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Research on Blended Teaching of Mobile Robot Path Planning Technology Course in the Context of Emerging Engineering Education

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Abstract:

With the rise of emerging engineering education and the rapid development of artificial intelligence technology, mobile robot path planning technology has become an important research direction in the field of intelligent robotics. To meet the new demands of enterprises for robotics professionals, higher education institutions are actively exploring reforms in teaching models. This paper focuses on the research of a blended teaching model for mobile robot path planning technology. Building on traditional classroom teaching, this study introduces project-based teaching, combining online resource learning with offline practical operations to enable students to deeply understand and master fundamental path planning knowledge. Taking the RRT algorithm as an example, after explaining its basic principles, students are guided to improve the RRT algorithm by incorporating ideas from the artificial potential field algorithm, aiming to enhance the efficiency and quality of path planning. This blended teaching model not only strengthens students' theoretical knowledge but also hones their practical skills and engineering awareness, effectively meeting the training requirements for robotics professionals in the context of emerging engineering education.

Keywords: Blended teaching; Path planning; Improved RRT algorithm; Mobile robot; Emerging engineering education; Curriculum innovation

INTRODUCTION

With the deepening development of the global technological revolution, the proposal of the emerging engineering education concept marks the entry of engineering and technical education into a new developmental stage [1]. Emerging engineering education emphasizes innovation, practice, interdisciplinary integration, and aims to cultivate high-quality engineering talents capable of meeting the demands of future industrial development [2]. Against this backdrop, mobile robotics technology, as a critical supporting technology in fields such as intelligent manufacturing, intelligent transportation, and intelligent services, has seen its educational and research significance increasingly highlighted. As a core component of mobile robotics technology, mobile robot path planning plays a vital role in enhancing robots' autonomous navigation capabilities, optimizing motion paths, and improving operational efficiency.

Mobile robot path planning technology refers to the process of planning an optimal or suboptimal path from a starting point to a target point based on information such as the robot's initial position, target location, and obstacle distribution in known or unknown environments [3]. This process involves multiple stages, including environmental perception, path search, and decision-making, requiring the integration of knowledge from various fields such as computer science, control theory, and artificial intelligence [4]. Therefore, teaching mobile robot path planning technology not only demands that students master solid theoretical foundations but also requires them to possess rich practical experience and innovative thinking.

However, traditional engineering education models often focus on the transmission of theoretical knowledge while neglecting the cultivation of practical skills and the enhancement of innovative capabilities [5]. This issue is particularly pronounced in the teaching of mobile robot path planning technology. Students may grasp the basic principles of algorithms but often struggle to flexibly apply their knowledge to solve complex real-world path planning problems. Additionally, traditional teaching methods lack the cultivation of soft skills such as teamwork and communication, making it difficult to meet the comprehensive quality requirements for talents under the emerging engineering education framework [6].

Therefore, exploring a teaching model that integrates theory and practice while emphasizing the cultivation of students' innovative abilities is of significant importance for improving the effectiveness of teaching mobile robot path planning technology. As an emerging teaching model, blended learning combines online and offline teaching, preserving the interactivity of traditional classroom instruction while leveraging the richness and convenience of online resources. This approach provides new ideas and methods for teaching mobile robot path planning technology [7].

In recent years, research on blended learning models for mobile robot path planning technology has been increasing, offering a rich theoretical foundation and practical experience for this study.

Regarding blended learning models, scholars both domestically and internationally have conducted extensive research and practice. Blended learning refers to a novel teaching model that integrates online network-based teaching with offline classroom instruction [8]. It fully utilizes the flexibility and convenience of online teaching, as well as the interactivity and practicality of offline teaching, achieving complementary advantages. In a blended learning model, students can independently learn theoretical knowledge through online platforms, participate in online discussions, and take tests, while offline classrooms focus more on practical teaching and interaction. Through group discussions, project-based learning, and other methods, students can master knowledge and skills in practice [9]. This teaching model not only enhances students' learning interest and engagement but also fosters the development of their self-directed learning abilities and teamwork skills [10].

In the research on blended learning models for mobile robot path planning technology, scholars have also made some attempts and explorations [11]. Some researchers have introduced virtual reality technology into blended learning models by constructing virtual environments for robot path planning, allowing students to practice path planning in these virtual settings. This teaching approach not only reduces experimental costs but also enhances the safety and operability of experiments [12]. Additionally, other researchers have integrated project-based learning into blended learning models by designing a series of project tasks related to path planning, enabling students to master the core knowledge and skills of path planning technology through completing these projects [13]. This method not only cultivates students' practical and innovative abilities but also improves their teamwork and problem-solving skills.

