

Reform in the Integration of Mathematical Knowledge in Materials Science Courses

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Keywords: Materials science major courses; mathematical knowledge; application; teaching reform

Abstract: With the development of society and advancement of technology, there is an increasing demand in the field of materials science and engineering. As students majoring in materials science, it is essential not only to possess a solid understanding of material knowledge but also to grasp the fundamental principles and methods of mathematical and physical sciences. These skills enable better tackling of intricate issues and challenges. Mathematics, as a foundational discipline, offers a crucial tool for materials science students to solve problems and analyze phenomena. This paper explores the reform of mathematical knowledge application in materials science major courses and provides corresponding suggestions and measures. Through these reforms, the aim is to cultivate more talents in the materials science field with a strong mathematical foundation and innovative capabilities, making positive contributions to the advancement of materials science and engineering.

1. Introduction

In recent years, with the rapid development of technology and the economy, the discipline of materials science has become increasingly significant in various fields. However, many students majoring in materials science often encounter difficulties in mathematics and physics during their learning process, which are crucial subjects in materials science. Therefore, strengthening the mathematical knowledge of materials science students and enhancing their mathematical application abilities have become important issues in the ongoing teaching reform in materials science discipline.

2. The Necessity of Enhancing the Application of Mathematical Knowledge in Materials Science Major Courses

The field of materials science and engineering involves numerous complex issues that require modeling, analysis, and solution through mathematical methods. For instance, there exists intricate correlation between the performance and structure of materials, necessitating the use of mathematical statistical methods for data processing and analysis. Mastery of mathematical knowledge and its adept application in practical problems is imperative for effectively solving these intricate issues. The design and manufacturing processes of materials require the consideration of multiple factors and variables, where mathematical methods aid in constructing mathematical models and determining

optimal designs and processing schemes through optimization algorithms. For example, in alloy design, material performance predictions and optimization designs can be achieved through mathematical models based on varying element contents and ratios. In material research, extensive data needs analysis and processing, where mathematical statistical methods aid in reasonable data analysis and interpretation, extracting valuable information. Mathematical methods also find utility in optimizing experimental design, enhancing experimental efficiency and accuracy through well-designed experimental plans. As a fundamental discipline, mathematics cultivates logical thinking, abstract thinking, and problem-solving abilities. Reinforcing the application of mathematical knowledge can promote the enhancement of students' comprehensive skills, nurturing their abilities to analyze problems, think independently, and innovate. This holds significant implications for materials science students in facing future intricate challenges and demands.[1]

3. Application of Mathematical Knowledge in Materials Science Major Courses

3.1. Application of Quantitative Change Knowledge

In materials science major courses, the application of quantitative change knowledge is extensively present in various aspects. In the synthesis and reaction processes of materials, quantity change is a crucial factor to consider. For example, by controlling the molar ratio of reactants, one can determine the quantity and proportions of products in chemical reactions. In material synthesis, it's necessary to calculate the relationships between the mass, volume, or moles of reactants and products to establish optimal synthesis processes and conditions. Quantity change is also a key factor in the crystal growth and phase transition processes of materials. Through the analysis of quantity change, the kinetic processes of crystal growth and the thermodynamic properties of phase transitions can be understood. For instance, in solid-state reactions, the transformation rate and equilibrium concentration of reactions can be calculated based on initial reactant molarities and equilibrium constants. In materials science, quantity change knowledge is also applied to describe the relationship between the mass and density of materials. Through quantity change analysis, one can calculate material mass, volume, and density to assess their physical and mechanical properties. For instance, in mechanical performance testing of materials, it's often necessary to measure material density and calculate mechanical indicators like strength and modulus by combining other parameters.[2]

Quantity change knowledge is also crucial in material failure and lifespan prediction. Analyzing material quantity change enables the assessment of fatigue lifespan, creep behavior, corrosion rates, etc. For example, in fatigue fracture analysis, material lifespan under specific stress cycles can be predicted through quantity change calculations. In the domain of material processing and heat transfer knowledge, numerical computations and optimization algorithms are employed to address issues like thermal coupling, deformation, and residual stress during forming processes. In the field of material heat transfer, partial differential equations and numerical simulation methods are used to describe heat conduction processes and temperature distributions. Statistical methods are used to process and analyze material sample data to extract information regarding material properties. Mathematical methods are also employed in optimizing experimental design, determining optimal experimental plans and parameter settings to enhance experimental precision and reliability.

