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Digital Empowerment Reform of Wind Farm Curriculum Design Based on Virtual Reality Integration

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Abstract: In the context of the construction of new engineering disciplines and the " carbon peaking and carbon neutrality goals" strategy, this study explores multidimensional teaching reforms to address the theoretical and practical gaps, single technical means, and limited evaluation systems in the course design of wind farm planning and design. By building a GIS+BIM digital twin platform and a virtual wind farm site selection simulation system, we aim to create a teaching scenario that combines virtual and real elements. This work design a multidisciplinary cross disciplinary task that integrates meteorology, ecology, and economics, and establish a tiered ability development system of "WindSim Foundation Layer - Machine Learning Innovation Layer". We implement three-stage project driven teaching, integrate ideological and political elements into the curriculum, and innovate dynamic evaluation mechanisms. Practice has shown that after the reform, the average score of students has increased by 2.61, the proportion of high scores has increased by 7.41%, and the design report has improved in terms of technical depth and innovation dimensions, respectively. This reform will provide ideas for the curriculum design of engineering majors such as wind farm planning, transport applied talents with theoretical and practical collaborative innovation capabilities, and promote the transformation of the new engineering education paradigm.

1. Introduction

As a clean and renewable energy source, wind power can achieve zero carbon emissions and effectively reduce dependence on traditional fossil fuels. Under the strategic background of the “carbon peaking and carbon neutrality goals”, the wind power industry, as a key area for achieving energy structure transformation and carbon neutrality goals, has put forward new requirements for talent cultivation. The rapid iteration and intelligent development of wind power technology require practitioners to have interdisciplinary knowledge reserves, including but not limited to aerodynamics, materials science, electrical engineering, and artificial intelligence; The sustainable development of the wind power industry requires talents to have environmental awareness and a sense of social responsibility; In the face of high risks and uncertainties in the wind power industry, talent cultivation also needs to focus on improving innovation and risk management capabilities to promote technological innovation and industry progress. Therefore, new energy majors such as wind power need to re-examine their curriculum and training models, strengthen the combination of theory and practice[1], and cultivate wind power talents with comprehensive qualities and professional abilities to meet the new needs of industry development under the "carbon peaking and carbon neutrality goals".

The construction of new engineering disciplines, as an important strategy to respond to the new round of technological revolution and industrial transformation, has put forward deep-seated reform demands for practical teaching. In traditional engineering education, the practical aspects are often limited to confirmatory experiments and single skill training, which is difficult to meet the needs of interdisciplinary integration, innovation ability cultivation, and solving complex engineering problems in the context of new engineering. Therefore, practical teaching urgently needs systematic reforms in terms of content, methods, and evaluation systems.

There are several typical problems in traditional curriculum design in practical teaching that urgently need improvement. The practical aspects in curriculum design are often limited to simulating or simplifying scenarios, which fail to fully reflect the multidimensional challenges in real wind farm planning[2], such as comprehensive considerations of geographical environment, meteorological conditions, power grid access, and environmental impacts, thus limiting students' ability to solve practical problems. Curriculum design usually focuses on individual completion and lacks team collaboration training, making it difficult to cultivate students' communication and coordination skills and team spirit, which are crucial in practical engineering projects. In addition, the evaluation system of curriculum design often focuses on results rather than processes, neglecting the cultivation of students' innovative thinking and practical abilities in the design process, and cannot comprehensively evaluate students' comprehensive qualities. Therefore, it is urgent to reform the curriculum design of wind farm planning and design in terms of practical depth, collaboration mode, and evaluation mechanism, in order to better meet the demand for high-quality talents in the wind power industry[3].

By reforming traditional curriculum design, strengthening the combination of theory and practice, and introducing interdisciplinary comprehensive projects, students' systematic thinking and engineering practice abilities can be effectively enhanced[4]. At the same time, a teaching model that emphasizes teamwork and the integration of industry and education can help cultivate students' communication and coordination skills as well as professional ethics, enabling them to better adapt to industry demands. Therefore, the teaching reform of wind farm planning curriculum design is not only a key measure to improve the quality of education, but also an important way to provide high-quality composite talents for the wind power industry.

2. Diagnosis of Existing Problems

2.1. Insufficient connection between theory and practice

There is a significant gap in the theoretical and practical integration of wind farm planning curriculum design. The course content often focuses too much on imparting theoretical knowledge and lacks deep integration with practical engineering scenarios, making it difficult for students to transform abstract theoretical concepts into the ability to solve practical problems during the learning process.