However, current research on blended learning models for mobile robot path planning technology still has some shortcomings. First, the research content is relatively narrow, primarily focusing on the design and implementation of teaching models, while lacking studies on the evaluation of teaching effectiveness and continuous improvement [14]. Second, the research methods are mostly qualitative, lacking support and validation from quantitative data. Finally, the scope of research is relatively limited, mainly concentrated in universities and research institutions, with insufficient attention paid to areas such as vocational education [15]. Therefore, building on previous research, this study will further explore blended learning models for mobile robot path planning technology, emphasizing the evaluation of teaching effectiveness and continuous improvement, while expanding the scope and depth of research to provide valuable insights and references for the reform of mobile robot path planning education.

In summary, this study aims to explore a blended learning model for mobile robot path planning technology in the context of emerging engineering education, addressing current issues in teaching and enhancing teaching quality and effectiveness. By conducting an in-depth analysis of the current state and problems of teaching, combined with the principles of emerging engineering education, this study designs a scientifically sound blended learning model and validates its effectiveness and advantages through empirical research, providing valuable insights and references for subsequent teaching reforms.

This study takes the RRT algorithm as an example, enabling students to understand its principles. After students master the application of the RRT algorithm in path planning, the study introduces the artificial potential field algorithm to improve the RRT algorithm, thereby helping students grasp the concepts of mobile robot path planning and enhancing the quality of robot path planning. Once students understand the principles of path planning algorithms, to improve their hands-on skills, the blended learning process involves students using open-source components to build robots. Through hardware assembly, students gain knowledge of robot hardware. Finally, the path planning algorithm is applied to the assembled robots, deepening students' understanding of the subject matter.

This study aims to explore the specific application methods of blended learning in mobile robot path planning and its impact on student learning outcomes. By comparing the effectiveness of traditional teaching methods with blended learning, it hopes to provide a new and more effective approach to teaching mobile robot path planning. Additionally, this study will delve into the characteristics, advantages, challenges, and potential improvements in the implementation of blended learning.

OVERVIEW OF THE EMERGING ENGINEERING EDUCATION CONCEPT

The concept of emerging engineering education has been proposed against the backdrop of the new economy and new industries. It aims to cultivate diverse and innovative outstanding engineering talents through inheritance and innovation, as well as interdisciplinary integration [16-17]. This concept not only focuses on the innovative development of engineering education but also emphasizes the reform and innovation of existing engineering disciplines to adapt to rapidly changing technological and industrial demands.

(1) Core Concepts

The core concepts of emerging engineering education can be summarized as follows [18]:

1) Innovation-Driven: Emerging engineering education emphasizes fostering students' innovative awareness and capabilities, enabling them to address future technological and industrial challenges. By introducing new teaching concepts and methods, it aims to stimulate students' curiosity and creative potential.

2) Interdisciplinary Integration: Emerging engineering education breaks down barriers between traditional disciplines, emphasizing cross-disciplinary integration. Students are expected to achieve depth in their major field while also acquiring interdisciplinary knowledge and skills to adapt to complex and dynamic work environments.

3) Practice-Oriented: Emerging engineering education prioritizes practical teaching and project-driven learning, allowing students to hone their abilities through hands-on experience. Collaboration with enterprises and engagement in research projects are encouraged to enhance students' practical skills and professional competence.

4) Forward-Looking Planning: Emerging engineering education focuses on future trends in technology and industry, making strategic plans to cultivate talents capable of leading future technological and industrial development. This requires educators to adopt a forward-looking perspective and continuously adjust disciplinary offerings and curriculum systems.

(2) Characteristics of Emerging Engineering Education

The characteristics of emerging engineering education are mainly reflected in the following aspects [19]:

1) Interdisciplinarity: Emerging engineering education emphasizes cross-disciplinary integration, encouraging students to broaden their knowledge base and improve their comprehensive qualities and abilities.

2) Innovation: Emerging engineering education focuses on cultivating students' innovative awareness and capabilities, enabling them to drive technological advancements and bring forth new ideas in their future work.

