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Research on Innovative Teaching of Core Courses for Professional Degree Graduate Students

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Abstract: ***Given the pressures imposed by policies such as the "Double First-Class" initiative, the program for outstanding engineers, and the "Dual Carbon" strategy, it has become an urgent priority to achieve multiple breakthroughs in core professional graduate courses-transforming knowledge delivery into innovation capacity, shifting from single-discipline to interdisciplinary approaches, and evolving from traditional teaching to digital-intelligent education. Taking the course development of "Advanced Combustion Science" at Henan Agricultural University as a case study, this article provides acomprehensive analysis of core professional graduate courses in the interdisciplinary field of energy and power engineering combined with agricultural engineering. Based on the integrated framework of "fundamental theory-frontier mechanisms-digital-intelligent simulation-engineering applications", the teaching content is designed to incorporate artificial intelligence and big data technologies, integrating universities, industries, and enterprises into a collaborative education network. The study proposes a course development model that combines interdisciplinarity, digital intelligence, and excellence-oriented goals. Practical implementation demonstrates that this model effectively promotes original innovation among graduate students, enhances capabilities in tackling complex engineering problems, and fosters multi-stakeholder collaboration, offering valuable and scalable experience for similar professional graduate programs.***

Keywords: Professional degree graduate students, Core curriculum development, Digital and intelligent empowerment, Industry-education integration, Outstanding engineers, Interdisciplinary studies.

1. Introduction

1.1 Research Background

The report of the 20th National Congress of the Communist Party of China clearly put forward the strategic deployment of "accelerating the construction of a strong country in education, science and technology, and talent", placing graduate education at the core of the national innovation system. In 2020, the Academic Degrees Committee of the State Council and the Ministry of Education issued the "Development Plan for Professional Degree Graduate Education (2020 - 2025)", which clearly proposed to "vigorously improve the quality of professional degree graduate education", emphasized the integration of industry and education, and school enterprise cooperation in professional degree graduate education, and cultivated "high-level applied specialized talents with solid and systematic professional foundations, strong practical abilities, and high professional qualities". In 2023, the Ministry of Education will launch the "Excellent Engineer Training Program" to further promote the reform of engineering professional degree graduate education, requiring core curriculum construction to closely align with industry needs, integrate cutting-edge technologies, and strengthen engineering practice.

The "dual carbon" strategy is constantly advancing, and there are new expectations for talent cultivation related to energy and power. Combustion science is a discipline that focuses on energy conversion and utilization, and is currently undergoing a significant transformation towards low-carbon or even zero carbon fuels such as hydrogen, ammonia, or biomass. After the combination of artificial intelligence, digital information (including big data and digital twins), and combustion science, modern research topics such as "smart combustion" and "AI combustion science" have been opened up. The resulting changes pose many previously unknown challenges to the updating of professional courses, methods, and teaching models for graduate students [1].

1.2 Asking Questions

There are still many unresolved issues regarding the core courses of professional degree graduate students at present.

Firstly, the courses taught have not kept up with the development of the industry reality. At present, the conventional teaching of combustion science mainly focuses on coal, petroleum, and natural gas fossil fuels. There is not much analysis on the combustion of new fuels such as hydrogen, ammonia, or biomass, and there is little discussion on the artificial intelligence technology used in combustion. Therefore, it cannot well meet the rapid and large demand for comprehensive talents in the energy field under the background of "dual carbon" [2].

Secondly, the relationship between teaching methods and the development of digitalization is currently misaligned. The commonly referred to graduate courses still focus on teacher lectures and student listening, without introducing AI modeling, data computing, virtual experiments and other digital methods into teaching. Therefore, the content taught may not meet the practical needs of intelligent analysis [2].

Thirdly, the proposed training model still cannot meet the requirements of outstanding engineers. Professional degree graduate students should focus on engineering practice and innovation. However, the current curriculum tends to be theoretical, knowledge oriented, and lacks skill training. The cooperation between schools and enterprises is not close enough, and students lack complete practice in dealing with complex engineering.