In practical teaching, there is a common problem of poor experimental site conditions, and traditional laboratory environments are difficult to meet the needs of curriculum design. And it lacks the ability to simulate key elements such as complex terrain and meteorological conditions required for real wind farm planning, making it impossible to experience the actual operation of core processes such as wind resource assessment and micro site selection in the laboratory, which limits its understanding and application ability of the entire process of wind farm planning.

In the curriculum design, the acquisition, processing, and analysis of meteorological data rely on simplified or idealized datasets, which fail to fully introduce long-term, multidimensional meteorological observation data from real wind farm projects, resulting in students lacking in-depth understanding and practical operation ability of complex meteorological conditions such as wind speed, wind direction, turbulence intensity, etc. In addition, the course content usually focuses on the explanation of basic statistical methods, lacking training in the application of modern data analysis tools such as machine learning, numerical simulation, etc.

2.2. Singularity of technological means

In curriculum design, teaching tools and methods are often limited to traditional theoretical explanations and the use of simple simulation software, lacking the introduction and application of modern technological means such as geographic information systems, numerical simulations, big data analysis, and artificial intelligence. In addition, the design of practical stages often relies on a single technical path, which fails to fully reflect the characteristics of multi technology integration in wind farm planning, such as collaborative optimization of wind resource assessment, micro site selection, environmental impact analysis, and other stages.

There are significant shortcomings in the curriculum design in terms of dynamic simulation and visual verification. Teaching methods are mostly limited to static theoretical analysis and simple model calculations, lacking simulation of dynamic characteristics (such as wind speed changes and wind turbine response) during the operation of wind farms. The application of visualization technology is relatively scarce, and students are unable to verify and optimize planning schemes through intuitive visualization tools such as 3D modeling, dynamic maps, etc., which limits their ability to understand complex spatial data and engineering scenarios.

2.3. Limitations of the evaluation system

2.3.1. Assessment method that emphasizes results over processes

There is a common problem in the assessment method of curriculum design, which emphasizes results over process. The assessment method usually relies on the final design report or presentation of results as the main evaluation basis, which can easily lead students to focus too much on the presentation of the final results and neglect the in-depth thinking and practical exploration of key links in the planning process. The lack of assessment of problem-solving ability, innovative thinking, and phased achievements in the design process makes it difficult for students to achieve comprehensive ability improvement in curriculum design.

2.3.2. Lack of evaluation of team collaboration and innovation capability

The current curriculum design usually focuses on individual task completion, lacking systematic training and evaluation of teamwork ability, which makes it difficult for students to effectively leverage the advantages of teamwork in practical engineering projects. At the same time, the evaluation system of curriculum design often focuses on the standardization of technical solutions and the correctness of results, while neglecting the assessment of students' innovative thinking, problem-solving ability, and practical exploration process.

3. Reform Implementation Paths

3.1. Construction of teaching scenarios combining virtual and real elements

3.1.1. GIS+BIM digital twin platform development

To enhance the practicality and cutting-edge design of wind farm planning courses, the "GIS+BIM

Digital Twin Platform Development" course reform plan will be implemented. This plan aims to build a digital twin platform for wind farm planning by integrating geographic information systems (GIS) and building information modeling (BIM) technologies, achieving dynamic simulation and visual verification of wind resource assessment, micro site selection, equipment layout, and environmental impact analysis[5]. In the curriculum design, students can use GIS to conduct spatial analysis of wind resources based on real geographic data and wind turbine models, combine BIM technology to achieve 3D modeling and optimization design of wind farms, and simulate the entire life cycle of wind farm operation through a digital twin platform[6].

3.1.2. Virtual wind farm site selection simulation system

To enhance the technicality of wind farm planning curriculum design, a reform plan for the "Virtual Wind Farm Site Selection Simulation System" course can be implemented. This program develops a simulation system based on virtual reality (VR) and numerical simulation technology to simulate the distribution of wind resources, topography, and meteorological conditions in a real wind farm environment, providing students with an immersive wind farm site selection practice platform[7]. Students can conduct wind resource assessment, micro site selection, and wind turbine layout optimization in a virtual environment, and verify the feasibility and economy of the planning scheme through real-time data feedback and dynamic simulation.

3.2. Multidisciplinary Interdisciplinary Task Design

3.2.1. Integration of Meteorology/Ecology/Economic Assessment

This plan integrates multidisciplinary knowledge to construct a comprehensive evaluation system for wind farm planning, covering core aspects such as wind resource meteorological analysis, ecological environment impact assessment, and technical and economic evaluation. Students will use numerical simulation and statistical analysis tools based on real meteorological data and ecological geographic information to evaluate the wind energy potential, ecological sensitivity, and economic benefits of wind farms, and propose planning schemes that balance environmental friendliness and economic feasibility through multi-objective optimization methods.

