomedical engineering graduates will engage in research and development of new methods and products within the biomedical engineering domain. Given that the diagnostic tools and medical devices they develop are intended for human use, maintaining the highest standards of integrity is non-negotiable. The reliability and accuracy of these products are not only technical requirements but also ethical imperatives [15]. Moreover, ethical considerations, such as patient privacy and the proper use of medical data, are at the forefront of biomedical research. As a result, students must be trained to adhere to strict ethical guidelines and be instilled with a strong sense of social responsibility [16]. This training should go beyond theoretical knowledge and involve real-world case studies and ethical discussions to prepare students for the complex ethical dilemmas they may encounter in their future careers.

Cultivating critical and creative thinking

Critical thinking and creative thinking are complementary processes. Critical thinking provides the analytical framework needed to evaluate and refine creative ideas, while creative thinking pushes the boundaries of what is possible by generating novel solutions. Together, they enable individuals to tackle complex problems, innovate, and make meaningful contributions to their fields. Traditional educational models often prioritize rote learning and compliance, but a shift towards fostering critical and creative thinking is necessary to prepare students for the dynamic and rapidly changing biomedical engineering landscape.

Lack of practical integration

The biomedical engineering curriculum should ideally provide students with hands-on practical experiences and a seamless integration of clinical practice and industrial development [17]. However, currently, many graduates lack sufficient exposure to clinical settings and industrial processes. This deficiency becomes evident when they transition to graduate-level studies or enter the workforce. In graduate programs, students may struggle to apply their theoretical knowledge to real-world research problems. In the industry, they may find it challenging to adapt to the fast-paced and application-oriented environment. Bridging this gap between theory and practice is crucial for the success of biomedical engineering students in their future careers.

The NICE strategy: a solution to the challenges

To address these multi-faceted challenges, we have developed the “NICE” strategy for biomedical engineering teaching (Figure 1), which has been implemented in the “Medical Diagnostic Frontier Technology and Innovation Applications” course for senior undergraduate students in the biomedical engineering department. In the past five years, more than 200 students have been through this program. The “new frontier” (N) aspect of the strategy focuses on introducing students to the latest advancements from both academia and industry in biomedical engineering. “Integrity” (I) is the core of the NICE strategy. Students are educated on the importance of ethical conduct in biomedical research and development. The “critical and creative thinking” (C) component of the NICE strategy aims to develop students’ ability to analyze information critically, think creatively, and solve complex problems. “Engagement” (E) in the NICE strategy refers to the active

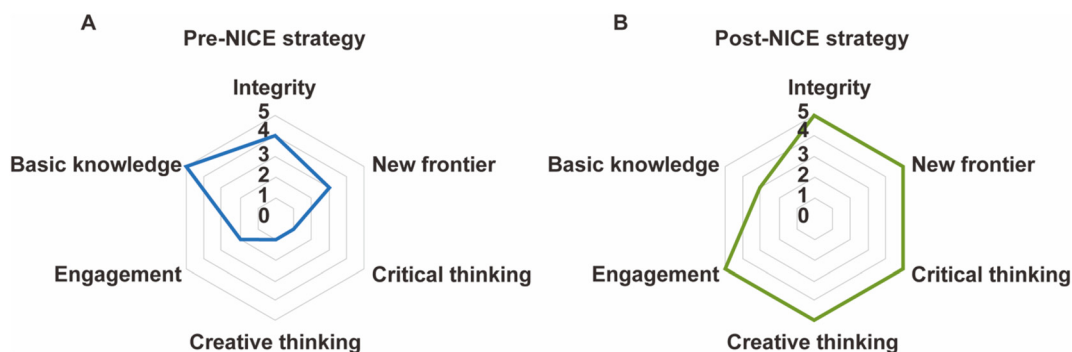


Figure 1: The radar map indicates the course design pre- and post-implementation of the NICE strategy.

involvement of students in clinical and industrial settings. This hands-on experience not only enhances their technical skills but also helps them build professional networks and understand the industry's needs.

