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Research on the Project Engineer Teaching Method Based on Process Roles Theory

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Abstract: *In project-based learning, the quality of group interaction is one of the key factors influencing instructional effectiveness. This article addresses the prominent issues associated with project-based learning activities within the context of material mechanics courses and proposes an instructional method for teaching materials mechanics using features from the process role theory, an aspect of the field of social psychology. In this model, students are assigned engineering roles according to the characteristics of engineering projects and wear engineer bracelets, enabling them to engage in authentic conflicts and collaborations within and among groups, contributing to the advancement of the project. A teaching practice demonstrates that this method effectively stimulates students' enthusiasm for participation, enhances the quality of project interaction, fosters a sense of responsibility and pride in students as engineers and yields favourable instructional outcomes.*

Keywords: *Project engineer teaching method, Material mechanics, Process role theory, Engineer bracelets*

1. Introduction

Material mechanics is a fundamental course offered to sophomore students in various engineering disciplines, with the aim of cultivating their ability to abstract, analyse, design and solve engineering problems using prior knowledge, critical thinking and methods from mechanics. The course encompasses numerous concepts, theorems and computational formulas, emphasising theoretical aspects and demanding a certain level of abstract analytical skills from students.

Project-based learning has partially addressed the issue of lower-level cognitive activities in material mechanics courses [1]. However, owing to the lack of deep-level optimisation in operational models, group interactions often become superficial, students' thought processes remain limited, and the effectiveness of project-based learning remains unsatisfactory, leading to an insignificant enhancement in the quality of talent development.

This article proposes an instructional "Project Engineer" teaching method based on the process role theory, leveraging principles from the field of social psychology. This model establishes an engineering team operation scenario, optimises the operational processes of project-based learning, reinforces students' responsibilities and obligations within project interactions and provides a learning framework that aligns with students' needs. The aim of the method is to stimulate students' enthusiasm for engaging in instructional activities, extend higher-order thinking processes during the learning process and enhance the quality of course instruction and effectiveness in talent development.

2. Problems in traditional project-based learning

Project-based learning has diversified the types of instructional activities in material mechanics courses and created conditions for elevating students' cognitive levels. However, after a period of exploration, the shortcomings of the traditional project-based learning model have gradually become apparent.

2.1. Design target offset

The students involved in the course are sophomore students who have not yet studied core professional courses or specialised courses and thus lack the foundational knowledge framework for understanding real engineering problems. When directly confronted with complex real engineering project topics, they tend to excessively focus on non-core issues such as engineering background, technical details and manufacturing difficulties. This diversion deviates from the core objective of the course instruction, which is to learn about safety-related issues (e.g., strength, stiffness and stability). Consequently, students have a shallow understanding of material mechanics concepts and their application in real-life scenarios, making it difficult for them to fully achieve the learning objectives in terms of knowledge and abilities.

2.2. Poor sense of student substitution

In project-based learning, a substantial amount of high-level, complex and in-depth thinking occurs during the project research phase. Students are required to reflect deeply on the application of course knowledge, expand collective thinking logic, experience team collaboration scenarios and understand the operational principles of complex engineering projects [2]. However, the insufficient guidance in project operation methods and a lack of interactive contexts among students result in issues with students' self-role positioning, inadequate task expectations and a lack of engineering pride during project execution. Moreover, the teams tend to lack essential high-level activities such as mutual assistance, conflicting demands and collective progress. Consequently, in many cases, a few individuals end up shouldering most of the design and calculation work, leaving others to "slack off" either intentionally or unintentionally. Group projects deteriorate into individual projects, and some students exhibit a phenomenon in which they receive adulation for their presentation skills but show little understanding outside of class. This situation affects the development of students' practical engineering abilities.

2.3. Ineffective integration of ideological and political education

Traditional course design for ideological and political education often involves presenting ideological and political considerations through the exploration of relevant case studies and analysing the ideological aspects of the topics. This instructional design lacks integration with project-based learning, resulting in limited immersion for students. Moreover, the course design has a relatively short-term impact and fails to incorporate students' ideological and political practices. Consequently, it becomes challenging for students to gain a deep understanding of ethical requirements for engineers, experience the responsibilities and obligations of engineers and develop a profound sense of professional pride and team honour as engineers.