3.2.2. Implantation of Full Lifecycle Design Concept

This program integrates the core elements of the entire lifecycle of wind farms (including planning, design, construction, operation, and decommissioning stages) into the curriculum design, requiring students to comprehensively consider multidimensional factors such as wind resource assessment, equipment selection, environmental impact, economic benefits, and decommissioning treatment, and develop sustainable planning schemes[8]. By introducing life cycle assessment (LCA) methods and digital tools, students can simulate the technical performance and environmental impact of wind farms at different stages, optimize design schemes to achieve maximum resource efficiency and minimize environmental loads.

3.3. Step by Step Ability Development System

3.3.1. Basic layer: WAsP wind resource assessment

Using WAsP software as the core tool, combined with the theoretical basis and practical needs of wind resource assessment, a multi-level capability development module is designed, including wind energy resource measurement data analysis, micro site selection of wind farms, optimization of wind turbine layout, and uncertainty assessment. Through a teaching model that combines theoretical lectures, case analysis, and practical operations, students can master the core technical methods of wind resource assessment and use WAsP to analyze and visualize wind energy potential under complex terrain conditions. In addition, completing comprehensive projects through team collaboration cultivates their ability to solve practical engineering problems and innovative thinking.

3.3.2. Innovation Layer: Machine Learning Power Prediction

Based on machine learning technology as the core and combined with the actual needs of wind power prediction, a multi-level capability development module is designed, covering data preprocessing, feature engineering, model construction (such as random forest, support vector machine, neural network, etc.), and prediction result evaluation. Through a teaching mode that combines theoretical lectures with programming practice, students can master the basic principles and application methods of machine learning algorithms, and use historical meteorological data and wind farm operation data to train and optimize power prediction models.

4. Teaching Implementation Plan

4.1. Three stage project driven design

4.1.1. Pre research stage: Policy interpretation and data collection

Systematically explain national and local wind power industry policies, environmental regulations, and grid access standards, cultivate students' understanding and analysis ability of policy environment, and ensure that planning schemes meet policy requirements. At the same time, by combining field research and data collection techniques, students are trained to acquire wind resources, geographic information, and ecological environment data, and to use professional tools such as GIS and remote sensing technology for data processing and analysis. Through case teaching and team collaboration, students can comprehensively apply policy interpretation and data collection skills in practical projects to develop scientifically reasonable wind farm planning schemes.

4.1.2. Design phase: Multi scheme comparison and optimization

Introducing multi-objective optimization theory and methods, students are required to comprehensively consider multidimensional factors such as wind resource utilization efficiency, economic benefits, environmental impact, and technical feasibility in wind farm planning and design, and generate multiple planning schemes. Students utilize professional software for wind energy resource assessment, wind turbine layout optimization, and economic analysis, then select the optimal design scheme by comparing and analyzing the performance indicators of each scheme. Through case teaching and team collaboration, students can master the technical methods of comparing and optimizing multiple solutions.

4.1.3. Defense Stage: 3D Visualization Presentation

Students are required to use traditional PPT presentations during the defense phase, while also presenting a three-dimensional dynamic model of the wind farm planning scheme, including wind resource distribution, wind turbine layout, topography, and environmental impact. Through visualization tools, students can intuitively present design ideas and technical details, enhancing the interactivity and persuasiveness of their presentations. At the same time, by simulating real engineering reporting scenarios, students' expression and adaptability abilities are cultivated.

4.2. Path of integrating ideological and political education into the curriculum

4.2.1. Interpretation of the Dual Carbon Strategy Policy

Systematically explain the background, goals, and implementation path of the national strategy of "carbon peak and carbon neutrality", combined with the important role of the wind power industry in energy structure transformation, guiding students to deeply understand the policy connotation and practical significance of the dual carbon strategy. In curriculum design, through case analysis, group discussions, and other forms, the dual carbon goals are closely integrated with wind farm planning to cultivate students' overall awareness and sense of social responsibility.

4.2.2. Ecological Protection Design Concept

It means teachers are supposed to explain ecological protection policies, environmental ethics, and sustainable development theories, combined with ecological environment impact assessment and mitigation measures in wind farm planning, to guide students to establish the design concept of ecological priority and green development. In curriculum design, through case analysis and practical operation, ecological protection requirements are integrated into wind resource assessment, micro site selection, and wind turbine layout optimization, cultivating students' environmental awareness and social responsibility, and strengthening their ecological civilization values and professional ethics.

