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Academic Article

A Problem-Oriented Training Paradigm for Undergraduate Students in Materials Science in the Era of Artificial Intelligence

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Abstract. In the era of artificial intelligence (AI), the fields of science and technology are experiencing profound changes, creating an unprecedented demand for talent development. This study comprehensively explores the extensive influence of AI on materials science, including accelerating materials discovery and optimization, transforming research paradigms and methods, and strengthening interdisciplinary cooperation. Based on this, a "problem-oriented" talent training model for the materials science major is proposed. This model integrates AI technology and is designed to cultivate students' practical problem - solving abilities, innovative thinking, and practical skills to meet the needs of the intelligent development of the industry. This paper also addresses the challenges that may be faced during the implementation of this training model, such as the difficulty of curriculum integration, the shortage of practical teaching resources, and the imperfection of the teaching evaluation system. Through continuous optimization and improvement, this training model is anticipated to cultivate high-quality innovative talents in the materials science field and promote the intelligent development and innovation of the industry.

Keywords: artificial intelligence, problem orientation, materials science, talent cultivation

INTRODUCTION

The rapid advancement of artificial intelligence (AI) is revolutionizing various sectors in the technology industry. Materials science, as a cornerstone of modern scientific and technological progress, is undergoing profound transformations due to AI technologies. AI is shifting materials research from empirical trial-and-error to a data-driven paradigm (Jan, Z. et al., 2023). For example, it accelerates material screening via machine learning. In education, it transforms passive learning into active problem-solving. Moreover, it significantly shortens the time traditionally needed for trial-and-error approaches (Liu, Y. et al., 2023; Vasylenko, A. et al., 2021). In material processing optimization, AI can achieve the dynamic adjustment of processing technology through real-time monitoring and analysis, thus enhancing the stability and consistency of material processing (Park, S. et al., 2022; Zhu, Z. et al., 2021). These developments pose new requirements for the knowledge structure and capabilities of materials majors. The traditional talent training model appears to be insufficient in the AI era (Sanchez-Gonzalez, A. et al., 2017). Consequently, developing a talent training paradigm suitable for the AI era is essential for cultivating professionals who can manage complex data, apply intelligent algorithms, and address interdisciplinary challenges in materials science.

The problem-oriented training paradigm focuses on practical problems in teaching, thus addressing the limitations of traditional education models. In line with the principles of new engineering education (Hmelo-Silver, C. E., 2004), this approach motivates students to be actively involved in problem analysis, solution exploration, and practical verification. For example, in the materials science course of a foreign university (Jonassen, D. H. and S. K. Khanna, 2011), within the problem-oriented teaching framework, students are grouped to solve problem modules based on real engineering scenarios. During this process, they integrate multidisciplinary knowledge such as materials science and chemical engineering and use AI algorithms to optimize material combinations. These practices not only deepen their understanding of AI applications but also cultivate their problem-solving abilities, innovative thinking, and practical skills. Moreover, the role of teachers has transformed from knowledge transmitters to learning facilitators. They offer strategic suggestions and conduct process evaluations. This teaching model is highly in line with the development needs of materials science in the AI era and plays a vital role in nurturing talents who meet the requirements of the new era.

IMPACT OF AI ON THE DEVELOPMENT OF MATERIALS SCIENCE

Materials science is mainly concerned with understanding the relationships among material structure, processing techniques, performance characteristics, and practical applications. However, current research in this field is restricted by manpower and data-processing capabilities. As a result, it mostly adopts the empirical trial - and - error method, which is both time-consuming and laborious.

The emergence of AI has brought new opportunities for the development of materials science (Zhang, R. et al., 2022). It empowers all aspects of traditional materials science and engineering research, as illustrated in Figure 1. AI greatly helps scientists to find hidden relationships between variables, predict material properties, guide synthesis routes, optimize process parameters, and improve characterization methods (Ramprasad, R. et al., 2017), thereby enhancing the efficiency of research, development, and application. Figure 2 presents the statistics of the number of highly- cited papers and citations on the theme of "materials science, artificial intelligence, machine learning" retrieved from Web of Science, which shows the rapid growth trend of AI-assisted new material research and development over the past decade. In summary, the integration of AI into materials science has three key characteristics.