Theoretical foundations of the NICE strategy

The NICE strategy is deeply rooted in established pedagogical frameworks, bridging its innovative approach with foundational educational theories. The “engagement” and “critical thinking” components align with constructivist learning principles [18, 19], emphasizing active knowledge construction through hands-on projects and collaborative problem-solving. This mirrors Kolb's experiential learning cycle, where students engage in concrete experiences, reflective observation, and iterative application. The case-based methodology for teaching integrity, critical thinking, and creative thinking reflects problem-based learning (PBL) [20], fostering ethical reasoning and analytical skills by immersing students in real-world dilemmas. Furthermore, the integration of industry and clinical experts embodies situated learning theory [21], enabling students to acquire tacit knowledge through mentorship and participation in professional communities. By synthesizing these theories, the NICE strategy not only addresses biomedical engineering challenges but also contributes to broader pedagogical discourse.

Materials and methods

The NICE strategy, implemented in the biomedical engineering teaching curriculum, is designed to address the multi-faceted challenges faced by students in this rapidly evolving field. Each component of the strategy – “new frontier,” “integrity,” “critical and creative thinking,” and “engagement” – employs distinct methods and materials to enhance students' learning experiences and professional development.

New frontier

The “new frontier” component of the NICE strategy focuses on immersing students in the latest technological advancements and products in biomedical engineering, while also sensitizing them to unmet clinical needs. To achieve this, two primary approaches were adopted.

First, students were required to engage with current research literature reading. They were tasked with reading research articles published within the past two years that were relevant to the course materials. This not only exposed

them to the most recent findings but also encouraged them to stay updated with the dynamic field. After reading, students were expected to summarize several related articles and present their findings orally in class. This exercise aimed to improve their literature review, critical analysis, and communication skills.

However, it was observed that undergraduate students often faced difficulties in searching for and understanding these publications. To alleviate this challenge, several artificial intelligence (AI)-based tools, including DeepSeek, ChatGPT, and Kimi, were introduced. These tools were used to assist students in literature search, summarization, and clarifying complex concepts. For example, ChatGPT could be used to generate summaries of long research articles, while Kimi could help in finding relevant keywords for more efficient literature searches.

Integrity

Teaching integrity in isolation can be a formidable task. Therefore, a case-study-based approach was adopted. The experience of renowned scientists and faculty members within our department was utilized as positive examples. These stories were shared to illustrate how innovation, perseverance, and hard work are integral to successful scientific research. For instance, students learned about how a faculty member overcame numerous obstacles to develop a novel diagnostic device through years of dedicated research.

International collaborations, such as the Human Genome Project [22], were also presented as examples of the spirit of cooperation in scientific research. These cases demonstrated how different teams from around the world worked together towards a common goal, highlighting the importance of collaboration in achieving large scale scientific breakthroughs.

In addition to positive examples, negative cases were also introduced. The Theranos fraud case, for example, was thoroughly analyzed [23]. Students were made aware of the unethical practices involved, such as false claims about the accuracy of diagnostic tests. This served to clearly demarcate the boundaries of acceptable behavior in biomedical engineering research and development, emphasizing the importance of integrity in every aspect of their future work.

Critical and creative thinking

To foster critical and creative thinking skills, students were actively engaged in case-based discussions. Different real-world cases related to biomedical engineering, such as the

development of a new drug or the ethical implications of a new medical device, were presented. Students were encouraged to analyze these cases from multiple perspectives, considering technical, ethical, social, and economic aspects.

During the individual oral presentation section, students were not only required to present the content of the selected research papers but also to provide their own insights, judgments, and critiques. This forced them to think deeply about the research and form their own opinions. The rest of the students were assigned the role of peer reviewers. They were required to evaluate the presenter's work based on predefined criteria, such as the clarity of the presentation, the depth of analysis, and the validity of the conclusions. This process not only provided valuable feedback to the presenter but also allowed the peer reviewers to practice their critical thinking skills by evaluating and providing constructive criticism of their classmates' work.