3.2. Application of Spatial Structure Knowledge

Spatial structure knowledge allows the description and analysis of geometric shapes of lattices, symmetry of unit cells, and arrangements of atoms or ions within crystals. Utilizing spatial structure knowledge, crystallographic parameters like point groups, space groups, and crystallographic parameters can be deduced, facilitating a deeper understanding of various properties and behaviors of crystals. Crystal defects refer to defect points, lines, or planes within crystals, such as vacancies, interstitials, dislocations, and grain boundaries. Through spatial structure knowledge, the types, forms,

and locations of crystal defects can be quantitatively described and analyzed. This holds significance in studying material performance and behavior, improving material properties, and designing defect engineering.[3]

Spatial structure knowledge is also employed in describing and analyzing properties of molecules, such as geometric shapes, bond lengths, bond angles, etc., and predicting and simulating interactions and dynamic behaviors among molecules. This is of importance in fields like molecular design, functionalization of materials, and pharmaceutical research.

By employing spatial structure knowledge, the composition, arrangement, and spatial distribution of microstructures within materials can be correlated with macroscopic properties (e.g., mechanical, electrical, and thermal properties). This aids in optimizing material microstructures to achieve desired macroscopic properties. In materials science courses, mathematical methods play a significant role in the study of material structures and crystallography. For instance, crystallography involves geometric knowledge of points, lines, and planes, as well as mathematical tools like coordinate systems and vector operations. Research into symmetry and crystal defects in crystallography also requires mathematical methods like group theory and matrix calculations. Mathematical methods are also pivotal in describing material properties and mechanical behavior. For example, material mechanics involves the use of calculus, differential equations, and variational methods to describe strength, stiffness, deformation behaviors, etc. Fatigue lifespan and fracture behavior of materials can also be predicted and analyzed using mathematical models.

4. Challenges and Issues in Enhancing the Application of Mathematical Knowledge in Materials Science Major Courses

The application of mathematical knowledge in materials science major courses presents several challenges and issues. Students in the materials science field may have varying levels of mathematical backgrounds. Some students might possess strong mathematical foundations, while others may have weaker mathematical skills. Hence, while strengthening the application of mathematical knowledge in teaching, it's important to balance the needs of all students. This involves catering to those with existing mathematical proficiency by providing more in-depth learning while also offering effective support and supplementation for students with weaker mathematical foundations. Integrating mathematical knowledge into materials science courses requires the seamless fusion of mathematical and materials science content. This can pose challenges in course design and the development of teaching materials. Teachers must bridge the gap between abstract mathematical concepts and real-world material issues, selecting appropriate case studies and examples to demonstrate the practical significance and value of mathematical knowledge.

Traditional teaching methods might not be sufficient to inspire students' interest and motivation in applying mathematical knowledge. To enhance students' mathematical application skills, innovative teaching methods are needed. For instance, introducing case studies, practical projects, group collaborations, etc., encourages students to analyze and solve real-world problems using mathematical knowledge, nurturing problem-solving abilities and innovative thinking. Strengthening the application of mathematical knowledge in teaching reform requires students to possess interdisciplinary comprehensive competencies. Beyond mathematical knowledge, students need a profound understanding of materials science, practical skills, and engineering applications. This reform also demands a teaching team with relevant background knowledge and instructional capabilities. Teachers not only need to master materials science and mathematical knowledge but also understand the learning needs and characteristics of materials science majors. Therefore, teacher development and support are essential challenges.