AI Technology Promotes Materials Discovery and Optimization

Through high-throughput experiments, a large amount of data can be processed, which accelerates the analysis of material composition, processing, and microstructure, and promotes decision-making and experimental planning (Liu, Y. et al., 2017). Moreover, AI models are able to predict properties according to the atomic structure of materials. This can reduce trial-and-error experiments, improve screening efficiency, and accelerate the discovery of high- performance materials.

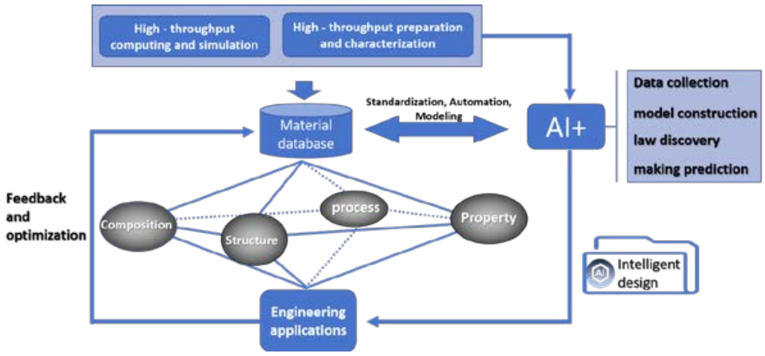

Figure 1: Schematic representation of the pathway for AI-enabled new material research and development.

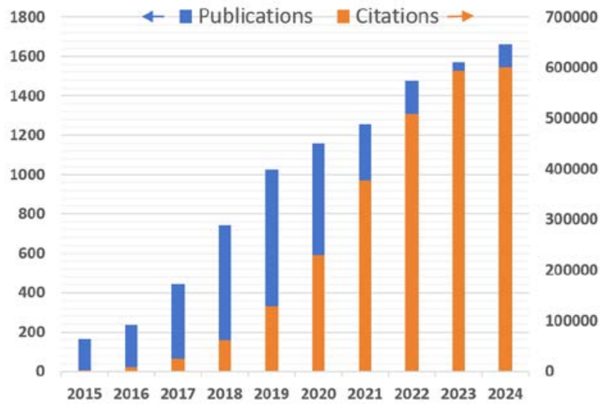

Figure 2: From 2015 to 2024 year, the research results of the combination of AI and materials science show a rapid growth trend.

Application of AI Changes the Paradigm of Materials Research

The application of AI has transformed the materials research paradigm from the trial-and-error model to the data-driven model. Through data mining, it reveals the relationship between material structure and performance, guides the research direction, and enhances the efficiency and accuracy of research (Jablonka, K. M. et al., 2020). Moreover, AI technology promotes the realization of autonomous experimental systems, which makes the experimental process automated and intelligent and accelerates the innovation process (Wang, Z. and X. Zhu, 2024).

Integration of AI Technology Strengthens Interdisciplinary Cooperation

The integration of AI into materials R & D requires multidisciplinary knowledge covering materials science, computer science, and mathematics. This interdisciplinary cooperation promotes educational reform and cultivates professionals who are proficient in both materials science and AI technologies. These professionals are crucial for promoting innovation in this field.