Engagement

In biomedical engineering teaching, student engagement is crucial, but it is equally important to involve clinical doctors and the related industry. To this end, clinical doctors and company R&D directors were invited to teach the product development sections of the course. These experts brought in real-world experience and industry-specific knowledge, providing students with a more practical understanding of the product development process.

Companies were also invited to provide objectives for students' group projects. In these projects, students, typically working in teams of three to five, were tasked with developing a design and development plan for a novel clinical product. To complete this project, students had to

conduct interviews with clinical doctors to identify unmet clinical needs. They then worked closely with industrial mentors to translate these needs into a viable product design. This hands-on experience not only enhanced students' understanding of the product development lifecycle but also improved their communication, teamwork, and problem-solving skills.

Results and discussions

To comprehensively assess the effectiveness of the NICE strategy implemented in the "Medical Diagnostic Frontier Technology and Innovation Applications" course, we conducted a detailed comparison between the performance of the students before and after the course reform, and observed the changes over the recent three-year period. The results have been remarkably positive, demonstrating the strategy's substantial impact on multiple aspects of students' learning experiences and professional development.

Student satisfaction

Student satisfaction has seen a significant upsurge. Through post-course surveys, we found that the percentage of students expressing high satisfaction with the course increased from 70 % before the reform to over 90 % in 2022–2024 (Figure 2A). Students reported feeling more confident in grasping the new developments in the biomedical engineering field. For example, one student commented, "The new teaching approach made complex emerging technologies more accessible, which really piqued my interest in further exploration." This new-found confidence has, in turn, greatly stimulated their enthusiasm for learning.

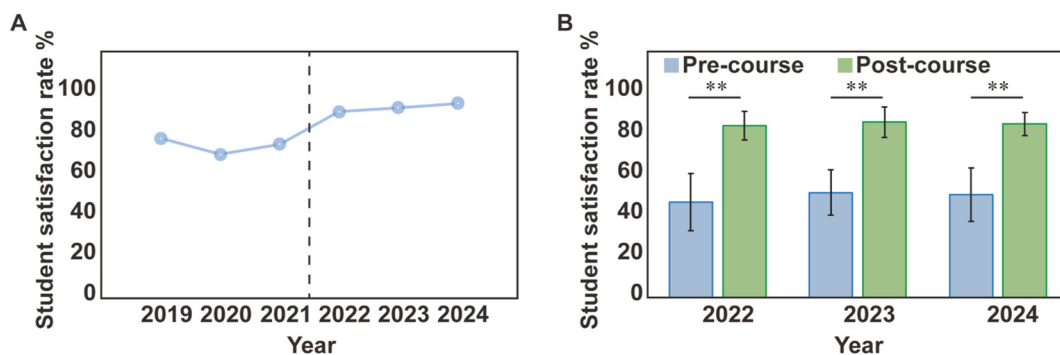


Figure 2: Analysis of students' satisfaction and understanding of integrity. (A) A dotted plot representing the students' stratification before (2019–2021) and after (2022–2024) implementing NICE strategy. (B) A bar chart comparing the level of understanding of integrity before and after taking the class with NICE strategy. (**) $p < 0.01$, $n = 40$ for 2022, $n = 42$ for 2023 and 2024).

Understanding of integrity

The case-based teachings on integrity have been highly effective. A study was conducted on pre- and post-course surveys to measure students' understanding of integrity. The results showed a significant increase in the mean score analyzed by the Student's *t* test (Figure 2B). Through the analysis of real-world cases, students have gained a much deeper understanding of why integrity is of utmost importance in the biomedical engineering field.

Critical and creative thinking ability

Students' critical and creative thinking ability has been markedly enhanced. In a pre- and post-course assessment of critical thinking skills, which included tasks such as analyzing research papers and evaluating arguments, the average score of students improved from 60 to 90 out of 100. During the questionnaire, students indicated that they could think more critically about others' work, especially that of their peers. They were able to identify flaws in arguments, question the validity of assumptions, and propose alternative viewpoints. For instance, when reviewing a peer's presentation on a new diagnostic technology, students were able to provide more in-depth and constructive feedback, demonstrating their improved critical and creative thinking skills.