3) Practicality: Emerging engineering education highlights practical teaching and project-driven learning, allowing students to master knowledge and skills through practice and improve their ability to solve real-world problems.

4) Forward-Looking Nature: Emerging engineering education pays attention to future trends in technology and industry, making strategic plans to cultivate talents who can meet the demands of future society.

(3) Impact on Teaching Models

The concept of emerging engineering education has had a profound impact on teaching models. Traditional teaching models often focus on knowledge transmission and exam-oriented skill development, whereas emerging engineering education emphasizes a student-centered approach, prioritizing the cultivation of practical and innovative abilities [20]. As a result, teaching models need to undergo the following transformations:

1) Reform of the Curriculum System: Emerging engineering education requires the construction of a competency-based curriculum system that emphasizes the development of students' knowledge, skills, practical abilities, and innovative capabilities. Course offerings should reflect interdisciplinarity, innovation, and practicality.

2) Innovation in Teaching Methods: Emerging engineering education encourages the adoption of new teaching methods such as project-based learning and flipped classrooms to enhance students' interest and learning outcomes. Through project-based learning, students can acquire knowledge and skills in practice and improve their problem-solving abilities. Through flipped classrooms, students can independently learn new knowledge before class, with classroom time dedicated to discussions and hands-on activities.

3) Reform of the Evaluation System: Emerging engineering education calls for the establishment of a diversified evaluation system that not only assesses students' academic performance but also evaluates their comprehensive qualities and abilities. By constructing a diversified evaluation system, it becomes possible to better assess students' learning outcomes and growth.

RRT ALGORITHM

The Rapidly-exploring Random Tree (RRT) algorithm is a commonly used path planning algorithm. The process of generating a random tree is briefly described as follows: First, the robot's starting position is set as the root node of the random tree. Then, the algorithm initiates a loop that continuously executes the following steps: A new random node is generated in the robot's workspace using a random function. Next, a parent node is selected from the existing nodes using a certain strategy (e.g., the nearest neighbor strategy) to minimize the risk of collision between the parent node and the random node. Subsequently, the random node is added to the random tree and connected to the selected parent node, forming a new branch. This process repeats until a generated node is within a preset threshold distance from the target point, at which point the path planning is considered successful, and the generation of new nodes stops [21-22]. Ultimately, the resulting random tree path represents a feasible path from the starting point to the target point. Figure 1 illustrates the construction process of the random tree.

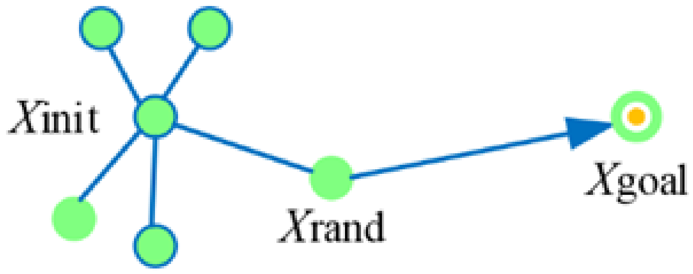

Figure 1. Construction Process of the Random Tree

The RRT algorithm is an efficient path planning algorithm [23]. Its advantages lie in its ability to quickly adapt to complex environments, particularly excelling in high-dimensional spaces. Additionally, the algorithm is simple to implement and exhibits strong real-time performance [24-25]. Moreover, the RRT algorithm does not require preprocessing of the space and can handle path planning problems involving nonholonomic constraints [26]. However, the RRT algorithm also has some drawbacks. For instance, the generated paths are often not optimal due to the randomness of node generation. Additionally, the algorithm's performance is highly influenced by parameter settings, such as the probability of random node generation and the radius of the nearest neighbor search. Furthermore, the RRT algorithm may perform poorly in narrow spaces and is prone to falling into local optima [27].

After students understand the basic principles of the RRT algorithm, they are guided to address its shortcomings by proposing improvements. One approach is to use a heuristic function to guide the probability of random tree node generation and introduce the concept of an artificial potential field to direct the generation of random tree nodes toward the target point. This method aims to reduce the time and length of random tree generation, thereby obtaining a more optimal path.

IMPROVED RRT ALGORITHM

In the RRT algorithm, the generation process of random tree nodes is highly random [28], which may result in nodes being generated near or even within obstacles, thereby affecting the efficiency of robot path planning. To enhance the effectiveness and safety of path planning, a heuristic function is introduced to guide the probability of random tree node generation, and the concept of the artificial potential field method [29-30] is incorporated to improve the RRT algorithm.