NEW OPPORTUNITIES BROUGHT BY AI TO THE CULTIVATION OF TRADITIONAL SCINCE AND ENGINEERING TALENTS

Innovative Teaching Models and Resources

The integration of AI into science and engineering education has transformed traditional teaching models by offering innovative resources and improving learning outcomes. In this regard, AI-driven intelligent tutoring systems (ITS) and virtual laboratories have become powerful tools. For example, AI-based virtual simulation environments like the Webots simulator allow students to perform complex robotic operations and get real - time feedback, which greatly enhances their understanding of operational principles. Moreover, studies have demonstrated that AI-enhanced learning platforms can increase student engagement and motivation. A gamified robotic simulator, for instance, has been shown to be more effective than traditional methods in promoting inquiry learning and reflective thinking. Furthermore, AI technologies have been proven to improve higher - order thinking skills (Liu, C. et al., 2025). Research indicates that students using AI - powered systems have better problem-solving abilities and computational thinking than those using conventional methods (Xu, W. and F. Ouyang, 2022). These innovative models not only offer flexible and immersive learning experiences but also overcome the limitations of traditional laboratories. Thus, AI is a transformative force in science and engineering education

Improving Learning Experience and Efficiency

In science and engineering education, AI tools like ChatGPT have greatly improved the learning experience and efficiency. They can offer immediate and precise answers to complex questions, which enables students to quickly understand difficult concepts and formula derivations (Bravo, F. A., and Cruz - Bohorquez, J. M. 2024). For instance, research has demonstrated that using ChatGPT in physics classrooms has a positive impact on students' perception and understanding of the subject (Almasri, F. 2024). Moreover, AI-driven intelligent tutoring systems (ITS) analyze student data to find knowledge gaps and then provide targeted exercises and personalized guidance. This method not only optimizes the learning process but also enhances student engagement and academic performance. According to research, AI-powered platforms can boost student engagement by up to 30% and improve learning outcomes by 25% through personalized interventions (Adewale, M. D., et al, 2024). These developments show that AI has the potential to change traditional teaching models and create more effective and inclusive learning environments.

Facilitating the Cultivation of Scientific Research and Innovation Abilities

AI tools have emerged as powerful enablers for fostering scientific research and innovation abilities among students. They empower students to process and analyze large scientific datasets, which allows students to explore complex relationships between material properties and component structures. For example, AI algorithms enable students to build and optimize models, test various design schemes, and quickly assess their feasibility and performance (Bettayeb, A.M. et al., 2024). This not only speeds up the research process but also stimulates innovative thinking and enhances students' ability to tackle interdisciplinary challenges. Furthermore, AI-driven platforms like Google AutoML and SPSS offer students tools for conducting robust statistical analyses and data visualizations. This makes it easier for students to identify patterns and gain meaningful insights. Research shows that AI tools can reduce the time spent on data analysis by up to 50%, enabling students to focus more on hypothesis generation and experimental design. In addition, tools such as ChatGPT have been proven to improve learning efficiency by providing instant and accurate answers, which helps students quickly understand complex concepts and overcome learning barriers. These developments highlight AI's potential to transform traditional research and innovation processes, equipping students with the skills necessary to drive scientific discovery and address multifaceted challenges in modern science and engineering.

CONSTRUCTION OF THE "AI + PROBLEM-ORIENTED" TALENT TRAINING MODEL

The problem-oriented teaching model emphasizes problem-driven and student-centered learning. This model is mainly characterized by four aspects: (1) Structured steps: The teaching process is divided into several distinct stages, such as problem triggering, group discussion, information search, result analysis, and presentation, with each stage having specific tasks and goals. (2) Presentation of real-world cases: Based on real-world cases or scenarios, for example, in the cultivation of materials talents, it involves real-life situations such as material design, material preparation, and material application, allowing students to be exposed to practical problems. (3) Student leadership and collaboration: Students actively participate in groups, independently choose their roles, jointly discuss and analyze problems, and complete tasks through mutual collaboration, which promotes interaction and knowledge sharing among students. (4) Continuous exploration and learning: During the process of problem-solving, students continuously identify learning outcomes that require further exploration, providing directions for subsequent learning and continuously deepening their understanding and application ability of knowledge. As depicted in Figure 3, the integration of AI is conducive to conducting adaptive learning around problems, using AI means for personalized tutoring, analyzing and evaluating learning effects, and contributing to the development of new targeted AI tools. To achieve problem-oriented talent training, the traditional teaching model needs to be reformed, mainly in the following aspects.