3. Design concept of the proposed instructional model

3.1. Design ideas

In traditional project-based learning, students often perceive themselves as "college students" who are assigned tasks related to design, implementation and evaluation rather than as real engineers who face contradictions and compromises, conflicts and cooperation, responsibilities and commitments. This cognitive and mutual understanding approach often leads to a mindset of laziness, dependence on others and reluctance to engage in deep thinking. Consequently, it results in suboptimal interaction quality and significant differences in learning outcomes among group members.

Role theory is one of the social psychological theories that explore how individuals' attitudes and behaviours are influenced by their social roles and societal role expectations. The process role theory is an important component of role theory, which views an individual's activity domain as a field in which they engage in social interactions. It focuses on studying the process of role playing, role expectations, role conflicts and role strains that occur during interpersonal interactions within respective fields [3-6].

Drawing upon the principles of the process role theory and referencing the composition of personnel in real engineering projects, the research team designed a project engineer instructional model. This model consists of four operational modules: establishing engineer role positioning, studying engineer role tasks, executing engineer role responsibilities and practicing engineer role missions. By replacing the identity of "college students" with the concrete role of "engineers" within the project group, a more

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appealing, responsible and goal-oriented learning context was created. This model strengthens students' higher-order interactive processes within the project and provides them with a tangible experience of engineer growth. The instructional model's principle is illustrated in Figure 1.

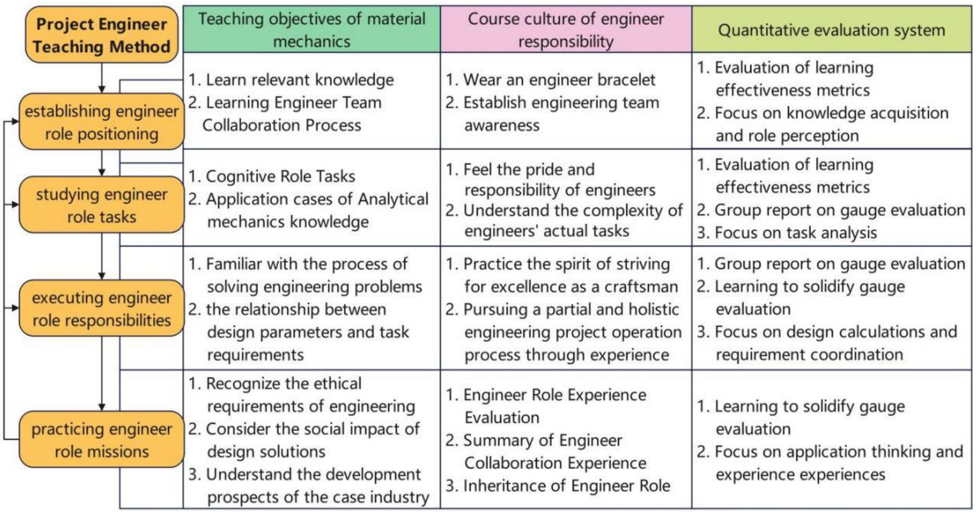

Figure 1: Design Principles of Project Engineer Teaching Method

First, students will establish their engineer role positioning within the project, understanding the differences and relationships between engineers in different positions. They will grasp the necessity of engineer collaboration and its implementation path. Additionally, they will recognise the potential design conflicts among engineers and explore possible solutions, laying a foundation for their subsequent participation in the project as "engineers."

The research team studied engineer role tasks by focusing on important safety issues (such as strength, stiffness and stability) in the material mechanics course. Considering various demands in the project process, such as configuration design, management coordination and competitive outcomes, the team has designed corresponding engineer roles and their responsibilities. Engineer roles are randomly assigned within the groups, and distinctive engineer bracelets are distributed to establish a learning community for each engineer role in the instructional class. This approach guides students in understanding their respective engineer role tasks, clarifying key requirements for task implementation, identifying influential parameters and facilitating interactions among different engineer roles within the group. Below are some examples of commonly used engineer roles and their responsibilities.