Fourthly, barriers and intersections-of disciplines-must be dealt with in a special manner. The pairing of energy, power, and agricultural engineering seems a good means of helping to revive the countryside and to attain carbon savings (or fixation) in rural contexts. Yet it is now evident that most schools do not offer fully integrated courses, nor do they coordinate well the various disciplinary intersections.

1.3 Research significance

Based on the background and relevant issues listed earlier, this article aims to analyze the significance of the course “Advanced Combustion Science” offered by Henan Agricultural University for professional degree graduate education, and propose a construction approach for core courses under the coordination of digital intelligence and industry education. The content discussed is expected to promote the development of graduate education, improve the training level of professional degree talents, assist in the construction of “Double First Class” disciplines, and implement the National Excellent Engineer Plan, thus having significant theoretical and practical value.

2. Concept and Objectives of Curriculum Construction

2.1 Construction Concept

The construction of the course “Advanced Combustion Science” should be based on the basic idea of “standing tall, relying on data and intelligence, and cross innovation”.

The so-called “top sky” refers to taking disciplines as the starting point, taking into account the international trends and relevant national plans in combustion science (such as the “two engine special project” for aviation engines, hydrogen energy development, and smart power plants), and using an academic perspective to promote the realization of basic innovation. “Site” refers to the specific analysis of various topics related to energy, boilers, and agricultural waste in Henan Province, based on engineering reality. It does not just talk about theory, but combines research results with the actual needs of the country and writes them into papers.

The so-called “digital intelligence empowerment” refers to the overall application of artificial intelligence, big data, and digital twin technologies, incorporating AI assisted modeling, big data analysis, and intelligent control into teaching content, and training students ability to handle complex engineering practices through digital intelligence methods. Cross innovation aims to break through the independent limitations of energy power and agricultural engineering, and focus on the intersection of hydrogen utilization, biomass fuel, and agricultural waste energy utilization, in order to cultivate modern engineering talents with broad knowledge and the ability to cross disciplines.

2.2 Course Positioning

This course is a compulsory core course for graduate students majoring in Energy and Power Engineering. It is a core knowledge module that supports the creation of the “Double First Class” discipline and the cultivation of outstanding engineers in the field of energy and power at Henan Agricultural University. The course is based on the high-end positioning of graduate students, focusing on the multi-scale physical and chemical mechanisms of combustion processes, extreme condition combustion regulation, low-carbon and zero carbon fuel combustion theory, and intelligent combustion systems. The research content has jumped from the description of traditional combustion phenomena to the intelligent optimization of combustion systems and the autonomous controllability of strategic energy equipment [3].

2.3 Construction Objectives

Curriculum construction sets a three-dimensional goal system of knowledge, ability, and literacy.

Knowledge objective: To enable students to understand the multi-scale coupling phenomena related to complex combustion (i.e. the combination of molecular dynamics, turbulence, and system thermodynamics), and to be able to apply a cross scale approach for analysis (from micro to macro); To understand the characteristics and kinetics of combustion of low-carbon or zero carbon fuels (hydrogen, ammonia, biomass, syngas); To understand the role that artificial intelligence and big data can play in combustion (modeling or optimization); To grasp the current international trends in combustion research.

Ability objective: To cultivate individuals with the ability to use intelligent means to handle advanced combustion systems or large-scale thermal equipment (full cycle); Master the simulation and optimization methods of combustion systems based on digital twins; Capable of conducting comprehensive analysis on complex combustion topics, from modeling to experimentation to optimization; Having an innovative mindset of interdisciplinary collaboration and multi unit cooperation, one can play the role of a technical leader in university enterprise cooperation projects.

Literacy goal: To educate students with a focus on serving the country through technology, taking into account engineering ethics, green thinking, and craftsmanship spirit, and striving to cultivate high-level applied talents who master combustion technology, have conscience, and social responsibility.