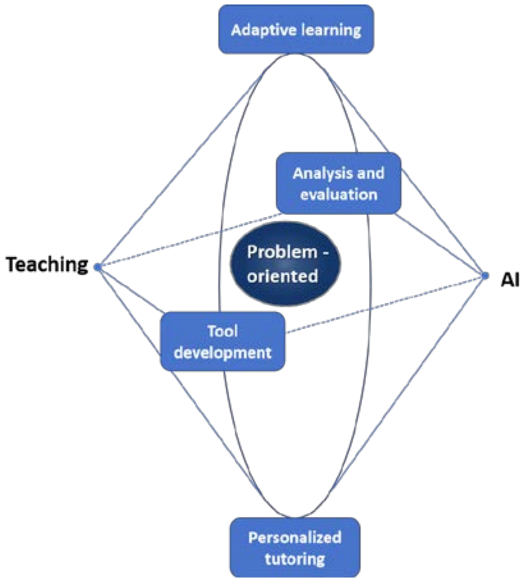

Figure 3: Schematic diagram of the problem-oriented AI-assisted teaching model.

1. Curriculum Reform

The curriculum system within the "AI+Problem-Oriented" training paradigm for materials majors encompasses four key characteristics: (1) Integration of AI technology: AI-related courses are incorporated into undergraduate materials science programs, endowing students with advanced data analysis and intelligent design approaches. This integration boosts the efficiency and innovation of materials R&D and applications. (2) Problem-oriented practice: Via project courses and practical training (such as photovoltaic material optimization projects), students utilize AI tools like genetic algorithms to solve real-world problems. Preliminary data from our "Physics properties of Materials" course indicates a 30% improvement in problem-solving accuracy in the AI-involved cohort in comparison to the traditional group. (3) Personalized development: Offer a diverse range of elective courses and practical projects to create personalized development space for students and satisfy the interests and career- planning requirements of different students. (4) Alignment with industry needs: The curriculum system closely ties in with the development trends and actual needs of the materials industry to cultivate high-quality undergraduate materials science talents capable of adapting to the development of the times. Specifically, regarding curriculum setting, it can be optimized and transformed based on the existing curriculum system and be dynamically adjusted periodically according to social development needs. The main measures are as follows.

1.1 Adding AI-related Courses

Integrate AI basic courses, such as "Introduction to Artificial Intelligence" and "Fundamentals of Machine Learning", into the curriculum system of materials majors. This enables students to comprehend the basic concepts, algorithms, and application fields of AI. Meanwhile, establish professional-direction courses like "Applications of Artificial Intelligence in materials science" to introduce specific application cases and methods of AI in material design, processing, and property prediction.

1.2 Integrating Traditional Materials Course Content

Reintegrate the content of traditional materials courses by using problems as clues to connect knowledge points. For instance, in the "Fundamentals of materials science" course, implement the "AI teaching assistant" model. Centering on the problem of "how to utilize AI to optimize material composition design", organically integrate the knowledge regarding material crystal structure, phase diagram, and diffusion, etc. Break the traditional chapter-centered teaching model and focus on problem analysis and solution. With the aid of virtual simulation, students can comprehend the significance of these knowledges in solving practical problems.

1.3 Setting Interdisciplinary Courses

Set up interdisciplinary courses, for example, "Materials-Computer Science Interdisciplinary Research" and "Materials-Physics-AI Integrated Innovation", in order to cultivate students' interdisciplinary thinking and the ability to comprehensively apply knowledge. These courses can be co-taught by teachers from different disciplines, guiding students to analyze and solve problems in the materials field from a multidisciplinary perspective.

2. Innovation of Teaching Methods

2.1 Incorporating AI Tools to Assist Teaching

Explore the utilization of large-language models to supply students with instant and accurate information regarding materials courses, facilitating students' rapid comprehension of complex concepts. Moreover, AI technology can be employed to simulate problem-cases in the actual scenarios of material research, development, and production, enabling students to analyze and formulate solutions to specific problems within a virtual environment, thereby strengthening their capacity to handle real - world problems.

