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Exploration and Practice of the Integration of Science and Education in the Development of Engineering Abilities

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Abstract: *"The Integration of Science and Education" aims to innovate, integrate, and share educational models and methods by focusing on technological advancements. This work explores the stages of in-class experiments, CDIO (Conceive-Design- Implement-Operate) experiments, and open innovation experiments, and proposes solutions for each instructional stage based on their characteristics. In the in-class experiment stage, advanced technology is introduced into classroom teaching using equipment as a medium. In CDIO experiments, simple research topics and research organizational forms are introduced, allowing students to have an initial experience with research by dividing the tasks and steps of the topics into research nodes. In stages such as open innovation experiments, teaching activities facilitate research by offering preliminary groundwork for projects. By organically combining these three stages, students' engineering abilities are greatly enhanced, and their innovative spirit is cultivated.*

Keywords: *Integration of Science and Education, Teaching Activities, Engineering Ability*

1. Introduction

The scientific and engineering-oriented trends in talent development are constantly changing with social progress[1-3]. In the era of Industry 4.0, there is a growing demand for cultivating engineering capabilities in talent development[4-6]. However, conventional engineering education often remains restricted to technical subjects, and instructional systems primarily rely on cognitive logic and the development of knowledge frameworks[7-9]. Current teaching organizations and methods are primarily centered around teachers and textbooks, with single-context designs and implementations. The teaching process is simply divided into different stages according to academic years and corresponding content is "filled in," lacking a comprehensive students' engineering innovation and other capabilities are underdeveloped, posing challenges for them in fulfilling the critical role of promoting and leading engineering and technological innovation.

In contrast to traditional educational approaches, the integration of science and education brings about innovation, integration, and knowledge sharing by leveraging technological advancements to align the educational system, talent development chain, and scientific research system[10-12]. This integration aims to prioritize practical aspects for students, with a particular emphasis on experiential learning. Experimental teaching acts as a crucial bridge between theoretical knowledge and real-world application, serving as a pivotal instructional component that enables students to acquire essential skills[13-15]. By integrating science and education, we are able to harness the power of technological advancements and create a dynamic learning environment that fosters innovation. This integration goes beyond traditional teaching methods by connecting various educational components and aligning them with the latest advancements in science and technology. It involves harmonizing the educational system, which encompasses curriculum design, teaching methods, and assessment approaches, with the rapidly evolving needs of the modern world.

"The Integration of Science and Education" model has emerged as an effective solution to address the issue of inadequate engineering capabilities among students, receiving widespread support from university educators worldwide[16-18]. However, during the actual implementation process, the following three issues still exist.

(1) How to incorporate it into the teaching content? Existing teaching content emphasizes the mastery of knowledge points, which are often theoretical in nature. However, there is often a significant

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disconnect between these knowledge points and practical engineering applications, leaving students unsure of how to apply them. In experimental teaching, standardized teaching equipment is commonly used, but there is a lack of scenarios that demonstrate the application of knowledge points in engineering.

(2) Unclear organizational patterns. In modern engineering education, there is a continuous emphasis on teamwork. However, in the process of organizing teaching, it is often seen that simple groupings of 3 to 4 students are assigned to complete an experimental project. This often leads to issues where students are unsure of how to collaborate effectively, and there is a phenomenon of relying on stronger students for support. Stronger students tend to independently complete the experiment, while other students lack opportunities for development.

(3) Lack of internal motivation for teacher reform. While the current teacher assessment system places a strong emphasis on undergraduate teaching, it is worth noting that research continues to be the primary focus for teachers, as it plays a crucial role in their personal and professional development. The challenge lies in effectively integrating teaching and research. On the one hand, this integration can address the issue of insufficient development of students' engineering capabilities. On the other hand, it can alleviate the burden on teachers and reduce time costs.

2. Strategies to address "The Integration of Science and Education"

In response to the existing hierarchical experimental teaching system, the School of Mechanical Engineering at Xi'an Jiaotong University has developed innovative solutions for "The Integration of Science and Education"[19]. These solutions are implemented through three key phases: in-class experiments, CDIO experiments, and open innovation experiments. Addressing the specific characteristics of each teaching phase, we propose novel approaches to integrate science and education.

(1) In-class comprehensive experiments. Scientific research equipment and engineering equipment are highly specialized and often challenging to operate due to their focus on real-world engineering applications. On the other hand, teaching equipment aims to help students understand the knowledge points within the curriculum and is closely integrated with theoretical instruction, making it relatively easier to operate. However, teaching equipment may lack the engineering complexity. Considering the limited knowledge, time, and energy resources available to undergraduate students, it becomes challenging for them to become proficient in operating scientific research equipment within a short period. To address this, in-class comprehensive experiments abstract the core principles from scientific research or engineering equipment and construct experimental setups within the classroom, thereby introducing engineering objects into the learning environment.

(2) CDIO experiments. CDIO is a practical course that aims to cultivate students' hands-on abilities. However, a notable challenge in the implementation of the CDIO approach is to prevent it from being limited to small-scale designs or inventions. It is crucial to ensure that CDIO aligns effectively with real-world engineering applications while simultaneously nurturing students' engineering awareness. To address this issue, in the implementation of CDIO, simple scientific research topics are introduced. These topics are divided into research nodes with step-by-step tasks, reducing the difficulty of scientific research. This approach not only helps students overcome their fear of challenges but also exposes them to broader research directions, enabling them to break away from the limitations of small-scale inventions or designs. By embracing this approach, students are empowered to explore and tackle more complex and impactful engineering projects.