Familiarity with product development

Students' familiarity with the product development process has significantly improved. Before the implementation of the NICE strategy, only 5 % of the students reported having a basic understanding of the product development cycle in biomedical engineering. After the course, this number increased to over 95 % (Figure 3). A pie chart can be used to visually represent this change. The pie charts for pre- and post-course situations are placed side by side. Each chart is divided into segments representing different levels of understanding, "no understanding," "basic understanding," "moderate understanding," and "in-depth understanding."

Their active participation in product development projects and witnessing the transformation of new principles into real-world clinical products have deepened their commitment to the related field. Many students expressed their intention to pursue careers in product development or research related to biomedical engineering products.

Industrial feedback

Industry partners, who served as co-teachers in the course, provided overwhelmingly positive feedback. They evaluated students' performance in terms of technical knowledge, practical skills, and teamwork. On a scale of 1–5, the average score given by industry partners for students' overall performance increased from 3.0 to 4.5. Industry partners specifically highlighted the students' improved preparedness and practical skills. They noted that students were more capable of applying theoretical knowledge to real-world problems, and their ability to work in cross-disciplinary teams had also improved significantly.

Limitations and future studies

While the NICE strategy has demonstrated promising outcomes, this study has several limitations. First, the reliance on self-reported satisfaction scores and qualitative feedback from students and industry partners introduces potential response bias (e.g., social desirability bias). Second, the sample was limited to a single institution, which may affect the generalizability of findings due to geographic and institutional specificity. Third, the short-term observational period (3-year follow-up) restricts our ability to assess longitudinal impacts on career development and knowledge retention. To address these limitations, future work should prioritize in the following three directions: (1) expanding the sample size to include diverse cohorts across multiple universities; (2) integrating multi-dimensional analytical tools (e.g., longitudinal performance tracking, psychometric assessments of critical thinking); and (3) conducting long-term follow-up studies (5–10 years) to evaluate career trajectories, such as leadership roles, patents filed, or clinical product

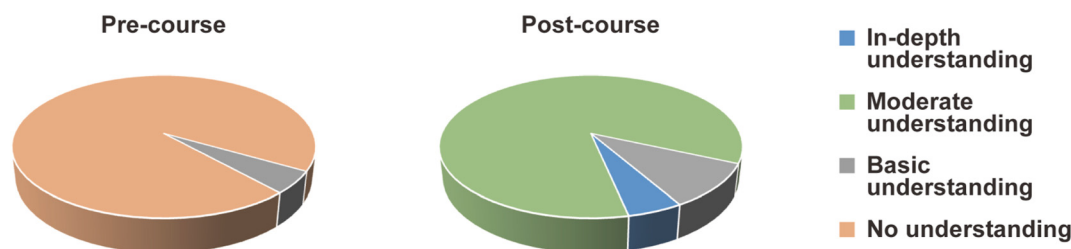


Figure 3: Pie charts represent the students' familiarity with the product development process before and after class with NICE strategy (class 2024, n=42).

commercialization rates. Additionally, comparative studies could explore how NICE performs against other pedagogical frameworks in fostering interdisciplinary competencies. These efforts will strengthen the validity of the findings and provide deeper insights into the strategy's scalability and adaptability across educational contexts.

Conclusions

The NICE strategy has received positive feedback from both students and industry partners. Students have reported increased confidence in their ability to understand and apply advanced biomedical engineering concepts, and industry partners have praised the preparedness of the students who have undergone the NICE-based curriculum. This strategy not only serves as a guiding framework for biomedical engineering teaching but also has the potential to be adapted and applied to other interdisciplinary fields. It offers a model for integrating theory, ethics, critical thinking, and practical experience to better prepare students for the challenges and opportunities in their future careers. Further research should be conducted to evaluate the long-term impact of the NICE strategy on students' career trajectories and the overall development of the biomedical engineering discipline. Longitudinal studies can track the progress of students over time, and feedback from various stakeholders can be used to continuously refine and improve the strategy.

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