4.2.3. Cultivation of Craftsmanship Spirit in Great Countries

It means teachers are supposed to introduce typical cases and outstanding figures in the wind power industry, combined with the technological innovation and design requirements of excellence in wind farm planning, to guide students to deeply understand the connotation and practical value of the spirit of craftsmanship. In curriculum design, high standard technical training and practical operations are used to cultivate students' rigorous and pragmatic professional attitude, and to pursue excellence. Through team collaboration and achievement display, students' sense of responsibility and team spirit are strengthened, and their patriotism and industry mission are stimulated.

4.3. Innovation of Dynamic Evaluation Mechanism

4.3.1. Process evaluation accounts for 40%

This reform raises the proportion of process evaluation to 40%, focusing on students' learning attitudes, practical operation abilities, teamwork performance, and phased achievements in curriculum design, comprehensively reflecting their comprehensive quality and ability improvement process. Specific evaluation indicators include classroom participation, iterative program design, data analysis ability, and team contribution. Through a combination of teacher evaluation, peer evaluation, and self-evaluation, the objectivity and comprehensiveness of the evaluation are ensured. At the same time, combined with summative evaluation (accounting for 60%), a comprehensive evaluation system is formed, which not only focuses on result orientation but also strengthens process management.

4.3.2. Enterprise experts participate in the defense scoring

This reform invites experts in the wind power industry to participate in the curriculum design defense, and evaluates and comments on students' planning proposals from the perspectives of engineering practice, technological innovation, and industry demand. The scoring weight of enterprise experts can be set at 30% -40%, focusing on the feasibility, economy, and innovation of the plan, ensuring that the evaluation results are closely integrated with the actual needs of the industry. Through expert feedback, students are able to gain a deeper understanding of cutting-edge industry trends and technological developments, enhancing their professional ethics and engineering practical abilities.

4.3.3. Achievement Management of Digital Archive Bags

This reform establishes a digital portfolio for students, systematically recording their entire process achievements in curriculum design, including stage reports, data analysis results, design iteration, and team collaboration records. The digital portfolio not only serves as an important basis for process evaluation, but also provides comprehensive and objective data support for comprehensive evaluation by visualizing the growth trajectory of students' abilities. The management and sharing function of digital portfolio helps students reflect on the learning process and optimize learning methods.

5. Analysis of Practical Effectiveness

5.1. Improvement of learning outcomes

5.1.1. Comparison of Performance Distribution in the Past Two Years

The curriculum reform has started for the 2022 students, and a systematic examination of the academic performance differences between the three grades (2021 grade n=54, 2022 grade n=62, 2023 grade n=60) before and after the implementation of the teaching reform will be conducted.

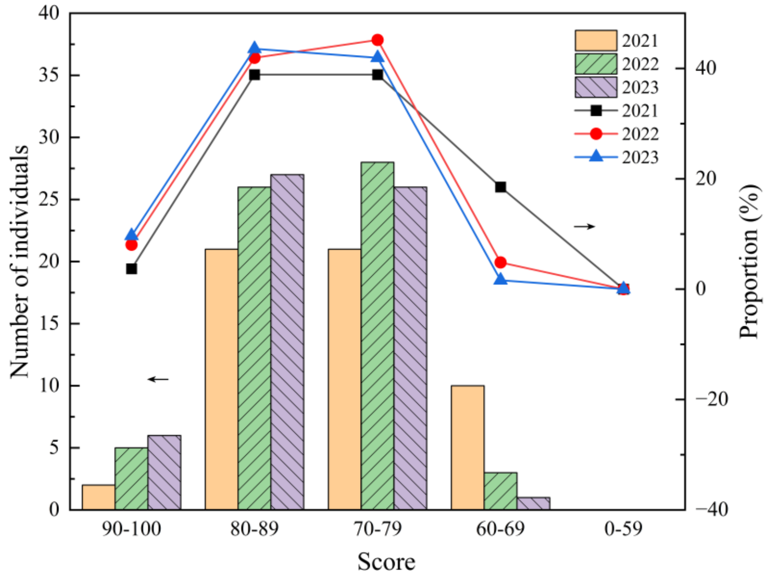

Figure 1: Distribution of student grades

From the observation of the evolution trend of score distribution (as shown in Figure 1), it shows a normal left shift feature after the reform. Specifically, the proportion of 2022 students in the 90-100 score range reached 8.06% (2021: 3.70%), while the proportion in the 80-89 score range increased to 41.94% (2021: 38.89%). The overall proportion in the high score range (≥ 80 points) significantly increased from 42.59% to 50.00%. It is worth noting that the data of 2023 level is highly consistent with that of 2022 level, indicating the continuity of the reform effect.