3. Construction of the Three in One Teaching Content System

3.1 System Architecture

The proposed goals need to be implemented, and the curriculum should be organized according to the four in one teaching content of “basic theory frontier mechanism numerical intelligence simulation engineering innovation”. Here, the Ministry of Agriculture and Rural Affairs’ “Thirteenth Five-Year Plan” textbook “Combustion” is used as the basic framework, combined with the cross-research ideas of 0858 Energy and Power and 0951 Agriculture. Renewable energy, dual carbon development, hydrogen and biogas co-production, and low consumption combustion of agricultural waste are regarded as special directions that need to be broken through, and are treated in layers and integrated uniformly to form an organic whole of knowledge.

3.2 Basic Theoretical Module

The content related to basic theories includes classical analysis of combustion thermodynamics, combustion chemical kinetics, and ignition and extinguishing, but all have been extensively updated. For the topics related to combustion thermodynamics, they are developed under extreme conditions such as non-equilibrium, real gas, and high-temperature dissociation, and the relevant results are practically integrated with rocket engines or scramjet devices. Regarding combustion chemical kinetics, taking various fuels (hydrogen, ammonia, biomass, aviation kerosene substitutes) as examples, detailed reaction mechanisms and feasible simplification methods are explained. A method for processing reaction models using machine learning and AI assisted rate constant prediction (using graph neural networks or reaction force fields) are proposed. In terms of ignition and extinguishing theory, the correlation between non adiabatic conditions, thermoacoustic oscillations, and tempering phenomena is examined, and a combustion stability scheme guided by deep reinforcement learning is proposed.

3.3 Frontier Mechanism Module

The cutting-edge mechanism module is a discussion on the latest developments in the discipline, focusing on topics such as turbulent combustion and numerical methods, advanced combustion of gas fuels, combustion of liquid and solid fuels, and carbon management. The content involved in turbulent combustion includes numerical methods such as large eddy simulation, flame surface thickening, partial stirred reactors, and the use of generative AI to assist in modeling or analyzing turbulent combustion fields. This article mainly explains the flame propagation characteristics of hydrogen gas and its tempering problem, the control methods of N_2O/NOx in ammonia fuel, and the mechanism of oxygen rich combustion for gas fuels. It also provides an example of a hydrogen gas turbine combustion chamber designed through school enterprise cooperation. In the liquid and solid fuel part, starting from multiphase spray combustion, the key technical points of “double carbon” such as biomass gasification + carbon capture and combustion carbon accounting and optimization are discussed.

3.4 Numerical Simulation Module

The numerical simulation module is a unique and innovative content of this course. The module mentioned in the article applies both artificial intelligence and big data, using Python/Cantera for machine learning analysis and verification of combustion mechanisms; Constructing an AI agent for combustion field using OpenFOAM+PyTorch and conducting corresponding training; Perform super-resolution processing on turbulent combustion; Design prediction and control methods for combustion instability based on LSTM/ Transformer mode; Combining CFD+AI to achieve dual optimization of low NOx and no backfire in the burner; Propose ideas or solutions for digital twin burners; Applying deep reinforcement learning to joint optimization of boiler combustion and environmental protection. The listed teaching methods (code exercises, virtual experiments, group discussions) help students gain practical mastery of “AI+combustion” cross skills [4].

3.5 Engineering Innovation Module

The engineering innovation module combines theory with practice and adopts existing engineering and technical standards of the enterprise. Using school enterprise collaboration to conduct case studies (such as joint research on a certain hydrogen gas turbine combustion chamber, retrofit experiments on coal-fired power flexibility, online analysis of boiler combustion and carbon emissions), guiding students to think about complex engineering problems and propose feasible solutions. The practice is also characterized by “hydrogen combustion device design”, “methane combustion device design”, and “gas combustion simulation”, enabling students to apply knowledge to design, data, and on-site, and receive training in various abilities.