5. Strategies for Enhancing the Application of Mathematical Knowledge in Materials

5.1. Enhance Course Knowledge Integration

Integrating course content facilitates students' better understanding and application of mathematical knowledge in materials science. Organic integration of mathematical and materials science content forms a cohesive curriculum. Teachers need to determine the relationship between mathematics and material expertise, embedding relevant mathematical concepts and methods into relevant sections or units in the materials specialty curriculum. In the curriculum design, teachers should also emphasize the horizontal and vertical connection of mathematical knowledge. Horizontal alignment involves merging mathematical knowledge with different course content areas. For example, employing mathematical modeling and equation solving in mechanics, thermodynamics, electromagnetics, etc. Vertical alignment signifies the consistent use of mathematical knowledge across various materials science courses. Therefore, teachers can help students consolidate and strengthen their mathematics background knowledge by offering basic mathematics courses or providing relevant self-study resources before the course begins.

Teachers can use concrete material cases and real-world problems in the classroom to demonstrate the application of mathematical knowledge in solving material-related issues. By explaining examples, they can guide students to actively think about how to apply mathematical knowledge to solve such problems and provide the corresponding mathematical methods and tools. Through teaching methods like group cooperation, discussions, and problem-solving, students' interest and proactiveness in learning can be ignited. Teachers should encourage students to apply mathematical knowledge in practice, for instance, by organizing experiments, case analyses, and other activities that allow students to directly participate and experience the application of mathematical knowledge in real-world problems. Teachers should also encourage students to integrate mathematical knowledge with other disciplines, fostering interdisciplinary thinking and abilities. For example, in material science courses, introducing mathematical modeling, data analysis, and optimization algorithms can combine mathematics with fields like engineering and physics, thereby developing students' comprehensive skills.

5.2. Introduce Example-Based Teaching Guidance

In materials courses, teachers can present specific material cases and real-world problems to guide students in applying mathematical knowledge to practical materials science problems. Teachers can select some cases or real-world problems relevant to the field of materials science and present these questions to students in the classroom, guiding them to apply mathematical knowledge for analysis and resolution. Teachers can begin by introducing the background and requirements of the case or problem, then lead students to consider how to use mathematical knowledge to address these issues. For instance, in a materials mechanics course, a tensile test of a material can be chosen as a case. Teachers can show students experimental data and guide them in analyzing the results, calculating mechanical parameters such as stress and strain for the material. Through guiding students in using mathematical formulas and methods, they can understand stress-strain relationships and study material mechanical properties.

Furthermore, teachers can guide students to use mathematical modeling and equation-solving methods to address practical material-related problems. For instance, in materials thermodynamics courses, guide students to calculate temperature distribution and thermal conductivity parameters by establishing heat conduction equations and boundary conditions. Example-based teaching allows students to connect abstract mathematical knowledge with practical problems, facilitating a better understanding of the importance and application of mathematics in materials science. This teaching strategy sparks students' interest, nurtures problem-solving abilities and innovative thinking, and enhances their practical skills in materials science.

5.3. Foster Inquiry-Based Learning

Through problem-setting, context, or projects, teachers encourage students to actively explore and learn. Students become involved in exploring and comprehending knowledge rather than passively receiving it. In class, teachers can form groups, where students cooperate, discuss, and contemplate together. For instance, teachers can present a material-related challenge and ask students to collect relevant data, devise solutions, and use mathematical knowledge for analysis and optimization. Encourage students to engage in experiments, observations, and data analysis activities to discover the link between materials science and mathematics. For instance, students can conduct materials mechanics experiments, measure mechanical parameters, and calculate stress and strain using mathematical formulas. These practical experiences help students merge abstract mathematical concepts with real problems, comprehending the application of mathematics in materials science.

Teachers can guide students in independent research and academic reading to understand the latest applications of mathematical methods in materials science. Students can choose an area of interest, then use mathematical knowledge to analyze and solve related problems. Teachers can provide guidance and feedback, aiding students in overcoming challenges and broadening their perspectives. By fostering inquiry-based learning, students can gain a deeper understanding and application of mathematics in materials science. This strategy cultivates self-directed learning, problem-solving abilities, innovative thinking, and enhances their practical skills and comprehensive qualities in materials science.