Design and analysis engineer (green bracelet): Responsible for the overall design of the project, coordinating with the teacher to determine the work direction, verifying critical designs, confirming the final project outcomes and leading the team members to complete the project requirements on time.

Structural construction engineer (blue bracelet): Mainly responsible for analysing and establishing multiple optional implementation configurations according to project requirements. They provide design ideas and justifications, supporting the team's solution selection and final evaluation.

Design calculation engineer (strength, stiffness and stability represented by red, yellow and purple bracelets, respectively): Tasked with component design and calculations based on the team-confirmed configuration. They prepare detailed design, calculation and verification (regarding strength, stiffness and stability) documents for key project components, collaborating with other engineer roles to complete related files.

Competitive design engineer (black bracelet): Primarily responsible for analysing the pros and cons of design solutions and calculation results. They evaluate the inter-group competitiveness of expected project outcomes (e.g., cost, manufacturing difficulty and aesthetics) and propose corresponding modification requirements.

Project acceptance engineer (white bracelet): Responsible for reviewing the final design proposals of all teams and evaluating and analysing them according to project requirements. This role is usually taken on by the teacher or selected students, depending on the teaching situation.

During student interactions, the students address each other as "engineer [role name]" and assess the quality of their collaboration and the successful completion of the project as an important component of their process-oriented assessment. In the field of material mechanics, inherent conflicts exist among various design parameters. For example, conflicts may arise between the strength design results of tension/compression members and the available structural space or between the design of a bending beam's cross section and the complexity of its manufacturing process (cost). Students need to understand their role requirements and balance them with the requirements of other roles to coordinate these conflicts and successfully complete project tasks. This requires students to learn the creative thinking and problem-solving abilities of engineers, make trade-offs and decisions among various task requirements, and timely communicate and coordinate with other engineer roles to ensure the smooth progress of the project.

To fulfil the mission of the engineer roles, it is necessary for the teachers to actively participate in the activities as engineers throughout the entire process. By establishing a serious and excellence-oriented course culture, teachers guide students to understand the responsibilities and obligations of engineers and become aware of the requirements of engineering ethics. Additionally, by incorporating an evaluation system based on the professional ethics of engineers, students are encouraged to prioritise design rationality, emphasise computational accuracy, uphold result safety, control project economy and consider the societal impact of their outcomes. This approach helps students internalise the responsibilities and requirements of technical professionals within the context of emerging engineering disciplines. Ultimately, it enables students to achieve the course objectives, enhances the quality of talent development and facilitates students' transition into true engineers.

3.2. Teaching evaluation metrics

Teaching evaluation has always been one of the important concerns of the research group. The research group proposed a set of quantified evaluation systems, analysed and organised the process evaluation in the course and established standardised evaluation metrics. This set of systems more effectively guides students into the interactive role of "engineers" and enables students and teachers to better control the progress and analyse the quality of project-based teaching activities, thereby enhancing the control of evaluation activities on project operation and improving the continuity of high-quality project interaction.

The evaluation metrics primarily include three types: learning effectiveness metrics, group presentation metrics and learning consolidation metrics. The learning effectiveness metrics mainly focus on students' independent online learning and offline interactive processes, assessing their knowledge accumulation, skill development and growth in engineer awareness during this process. The group presentation metrics are targeted metrics designed for different types of project-based teaching. They mainly assess students' performance in classroom interactions, facilitate horizontal evaluations between different groups and vertical evaluations across different grades, help students assess their development level and assist teachers in confirming students' growth profiles. The learning consolidation metrics guide students to comprehensively summarise their learning achievements and gains in engineering thinking, help students identify the value of design innovation and their shortcomings and provide teachers with references for improving interactive activities.

3.3. Incorporating ideological and political education

According to the project engineer teaching model, the research team designed a "knowledge case + course culture" curriculum integrating ideological and political teaching systems. The curriculum mainly consists of two parts: ideological and political case teaching and the "engineer responsibility" course culture.