(1) Guiding Random Tree Node Generation Probability Using a Heuristic Function

The robot uses lidar to scan the surrounding obstacle environment, generating an obstacle map. The map is divided into grids of a certain resolution (the grid size can be adjusted based on actual conditions). If a grid contains an obstacle, it is marked, and no random tree nodes can be generated within that grid. As shown in Figure 2, the map obtained by the robot's scan includes the starting point X_{init} and the target point X_{goal} of the random tree, with "obstacle" representing the obstacles detected by lidar.

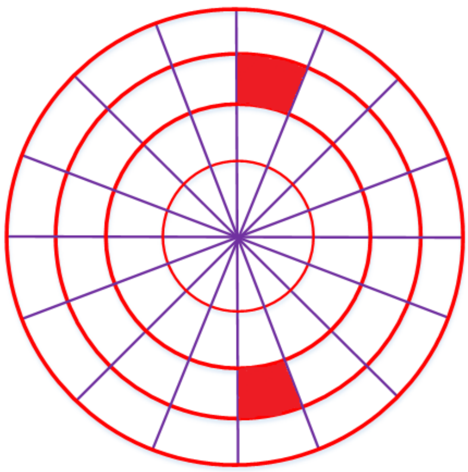

Figure 2. Grid Map

After constructing the map, random tree nodes are generated using a random function. In the traditional RRT algorithm, nodes are generated purely randomly. However, in the improved RRT algorithm, the generation probability of nodes is guided by the concept of the artificial potential field. The specific principle is as follows:

In grids without obstacles, the centroid coordinates of each grid are used as the positional information of that grid. According to the artificial potential field method, the attractive potential field $U(q)$ exerted by the target point on the centroid coordinates of a grid can be expressed as:

$$U(q)=\frac{1}{2}k\cdot\rho^2(x_{\text{goal}},x_{\text{near}}) \tag{1}$$

where k is a scaling factor, and $\rho(x_{\text{goal}},x_{\text{near}})$ is the distance between the centroid of the grid and the target point. By taking the derivative of Equation (1), the attractive force $F(q)$, exerted by the target point on the centroid of the grid can be obtained as:

$$F(q)=k\cdot\rho(x_{\text{goal}},x_{\text{near}}) \tag{2}$$

For all grids not occupied by obstacles, the attractive force $F(q)$, is calculated for each grid and denoted as $F_1(q)$, $F_2(q)$, $F_3(q)$, ……, $F_n(q)$. The probability pi of generating a random tree node in each empty grid is defined as:

$$p_i=\frac{F_i(q)}{\sum_{i=1}^{n}F_i(q)} \tag{3}$$

(2)Selection of Random Tree Nodes

After generating random tree nodes, a heuristic function is used to select random tree nodes. For nodes generated in a blank grid, the Euclidean distance between the starting node X_{init} and the generated node is $f(x)$, and the Euclidean distance between the node and the target point X_{goal} is $g(x)$. Then, the heuristic function $h(x)$ can be used to filter the selected nodes, where $h(x)$ can be expressed as:

$$h(x)=f(x)+g(x) \tag{4}$$

Substitute the nodes generated in the empty grids into Equation (4) to calculate the value of $h(x)$. The node with the smallest $h(x)$ value is selected as the next random tree node, which is the node closest to the target point. Repeat the above process until the generated random tree node is near the target point. By connecting each node to the target point, the random tree path is obtained.

DESIGN OF BLENDED TEACHING MODEL IN THE CONTEXT OF EMERGING ENGINEERING EDUCATION

Under the guidance of the emerging engineering education concept, the teaching of mobile robot path planning technology is no longer confined to traditional classroom lectures. Instead, it places greater emphasis on the integration of theory and practice, as well as the cultivation of students' innovative abilities. To this end, a blended teaching model has been designed, aiming to achieve multi-dimensional teaching objectives—knowledge transfer, skill enhancement, and innovation capability development—through the organic combination of online and offline modules.