4. Innovative Teaching Methods Empowered by Mathematical Intelligence

4.1 AI+Big Data Driven Teaching

The course includes artificial intelligence combustion reaction simulation and big data combustion diagnosis in the teaching content. In terms of theoretical aspects, new ideas such as machine learning potential functions and intelligent simplification methods related to combustion mechanisms are adopted to illustrate the help of AI in combustion research. Regulations have been made for the methods used in experimental teaching: using Python (Scikit learn/PyTorch) for AI inversion processing of combustion components and temperature, and designing a training scheme for combustion field proxy AI models based on open-source ideas. The content related to grade evaluation is to enable AI to analyze learning situations, track individual learning dynamics comprehensively, and provide specific and targeted learning suggestions.

4.2 Online Digital Presentation

All resources involved in online courses, including micro course theory, AI simulation experiments, enterprise real-life videos, case databases, and online assessments, should be organized to ensure that they are fully available, shareable, and recorded throughout the course. The cloud platform used in the course already contains information on combustion mechanisms, DNS/LES data, AI methods, and digital twin instances, making it a readily accessible resource for learners [5]. Before class, use the latest papers in Nature or Combustion and Flame as guidance to encourage students to actively verify and think; After class, use AI tools to complete literature review exercises and train their ability to keep up with academic trends.