The research team delves deep into the ideological and political resources inherent in the knowledge system of material mechanics. By collecting cases related to the background, application and research of knowledge points, they establish a transitional, thought-provoking and substantial curriculum incorporating ideological and political case libraries. By integrating cases that combine scientific research, engineering practice and industrial applications into the curriculum teaching process, the ideological, cutting-edge and contemporary aspects of the curriculum are enhanced. This provides students with more vivid and three-dimensional examples and role models, helping them recognise the value of the curriculum, identify with the spirit of craftsmanship and ignite their patriotism.

The research team designed the "engineer responsibility" course culture, which concretises engineer responsibilities and obligations among students by requiring them to wear engineer wristbands of corresponding colour. Taking the "compression and tension problem" as an example, in the teaching process, mechanics competition questions and project background questions regarding the curriculum

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integrating ideological and political elements are introduced and explained. Then, the students are divided into groups and wear the “engineer wristbands” to participate in project operations as engineers until the end of the course.

Wearing the engineer wristbands can facilitate students’ transition from the identity of “university students” to that of “engineers,” enabling them to quickly immerse themselves in the role and gain a deeper understanding and experience of the responsibilities, mission and spirit of an engineer. It allows team members to easily recognise and understand their respective responsibilities, promoting collaboration and interaction. Wearing the wristbands also empowers students to confidently showcase their abilities and value, reinforcing their sense of identification and pride in being an engineer, thereby stimulating their motivation and creativity in learning.

4. Process and effectiveness of the practice of curriculum-based teaching

4.1. Implementation process

The research team implemented the project engineer teaching model in the spring semester of the 2020 academic year within the course of material mechanics in the nationally recognised first-class undergraduate programme, Mechanical Design, Manufacturing and Automation. Following the course objectives and instructional design, the course practice was conducted through a blended approach, combining online and offline teaching methods.

Taking the chapter on tension and compression rod problems in material mechanics as an example, the instructional practice process is reported in Figure 2. At the beginning of the chapter, students initially learn about concepts and calculation methods related to tension and compression rods, such as definitions, internal forces, stresses, strength conditions and stiffness conditions, through the Smart Tree teaching platform. Moreover, they engage in problem exercises. In the offline classroom sessions, the instructor analyses and reinforces key and challenging issues encountered by students during their learning processes, such as stress calculation on oblique sections and the application of strength conditions. The instructor introduces the team competition problem for the Mechanics Competition, explaining the application approach to tension and compression rod knowledge. Building upon this foundation, a project-based teaching topic (open design of inclined support structures) is introduced using the case of the gantry crane support structure. A preliminary analysis is conducted.