Key indicator analysis (as shown in Table 1) shows that: 1) In terms of central tendency, the average score has increased from 77.65 before the reform to 80.26 (2022 level) and remained stable at 80.43 (2023 level); 2) In terms of dispersion, the standard deviation narrowed by 0.47 points, reflecting a trend towards balanced distribution of scores; 3) The extreme value change shows that the highest score has increased from 90.62 to 94.06 (Δ =3.44), while the lowest score remains relatively stable (62.50 → 63.15 → 63.08); 4) The pass rate remains at a high level.

From the above results, it can be seen that this curriculum reform has an important effect in promoting academic performance improvement.

Table 1: Key indicators of student grades

Score	Class of 2021	Class of 2022	Class of 2023
Average	77.65	80.26	81.88
Highest	90.62	93.86	94.06
Lowest	62.20	66.34	66.58
High score ratio (≥80)	42.59%	50%	50.23%

5.1.2. Quantitative analysis of design report quality

The course design report is quantitatively graded based on the completeness of content, technical depth, innovation, and standardability. The explanations of each indicator are shown in Table 2.

Table 2: Indicators for evaluating course reports

Index	Content
Completeness	Whether it fully covers all aspects of wind farm planning, such as wind resource assessment, micro site selection, wind turbine layout, environmental impact analysis, and economic evaluation.
Technical depth	The depth and accuracy of the technical analysis in the report, including the scientificity of data processing, the rationality of model construction, and the credibility of the results.
Innovation	Whether the design plan reflect innovative thinking, such as the application of new technologies, multi-objective optimization methods, or unique design ideas.
Standardability	Whether the report format comply with academic standards, including clear structure, standardized charts, accurate citations, and fluent language expression.

According to the statistics of the course design scores of students in the 2021-2023 class, as shown in Figure 2, the average scores of standardization, innovation, technical depth, and content completeness are gradually increasing. In terms of innovation, students consciously deconstruct and optimize actual data with multiple objectives, but there is still room for improvement in practical application and integration. In terms of technical depth, students conduct multivariate validation based on experimental platforms, effectively enhancing their thinking depth and making the content more profound.

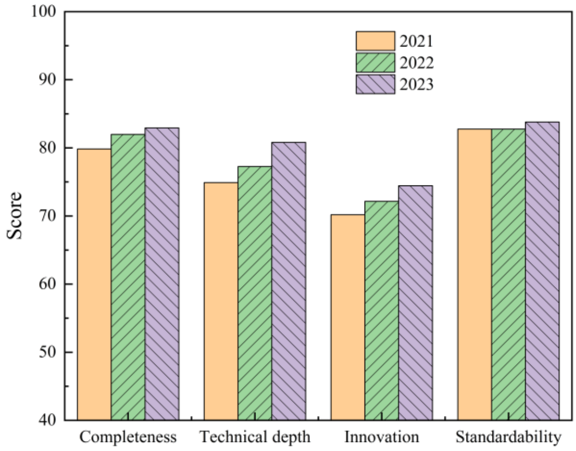

Figure 2: Average score of indicators

6. Conclusions

This article systematically analyzes the demand for high-quality composite talents in the wind power industry, diagnoses the pain points of traditional curriculum design in terms of the connection between theory and practice, the application of technical means, and the evaluation system, and proposes a teaching reform path based on the combination of virtual and real, interdisciplinary, and step-by-step ability cultivation. By constructing innovative teaching scenarios such as the "GIS+BIM Digital Twin Platform" and the "Virtual Wind Farm Site Selection Simulation System", designing interdisciplinary tasks and step-by-step ability development modules, implementing a three-stage project driven teaching plan, and integrating curriculum ideology and dynamic evaluation mechanisms, students' practical abilities, innovative thinking, and comprehensive qualities have been significantly improved.

The analysis of practical effectiveness shows that the curriculum reform has achieved significant results: the distribution of student grades has shown a normal left shift, the proportion of high score intervals has significantly improved, and the quality of design reports has significantly improved in terms of content completeness, technical depth, innovation, and standardization. The reform achievements have verified the effectiveness of the combination of virtual and real, interdisciplinary and dynamic evaluation mechanisms in improving teaching effectiveness, providing a practical example for the reform of wind farm planning curriculum design under the background of new engineering disciplines.

In the future, curriculum reform can further optimize the integration of digital teaching platforms, strengthen students' comprehensive application abilities in complex engineering scenarios, and continuously track industry demand, adjust teaching content and methods, and provide more high-quality composite talents suitable for the "dual carbon" target needs for the wind power industry.

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