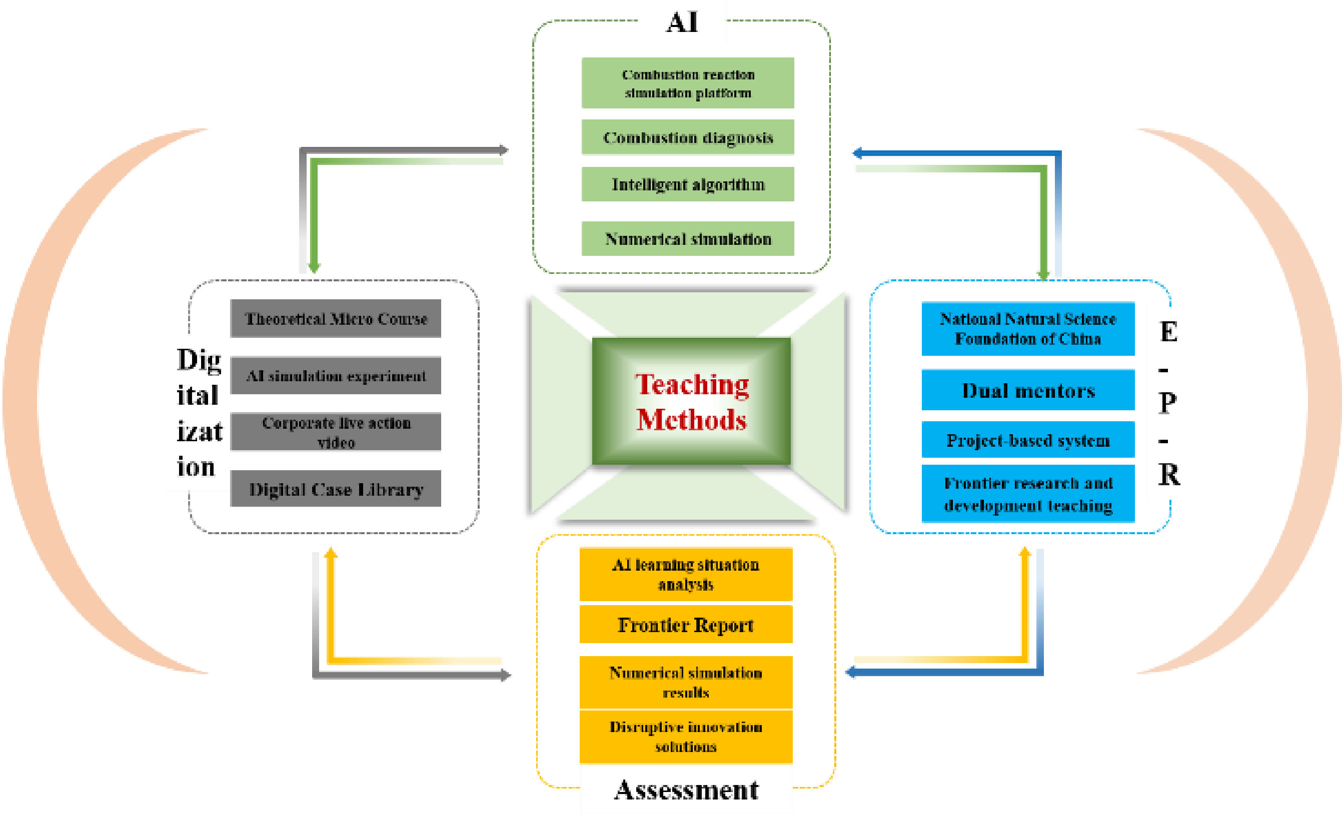

Figure 1: Teaching methods

4.3 Collaborative Teaching Between Teaching, Research and Production

Design teaching cases for professional degree graduate students based on high-level scientific research achievements such as the National Natural Science Foundation of China, known as "research feedback teaching". Treat Henan Sitong Boiler Company, Zhengzhou Dingtai Technology, and Bangyao Network as leading enterprises, and arrange teaching according to dual mentors, projects, and cutting-edge ideas. Enterprise mentors need to teach, provide guidance, and offer examples, and the technical and engineering requirements used must come from actual projects. Students go to relevant units for on-site internships or project work, forming a unified training mode of "teaching training practice" in each link.

4.4 Process Based Innovation Assessment

"AI learning analysis+latest reports+digital simulation results+breakthrough innovation" should be regarded as an integral part of the comprehensive assessment, and the innovation ability of professional degree graduate students should be given top priority. The evaluation of the process should account for 50%, which is calculated based on classroom discussions and cutting-edge reviews (15%), numerical intelligence assignments or projects (20%), and experiments and collaborative innovation (15%). The proportion of summative assessments is 50%, and closed book exams will no longer be used. Instead, students will select combustion related topics and write relatively complete innovative research, which should include literature review, application of AI methods, and thinking and analysis of engineering significance.

5. Collaborative Education Mechanism Integrating Industry and Education

5.1 Construction of School Enterprise Collaboration Platform

The construction of courses is the result of school enterprise cooperation. Since 2003, Henan Agricultural University has established a teaching and experimental internship base together with Henan Sitong Boiler Company. Later, both parties were approved to establish the Henan Intelligent Boiler Manufacturing Innovation Center or the Key School Enterprise Research and Development Room for Low Carbon Renewable Energy. In addition, the school has included Zhengzhou Dingtai Technology and Bangyao Network as cooperative partners and obtained intellectual property rights in computer software through various means. The various platforms mentioned above are of practical help in using examples in teaching and in joint talent cultivation.

5.2 The Collaborative Guidance System of the "Three Teachers"

A collaborative training model of "on campus mentor+corporate mentor+AI virtual mentor" should be established. On campus mentors need to handle the theoretical and academic lectures, while enterprise mentors need to provide engineering demonstrations or case studies based on actual situations. AI virtual mentors provide learning assistance through learning situation analysis, self-adjusting learning prompts, automatic code verification, and other methods. The experiment must be conducted under the guidance of school supervisors and enterprise engineers, highlighting the idea of school enterprise cooperation; The experimental data should be uploaded to the course website, and AI tools should be used to analyze the data in the cloud according to the course regulations.

5.3 Reconstruction of Practical Teaching System

Provide an explanation on the practical teaching of core courses for professional degree graduate students, proposing a 4-hour experimental content: namely, the topic of "LIBS/Spectral Analysis of Combustion Field and Using AI to Find Temperature and Components" (2 hours, innovative experiment) or the topic of "Digital Twin Model and Stability Prediction of Hydrogen/Ammonia Blended Combustion" (2 hours, comprehensive experiment). The experiment involved was jointly developed and operated by the Energy Engineering Department of the School of Mechanical and Electrical Engineering at Henan Agricultural University and relevant enterprises, utilizing modern combustion diagnosis, AI methods, and digital twins. There should be a basic understanding of laser combustion diagnosis, high-speed image recording, and AI data processing, and the ability to use digital twins for simulating or optimizing combustion processes.