(1) Setting Teaching Objectives

In the context of emerging engineering education, the teaching objectives for mobile robot path planning technology should encompass knowledge acquisition, skill enhancement, and innovation capability development. Specifically, the teaching objectives can be set as follows:

1) Knowledge Acquisition: Students should gain a deep understanding of the basic concepts, main algorithms, and practical application principles of the RRT algorithm. This includes core knowledge points such as map modeling, environmental perception, path search, and optimization.

2) Skill Enhancement: Students need to master the skills of using relevant software for path planning simulation, coding the RRT algorithm, and conducting path planning experiments on actual robot platforms.

3) Innovation Capability Development: Students are encouraged to explore new path planning algorithms or optimize existing ones to solve real-world engineering problems. Through project-based learning and group discussions, students' innovative thinking and practical abilities are stimulated.

(2) Innovation in Teaching Content and Methods

To achieve the above teaching objectives, a blended teaching model combining online and offline modules has been designed.

1) Online Module Design

The online module mainly includes course videos, online resources, interactive forums, and self-assessment tools.

(a) Course Videos: High-quality instructional videos are created to cover the core knowledge points of the RRT algorithm. These videos should be well-structured, detailed, and easy to understand, facilitating students' self-directed learning.

(b) Online Resources: Reading materials, case studies, algorithm implementation codes, and other resources related to the course content are provided for in-depth learning and reference. These resources should include the latest research findings and industry application cases to broaden students' horizons.

(c) Interactive Forums: Online interactive forums are established to encourage students to ask questions, discuss, and share learning experiences. Through these forums, students can promptly resolve doubts and enhance their motivation to learn.

(d) Self-Assessment: Online self-assessment questions are designed to help students evaluate their learning outcomes. These questions should cover key knowledge points from the course to assess students' mastery of the content.

2) Offline Practical Activities

Offline practical activities mainly include laboratory operations, group discussions, project-based learning, and instructor guidance.

(a) Laboratory Operations: In the laboratory environment, students will personally operate mobile robots to conduct path planning experiments using the RRT algorithm. Through hands-on practice, students can gain a more intuitive understanding of the principles and implementation process of the RRT algorithm.

(b) Group Discussions: Students are organized into groups to discuss challenging and hot topics in the course. Through group discussions, students can inspire each other, improve collectively, and develop teamwork and communication skills.

(c) Project-Based Learning: Students are encouraged to engage in project-based learning by applying their knowledge. They will work in groups to design and implement path planning projects that improve the RRT algorithm, followed by simulation and experimental validation. Through project-based learning, students can comprehensively apply their knowledge and enhance their practical and innovative abilities.

(d) Instructor Guidance: Instructors provide guidance and support to students. They will regularly communicate with students to understand their learning progress and challenges, offering personalized advice and guidance.

3) Integration Strategies

To achieve seamless integration between online and offline modules, a series of strategies have been adopted.

(a) Course Content Alignment: The online module focuses on theoretical knowledge transfer and self-learning ability development, while the offline module emphasizes practical skill development and innovative thinking stimulation. By carefully designing the course content, a close connection and mutual complementarity between the online and offline modules are ensured.

(b) Synchronization of Learning Progress: In the online module, students follow a predetermined learning schedule to study course videos and online resources independently. In offline practical activities, instructors arrange corresponding experiments and project tasks based on students' learning progress. By synchronizing learning progress, students can promptly apply their knowledge in practice.

(c) Feedback Mechanism Establishment: In the online module, students receive feedback through interactive forums and self-assessment tools. In offline practical activities, instructors provide feedback by observing group discussions and project presentations. By establishing a comprehensive feedback mechanism, the internalization of knowledge and the practice of skills are promoted.

(3) Evaluation and Feedback Mechanism

To comprehensively evaluate the effectiveness of the blended teaching model, a diversified evaluation system has been designed, along with strategies for continuous improvement.

1) Diversified Evaluation System: The evaluation system includes formative assessment, peer assessment, and project presentations. Formative assessment focuses on indicators such as students' learning attitudes, participation levels, and online learning duration. Peer assessment encourages students to evaluate each other's learning outcomes and teamwork abilities. Project presentations require students to demonstrate the comprehensive application of their knowledge and skills. Through this diversified evaluation system, students' learning outcomes and growth are fully reflected.

2) Continuous Improvement Strategies: Based on evaluation results and student feedback, the blended teaching model is regularly adjusted and optimized. For example, course content and learning schedules are adjusted to address students' difficulties and confusions. Additional experimental projects and case studies are added to tackle challenges encountered in practice. Teaching resources and faculty support are strengthened to address identified shortcomings. Through continuous improvement strategies, the quality and effectiveness of the blended teaching model are consistently enhanced.