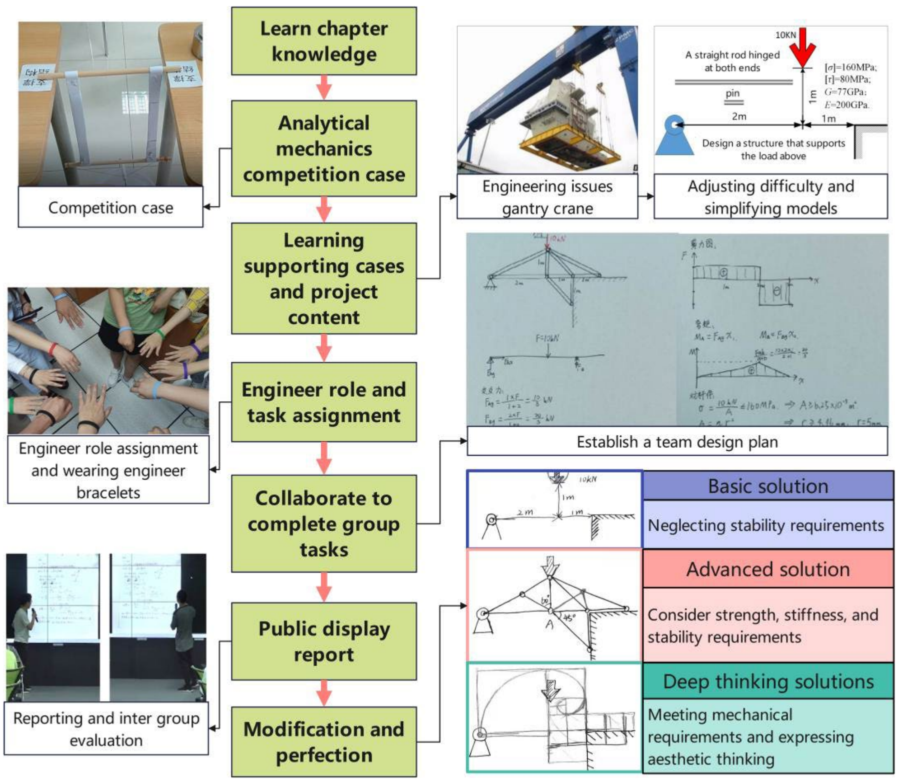

Figure 2: Practical Example of Project Engineer Teaching Method in Material Mechanics

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Students are randomly assigned to engineering roles within their groups and are provided with the corresponding engineer wristbands. The instructor explains the collaborative process of the engineering team and conducts a preliminary analysis of potential conflicts in design requirements (e.g., the complexity of the structure vs. the stability and length of the support structure vs. the thickness of the rods). The student groups engage in group interaction activities after the specified operational procedures and maintain strict records. Following sufficient autonomous interaction within each group, the students submit their final design proposals and all process-related analytical calculations. A representative from each group, randomly selected from its members, presents the design outcomes and shares their experience in the engineer role. Other groups evaluate and score the presentations. After the class, each group refines the project proposal according to the results of the interactions in class and evaluates learning outcomes using the learning consolidation metrics.

During the instructional practice process, students generally demonstrate active engagement in the learning process. They actively design alternative solutions, perform detailed calculations for the final design, engage in meaningful group discussions and think deeply about the social value of the project. The quality of interactions shows a considerable improvement. For instance, in the spring semester of the 2021 academic year, Group 3 of a certain class had the structural construction engineer perform structural design and modelling, followed by preliminary calculations conducted by the design calculation engineer. The design proposal was then verified through simulation analysis using finite element modelling software. The competitive design engineer analysed the design proposal in terms of several aspects, including design cost, material volume and load deformation. Finally, the design analysis engineer summarised the work of all students and prepared the presentation materials.

The overall course grade consists of three components: online learning data (10 points), project interaction (50 points) and the final exam (40 points). The online learning data are automatically evaluated and exported by the course teaching platform. The project interaction score is mainly based on the evaluation metrics and additional scoring provided by the instructor.

4.2. Practical effects

The research team collected and analysed the learning data from the classes that implemented the project engineer teaching model (Teaching classes 3,4) and the classes that did not undergo teaching reform (Teaching classes 1,2) during the spring semesters of 2021 and 2022. The focus of the analysis and research was on students' attendance rate, the number of design alternatives in group projects, the quality of the final project proposals and the final grades.

The statistics revealed that the attendance rate of students in the classes that implemented the teaching reform was higher than those in the classes that did not undergo the reform. Over 94% of the students in the reform classes participated in the theoretical course learning, and over 97% participated in the project-based teaching and sharing sessions. These findings demonstrate that the project-based teaching activities implemented after the reform were well-received by the students.

A comparison of the number and quality of alternative proposals presented by each group revealed that the reform classes' groups, on average, proposed more than five possible solutions for each open-ended design problem and selected three of them for the final stage of evaluation and analysis. This represents a remarkable improvement compared with the non-reform classes, which presented, on average, one or two alternative proposals in Figure 3. The teachers observed that the reform class students actively divided tasks, had clear responsibilities, cooperated smoothly, engaged in reasonable debates and had a stronger sense of team honour, thereby achieving a high level of teamwork collaboration.

Reform class students generally expressed that the project engineer teaching model helped them solidify their knowledge framework and allowed them to experience the unique spirit of excellence, professional ethics, a strong sense of responsibility and a collaborative work environment associated with the role of an engineer. They truly felt proud and confident as future engineers, and their responsibilities and future goals became clearer.