6. Construction Effectiveness and Demonstration Radiation

6.1 Improvement of Teaching Effectiveness

Utilize curriculum construction to implement the professional degree graduate curriculum concept of "high-end leadership, promoting teaching with digital intelligence, cross integration, and combining teaching, research, and production". In the past three academic years, the course leader has systematically taught core graduate courses in the field of "Advanced Combustion" three times. They have also supplemented their undergraduate courses in "Combustion", "Hydrogen Energy Technology and Applications", and "Combustion Equipment Design" as resources, considering the undergraduate courses as a whole and arranging them in a hierarchical manner. In total, more than 1100 graduate and undergraduate students have benefited from this type of teaching. The satisfaction with the course and the innovation ability of graduate students have both increased, and the experience of constructing interdisciplinary and digital courses has promotional value.

6.2 Textbook and Resource Construction

The course research group has compiled "Combustion Science" as a textbook for the 13th Five-Year Plan of the Ministry of Agriculture and Rural Affairs and a series of textbooks for renewable energy engineering in higher education institutions nationwide. It has been adopted as the core course textbook by many domestic universities such as Zhejiang University and Harbin Institute of Technology. The course has a combustion mechanism database, virtual simulation experiment projects, and self written supporting textbooks that have been used for 5 sessions. We plan to further publish one textbook or teaching reference book related to advanced combustion science for professional degree graduate students, and establish an artificial intelligence combustion simulation library, big data case library, digital twin teaching module, and online premium course platform.

6.3 Output of Educational Reform Achievements

The course leader focuses on the construction of new engineering disciplines and the "Double First Class" initiative, deeply cultivating the education and teaching reform of energy and power majors. They have published 18 papers on educational reform (13 as first author and 5 as corresponding author), including 2 CSSCI core/extended journals. Hosted 6 key projects, including the China Higher Education Association Key Project, the Ministry of Education Industry University Cooperation Collaborative Education Project, and the Henan Higher Education Association Key Project, with a total funding of 120000 CNY. Pioneering and practicing the innovative teaching model of "four-year scientific and technological innovation method", establishing a virtual simulation training platform for photosynthetic biohydrogen production, and winning the first prize of undergraduate higher education teaching achievements in Henan Province.

6.4 Cultivation of Students' Innovation Ability

The curriculum construction effectively supports the cultivation of innovation ability for professional degree graduate students. In the past three years, the course leader has guided students to publish 12 academic papers as first authors and won 5 awards in national subject competitions. Guided students to win more than 10 awards (including 5 first prizes) in national level discipline competitions such as the National College Student Energy Economics Academic Creativity Competition, the National College Student Energy Conservation and Emission Reduction Social Practice and Technology Competition, and the National College Student Renewable Energy Excellent Science and Technology Works Competition. They have accumulated rich experience in science and education collaborative education in the fields of simulation innovation, device research and development, and engineering practice in cutting-edge directions such as solar energy supply and biomass hydrogen alkane co production.

6.5 Social Services and Demonstration Radiation

The curriculum construction supports the creation of disciplines for the school's "Double First Class" initiative, emerging interdisciplinary fields, and urgently needed disciplines for extraordinary layout, in order to enhance the influence of the school's energy power and agricultural engineering disciplines. Provide high-level talent support and digital technology services for Henan's energy transformation, dual carbon strategy, rural revitalization, and boiler equipment industry upgrading. Form a curriculum construction model led by young backbone, with distinct features of digitization and intelligence, and a benchmark for professional degree graduate students, providing a demonstration for the high-quality development of professional degree graduate education in the province.

7. Conclusion

Artificial intelligence is of great significance to the progressiveness and originality of the content involved in the course, which helps graduate students to grasp the idea of dealing with complex projects in a mathematical and intelligent way, and should become the direction of curriculum reform. The collaborative education approach of "university+industry+enterprise" is very meaningful for the cultivation of professional degree graduate students, and relying on platforms or adopting methods such as dual mentors and project-based teaching is expected to fully develop engineering abilities and collaborative spirit.

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