5.4. Adopt a Diverse Assessment Approach

Teachers can employ a variety of assessment methods, such as classroom performance, project reports, and experimental results, to evaluate students' ability to apply mathematical knowledge. Emphasis is placed on a comprehensive assessment of students' overall abilities, which goes beyond just mathematical computation skills. It also assesses their problem-solving skills, innovative thinking, and teamwork capabilities. Traditional assessment methods often focus solely on students' memory and expression abilities, often failing to fully reflect students' comprehensive abilities in mathematical application. Hence, introducing diverse assessment methods can better assess students' mathematical application abilities.

Teachers can design practical projects related to the course, requiring students to apply mathematical knowledge to problem-solving. These assignments assess students' mathematical skills and increase their understanding and application of materials science practice. In materials experiments, students need to collect, process, and analyze data. Teachers can evaluate students' abilities to analyze and interpret experimental data in their reports, as well as their proficiency in using mathematical tools and methods. Students can form groups to collaboratively solve complex materials science problems, presenting their findings in class discussions and presentations. Teachers can assess students' performance in teamwork and evaluate their mathematical application abilities. Students can present their understanding and application of mathematical knowledge through oral presentations or demonstrations. Teachers can evaluate their mathematical application level based on their performance. Apart from project assignments and practical assessments, comprehensive exams remain a significant assessment method. Exam content should test students' understanding and mastery of mathematical application, covering key concepts and skills throughout the course.

5.5. Integrate Mathematical Practice

Teachers should combine practical links with the application of mathematical knowledge, such as organizing experimental practice, enterprise practice, etc., so that students can use mathematical knowledge to solve material problems in practical operation. Practical experience lets students perceive the practical application of mathematical knowledge, enhancing their interest and motivation.

Design materials experiments where students are responsible for planning the experiment, collecting data, and performing data analysis using mathematical knowledge. Through practical work, students apply mathematical knowledge to solve experimental issues, such as statistical analysis, error estimation, and curve fitting. Teachers can use computer software or programming tools to guide students to conduct the simulation calculation and modeling of material characteristics. Students need to apply mathematical methods to describe material behaviors, choose appropriate models and algorithms, and analyze the results. Such practical activities provide a platform for comprehensive application of mathematical knowledge, helping students understand the practical application of mathematics in materials science.

Teachers can guide students in participating in mathematical modeling projects, where they apply mathematical knowledge to real-world materials science problems. For example, students can choose a material-related challenge, like optimizing material structures or predicting material properties, and use mathematical modeling methods for analysis and solution. Such projects cultivate problem-solving abilities and innovative thinking while enhancing students' understanding of mathematical application. Teachers can guide students to use mathematical tools and software to assist in materials science research and analysis. For instance, students can learn to use statistical software for data processing and analysis, numerical computation tools for solving complex systems of equations, or finite element analysis software for material mechanics simulations. These practical activities deepen students' familiarity with mathematical tools, improving their application abilities in real-world problems.

For instance, in a classroom setting where students are conducting a tension experiment and measuring the stress-strain curve of a material, they need to plot the curve and calculate key mechanical parameters such as Young's modulus and yield strength. This requires data processing and curve fitting skills, involving the application of mathematical knowledge to analyze experimental results. When students use finite element analysis software to simulate the heat conduction of a specific material, they need to set appropriate boundary conditions, mesh divisions, and numerical methods, then analyze the computed temperature distribution, which requires numerical computation and mathematical modeling skills. When students model a specific property of a material, like electronic structure, optical properties, or mechanical behavior, they need to collect relevant data, choose suitable mathematical models, and use mathematical tools for computation and analysis. Through these project-based practical teachings, students deeply comprehend the application of mathematical knowledge in materials science and enhance their problem-solving abilities. This forms a central point in integrating mathematics teaching with materials science education.

6. Conclusion

In summary, enhancing the application of mathematical knowledge in materials science major courses is a key measure to improve students' mathematical application abilities and the quality of materials science education. Through effective integration strategies between materials science and mathematics education, students can gain a better understanding of the practical application of mathematical knowledge in the field of materials science and enhance their mathematical application abilities. This lays a solid foundation for their future learning and career development, while also promoting the advancement and innovation of materials science. In future teaching endeavors, we should continue to explore more effective teaching methods and strategies to further enhance the mathematical application abilities of materials science students and cultivate more outstanding talents in the field of materials science.

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