2.2 Optimizing the Problem-Oriented Learning Process

In the teaching process, design a series of structured problems in line with the general laws of the discipline. For example, range from material structure analysis to performance optimization. Guide students to explore materials science problems gradually and cultivate their systematic thinking. Encourage students to independently explore answers to problems and at the same time solve complex problems through group collaboration so as to strengthen their teamwork.

2.3 Cultivating Critical Thinking

Guide students to cross-verify the information offered by AI through multiple information sources. For instance, compare academic databases, professional textbooks and ChatGPT's answers to judge the information's accuracy. When studying material composition analysis, students are able to verify the reliability of the composition detection method provided by AI from multiple sources. By setting controversial or open-ended materials science problems, students can be stimulated to think from different perspectives and cultivate their critical analysis ability.

2.4 Providing Personalized Learning Support

Based on students' learning progress, knowledge mastery, and interest preferences, AI technology will be utilized to customize personalized learning paths for students. AI systems will be used to analyze students' learning performance, offer targeted feedback and tutoring suggestions, and foster students' independent thinking and innovation ability.

2.5 Teacher Guidance and Supervision

During students' problem-oriented learning with AI tools, teachers should guide the discussion direction to ensure that the discussion centers on key knowledge points and the core of the problem. Meanwhile, teachers need to supervise students' use of AI tools, assess students' learning outcomes, such as knowledge acquisition and improvement in thinking ability during the problem- solving process, and adjust teaching strategies in a timely fashion.

3. Strengthening Practical Teaching

3.1 Establishing an AI Laboratory

Rely on the school-level public platform to establish an AI laboratory furnished with hardware and software resources like high-performance computers, data acquisition equipment, and machine-learning software. In this laboratory, students are able to explore and build models in line with the characteristics and requirements of their disciplines, carry out material data mining, model training, and simulation calculation, etc., and get acquainted with the application process and technology of AI in materials science.

3.2 Carrying out School-Enterprise Cooperative Practical Projects

Cooperate with materials-related enterprises to carry out practical projects, and introduce the actual material problems encountered by enterprises into practical teaching. For instance, collaborate with materials-field enterprises to conduct technology commission services or "revealing the list and taking the lead" research projects. Enable students to participate in project implementation under the joint guidance of enterprise engineers and school instructors, so that they can understand the actual needs of enterprises and the engineering practice environment, and enhance their ability to solve practical problems.

3.3 Organizing Disciplinary Competitions and Scientific Research Activities

Encourage students to take part in disciplinary and professional competitions, which can promote talent exchanges among colleges and universities and stimulate innovation vitality. Meanwhile, organize students to participate in teachers' scientific research projects or carry out small-scale scientific research topics, and cultivate students' innovation and practical abilities in competitions and scientific research activities.

4. Building the Teaching Staff

4.1 Improving Teachers' AI Technology and Interdisciplinary Knowledge Reserves

Formulate a systematic AI technology training plan, and regularly organize teachers to take part in training courses which cover machine learning, deep learning, data mining, etc. Meanwhile, encourage teachers to join online learning communities so as to timely grasp the frontier knowledge and application skills in the AI field. Promote teachers to carry out interdisciplinary learning, and require teachers majoring in materials to learn relevant disciplines such as computer science and data science.

4.2 Enhancing Teachers' Teaching Ability and Resource Integration Ability

Carry out training workshops centered around the problem-oriented teaching method. Invite experts to perform demonstration teaching and share their experiences, which will assist teachers in proficiently grasping the teaching concept, design method, and implementation skills. Particularly in the "AI + problem-oriented" teaching scenario, teachers can effectively guide students to independently study and solve problems in materials majors through teamwork. Emphasize on cultivating teachers' capacity to integrate AI-related teaching resources, guide them to screen and optimize resources such as online course platforms, virtual laboratories, and intelligent learning systems, and organically incorporate these into the teaching of materials courses. This will enrich teaching methods and content and enhance teaching quality.