In terms of final grades, the average score of the reform classes exceeded 86.4%, with a pass rate of over 96.3%. These results surpassed the parallel classes' averages of 76.3% and 80.1% in Figure 4. The teaching reform enhanced the effectiveness of student interaction in project-based teaching, ultimately enhancing the quality of the course instruction.

In recent years, driven by teaching reforms, students' enthusiasm for participating in various subject competitions and social practice activities has remarkably increased. In particular, over the past three

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years, students who participated in course learning have won more than 40 national-level competition awards. The educational effects of the teaching reforms are becoming increasingly prominent. The course team has also received multiple national-level teaching competition awards and has been invited to share their teaching reform experiences on numerous occasions. The teaching model has had a wide-ranging influence, and its impact continues to grow.

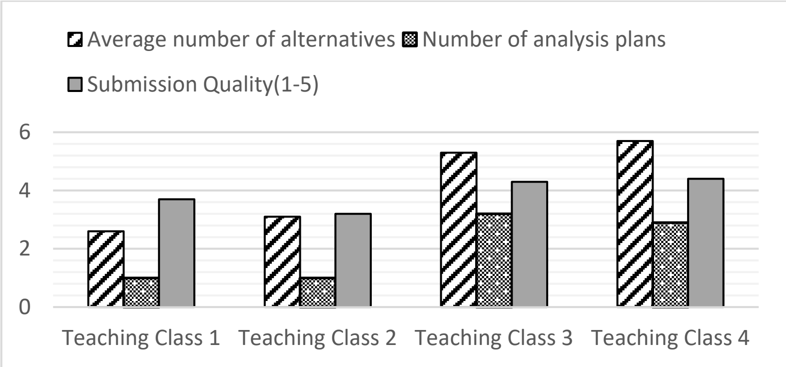

Figure 3: Comparison of Group Plan Data of Material Mechanics in 2021 and 2022

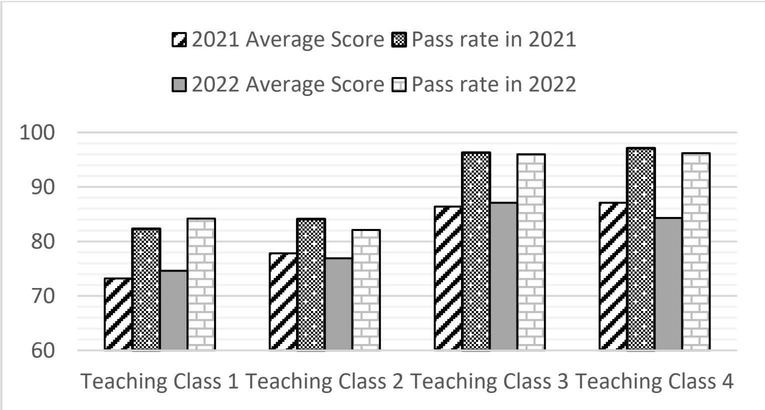

Figure 4: Comparison of the Final Grades of Material Mechanics in 2021 and 2022

5. Conclusion

To address the issues associated with the teaching of material mechanics, this paper proposes a project engineer teaching model based on the theory of roleplaying in processes. This model incorporates the concepts of roleplaying, role expectations, role conflicts and role tensions from the theory of roleplaying. A project engineer teaching model that focuses on the roles, tasks, responsibilities and missions of engineers is established. Additionally, the designed course culture concretises the sense of responsibility, pride and ethical requirements of engineers among students by requiring them to wear engineer wristbands. The established model allows students to receive explicit education on the responsibilities of an engineer while being influenced by implicit engineer behavioural guidelines. Moreover, it encourages students to internalise the spirit of craftsmanship, patriotism and resilience as their code of conduct. The analysis of teaching data indicates that the project engineer teaching model can enhance the effectiveness of material mechanics teaching, improve the experience of project-based learning and consequently drive professional and curriculum development, thereby enhancing the quality of talent cultivation.

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