IMPLEMENTATION CASE AND EFFECTIVENESS ANALYSIS

To verify the effectiveness of the blended teaching model, a pilot course on mobile robot path planning technology was selected, and a detailed implementation plan was designed, followed by data collection, analysis, and effectiveness evaluation.

(1) Implementation Plan Design

Pilot Course: The improved RRT path planning algorithm, as an important chapter in the mobile robot path planning technology course, was chosen as the pilot course.

Participants: Third-year students majoring in automation were selected as participants. These students already possessed a certain level of programming skills and professional knowledge, making them suitable for the pilot of the blended teaching model.

Implementation Steps: The implementation followed the sequence of online modules and offline practical activities. In the online module, students independently studied course videos and online resources. In the offline practical activities, students worked in groups to conduct experiments and project-based learning. Simultaneously, a regular feedback mechanism was established to promptly understand students' learning progress and challenges, allowing for adjustments and optimizations based on feedback.

Quantitative Research Methods: Data such as students' exam scores and online learning duration were collected to evaluate their learning outcomes and engagement levels. By comparing indicators such as academic performance and online learning duration among different students, the impact of the blended teaching model on learning effectiveness was assessed.

Qualitative Research Methods: Data such as student feedback and interview records were collected to gain an in-depth understanding of students' perceptions and experiences with the blended teaching model. Through interviews and questionnaires, feedback on course content, teaching methods, and learning experiences was gathered and analyzed. Additionally, instructors were invited to evaluate students' learning outcomes and teamwork abilities to comprehensively understand their learning progress.

(2) Student Learning Outcomes and Achievements

Through the blended teaching model, students achieved significant results in mobile robot path planning. They successfully applied the learned path planning algorithms and tested them in real-world environments. Below are some of the students' achievements:

1) Mobile Robot Construction:

The mobile robot was built using an open-source robot mobile platform, with hardware components including a development board, ultrasonic sensors, lidar, a camera, and encoders. The robot is shown in Figure 3.

Figure 3. Image of the Robot

2) Path Planning Experiments:

Students used both the RRT algorithm and the improved RRT algorithm to plan optimal paths for the robot from the starting point to the target point, ensuring the robot could complete tasks in the shortest possible time. Multiple experiments were conducted, and the results were recorded as shown in Table 1. One of the experimental path planning results is illustrated in Figure 4. By analyzing the experimental data, it was found that the average path length planned by the improved RRT algorithm was 42.05 cm shorter than that of the original RRT algorithm. Through hands-on practice, students were able to master the relevant knowledge of robot path planning and complete hardware construction, significantly enhancing their capabilities. Through these practical activities, students not only deepened their understanding of robot path planning but also gained hands-on experience in hardware construction, leading to a substantial improvement in their overall skills.

Table 1. Experimental Results of Path Planning

Experiment Number	RRT Path Length (cm)	Improved Algorithm Path Length (cm)	Experiment Number	RRT Path Length (cm)	Improved Algorithm Path Length (cm)
1	389	341	11	356	341
2	381	333	12	371	343
3	378	346	13	393	350
4	365	336	14	359	329
5	368	331	15	369	322
6	391	328	16	390	334
7	369	330	17	389	330
8	373	332	18	379	341
9	393	329	19	396	351
10	368	341	20	394	342