4.3 Strengthening Teachers' Scientific Research Innovation and Cooperation Ability

Actively encourage teachers to apply for scientific research projects at the intersection of AI and materials. The school and the college provide comprehensive support in terms of funds, equipment, and team building. Meanwhile, establish a scientific research cooperation platform to promote in- depth cooperation between teachers and enterprises as well as research institutions in AI-material research and development and intelligent material design, enhance teachers' scientific research innovation ability, and enable them to feed back the latest scientific research achievements to teaching, specifically "AI + problem - oriented" teaching.

DEVELOPMENT PROSPECTS AND CHALLENGES OF THE PROBLEM-ORIENTED TRAINING MODEL

1. Development Prospects

The problem-oriented training model is increasingly conforming to the expanding application requirements of AI in materials science, and is effectively cultivating talents who are able to utilize AI technology to solve complex industrial problems. This model is in line with the increasing role of AI in materials science. AI tools, like genetic algorithms, are widely applied to optimize material properties and accelerate the discovery of new materials. In addition, AI-driven tools are more and more integrated into project-based learning (PBL) courses, such as photovoltaic material optimization projects. These projects offer students practical experience in applying AI techniques to real-world problems, promoting innovation and critical thinking. The increasing adoption of AI in materials science education highlights its potential to transform traditional teaching models and prepare students for the changing demands of the industry.

2. Challenges

The problem-oriented training model is able to tackle its challenges by means of targeted strategies. Firstly, in order to bridge the gap between AI and traditional materials curricula, universities need to establish interdisciplinary teacher training programs. They should cooperate with computer science departments and industry experts to jointly design modular courses (for example, "AI for Materials Science") and offer workshops on AI tool integration. Secondly, resource shortages can be alleviated through the adoption of open-source platforms such as TensorFlow Materials Library for simulations and collaborating with technology firms (such as Huawei Cloud, NVIDIA GPU grants) to obtain scalable computational resources and real-world datasets. Thirdly, teaching evaluations should be redesigned to incorporate competency- based rubrics for assessing problem-solving, innovation, and teamwork, like peer-reviewed project portfolios or industry-sponsored problem-solving challenges, which can replace the conventional exam-centric metrics. Finally, to address the over-reliance on AI, educators should adopt a hybrid pedagogy. AI tools can be used to handle data-driven tasks (for example, material property predictions), while students concentrate on hypothesis formulation, experimental design, and critical analysis through debates or case studies comparing AI outputs with traditional methods. Collectively, these solutions enhance feasibility while maintaining core educational values.

CONCLUSION

The rapid development of artificial intelligence (AI) has deeply transformed materials science, making it necessary to shift the paradigm in undergraduate education to meet the requirements of the AI era. The proposed "AI + Problem- Oriented" training paradigm combines AI technologies with a problem - driven approach to foster students' problem-solving skills, innovative thinking, and practical abilities. This model overcomes the limitations of traditional education by stressing curriculum reform, innovative teaching methods, strengthened practical training, and the cultivation of interdisciplinary teaching staff.

Despite its potential, the implementation of this paradigm is faced with several challenges. These include integrating AI into traditional curricula, the lack of practical resources, and the need for a comprehensive evaluation framework. Moreover, over-reliance on AI tools may undermine students' critical thinking skills. However, this training model provides a promising way to cultivate high-quality, innovative talents in materials science, which supports the intelligent development and global competitiveness of the industry. By continuously improving this approach, it can effectively bridge the gap between education and industry needs, driving future innovation in materials science. Future research should explore: (1) the long-term ethical impacts of AI dependency, such as the erosion of hypothesis independence; (2) interdisciplinary extensions, for example, quantum materials; and (3) standardized AI literacy training for instructors.

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