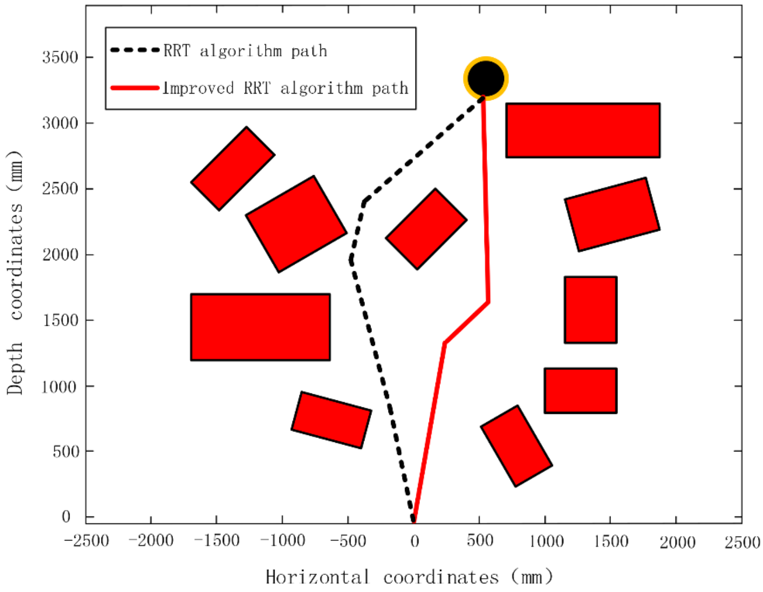

Figure 4. Path Planning Diagram from One Experiment

(3) Effectiveness Evaluation

To compare the impact of implementing blended teaching versus traditional teaching on students, blended teaching was applied to Class 1, while Class 2 followed the traditional teaching method. After the course, data was collected and analyzed, yielding the survey results shown in Table 2.

Table 2. Survey Results

Class	Number of Students	Interest in the Course (%)	Impact on Knowledge Mastery (%)	Impact on Practical Skills (%)	Satisfaction with the course (%)	Impact on Innovative Thinking (%)
Class 1	59	89	88	96	95	98
Class 2	56	80	85	89	92	95

From Table 2, the following evaluation results can be derived:

1) Impact on Student Interest in Learning

The blended teaching model stimulated students' interest in learning. The diverse and easy-to-understand course videos and online resources in the online module, combined with hands-on experiments and project-based learning in the offline practical activities, allowed students to experience the charm and challenges of path planning technology firsthand. These factors contributed to enhancing students' learning motivation and engagement.

2) Impact on Knowledge Mastery

The blended teaching model improved students' mastery of mobile robot path planning technology. By integrating theoretical learning in the online module with practical operations in the offline activities, students gained a deeper understanding of the principles and implementation processes of path planning algorithms. Additionally, through formative assessments and peer evaluations in the diversified evaluation system, students were able to promptly identify their learning progress and shortcomings, enabling targeted improvements.

3) Impact on Practical Skills

The blended teaching model significantly enhanced students' practical skills. Through experiments and project-based learning in the offline activities, students were able to operate mobile robots for path planning experiments and apply their knowledge to solve real-world problems. These practical activities not only honed students' hands-on abilities and teamwork skills but also fostered their innovative thinking and problem-solving capabilities.

4) Impact on Innovative Thinking

The blended teaching model cultivated students' innovative thinking. Through project-based learning and group discussions, students were encouraged to explore new path planning algorithms or optimize existing ones to address practical engineering challenges. These activities stimulated students' innovative thinking and creativity, enabling them to better adapt to the demands of future technological and industrial developments.

In summary, the blended teaching model demonstrated significant advantages over traditional teaching methods in terms of enhancing students' learning interest, knowledge mastery, practical skills, and innovative thinking. These findings highlight the effectiveness of the blended teaching approach in achieving comprehensive educational outcomes.

DISCUSSION

Through an in-depth analysis of the emerging engineering education concept and the teaching requirements of mobile robot path planning technology, a blended teaching model combining online and offline modules was designed and implemented. This model not only enriches teaching resources and enhances students' learning interest and engagement but also effectively promotes the dual improvement of students' theoretical knowledge and practical skills.

The research results demonstrate that the blended teaching model has significant advantages in the teaching of mobile robot path planning technology. The online module provides students with flexible learning schedules and abundant course resources, helping them independently construct their knowledge systems. The offline practical activities, through laboratory operations and project-based learning, hone students' practical abilities and innovative thinking. Additionally, the diversified evaluation system offers comprehensive and objective feedback on students' learning outcomes.

In the future, the application of the blended teaching model in mobile robot path planning technology education will be further deepened. On one hand, the design of the online module will be optimized by incorporating more cutting-edge technologies and industry trends to maintain the timeliness and relevance of the course content. On the other hand, the organization and guidance of offline practical activities will be strengthened to provide students with more hands-on opportunities and innovation platforms, fostering their teamwork and problem-solving skills.

Furthermore, the application of the blended teaching model in other engineering disciplines will be actively explored, aiming to provide more valuable experiences and insights for the promotion and practice of the emerging engineering education concept.

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Conflict of interest

The authors declared that they have no conflicts of interest to this work.

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