(3) Teaching feeding back into research. Delving deeply into teaching resources and integrating teaching with research represents an exploratory aspect of higher education that significantly contributes to students' future academic pursuits. During undergraduate education, it is essential to fully integrate undergraduate students' CDIO experiments, undergraduate thesis projects, and extracurricular research activities with faculty research. This approach not only stimulates undergraduate students' enthusiasm for research but also cultivates their interest in research and engineering capabilities. Simultaneously, it allows faculty members to focus on their research directions and leverage their teaching initiatives.

3. "The Integration of Science and Education" model implementation

Building upon the issues and implementation strategies discussed earlier regarding the "The Integration of Science and Education", the author explores the application of the "Science-Education Integration" model in undergraduate practical teaching through three aspects: in-class comprehensive

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experiments, CDIO experiments, and the integration of teaching and research activities, as shown in Figure 1. We will provide a detailed description of the implementation methods in this section.

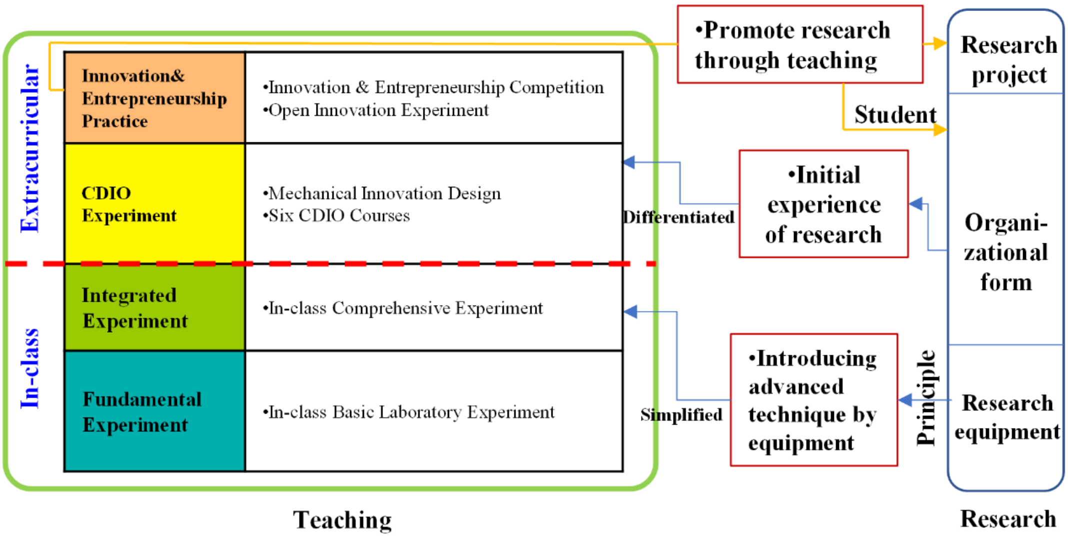

Figure 1: Schematic diagram of the integration of science and education solution strategies.

3.1. Introducing advanced technology into experimental teaching by utilizing devices as a medium

By incorporating scientific research equipment or engineering equipment into experimental teaching, a comparison between experimental equipment and scientific research equipment reveals that:

(1) The principles of scientific research equipment are in line with those of teaching equipment. The purposes of scientific research equipment align with those of teaching equipment. However, scientific research equipment exhibits higher technical performance compared to teaching equipment, whereas teaching equipment stands out in terms of openness and portability when compared to scientific research equipment.

(2) The team composition in scientific research activities aligns with student grouping in teaching. The functions of the scientific research team and the students in teaching overlap, and each student's assigned tasks are consistent with the responsibilities of team members in scientific research.

(3) The milestones of scientific research activities align with the division of nodes in experimental teaching. However, the duration of scientific research activities is significantly longer than that of experimental teaching.

During in-class experimental sessions, the utilization of equipment facilitates the experimental process. Furthermore, engineering elements and organizational methods utilized in engineering implementation are introduced. However, the teaching equipment is not merely a simplified version of engineering equipment. It is reconstructed based on principles, with open-source modifications. Furthermore, student teams in teaching are formed to align with the roles and responsibilities of engineering teams. Nonetheless, the implementation time is shortened compared to actual engineering activities.

The teaching team of "Engineering Finite Element and Numerical Computation", to which the author belongs, has explored the application of this method in undergraduate education[20]. This course primarily focuses on addressing two problems in engineering practice: 1) the consistency between finite element computation results and actual test results, and 2) the approach to solving the identified problem once its cause has been determined. To tackle these issues, the author's teaching team has streamlined the experimental teaching process based on previous research cases, as depicted in Figure 2.

In the research project, the team successfully developed a dynamic experimental platform specifically designed for high-speed railway switchgear devices. This platform was primarily utilized for conducting modal testing on the bottom shell of the switchgear machine, which served as a reference for optimizing the structure of the bottom shell. Through modal analysis of the switchgear machine's bottom shell, resonant frequencies were identified, and additional modal tests were carried out to validate the accuracy of the finite element analysis. Subsequently, structural optimization was implemented, leading to improvements in the bottom shell. The effectiveness of this modification was confirmed through a

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combination of finite element analysis and physical measurements.

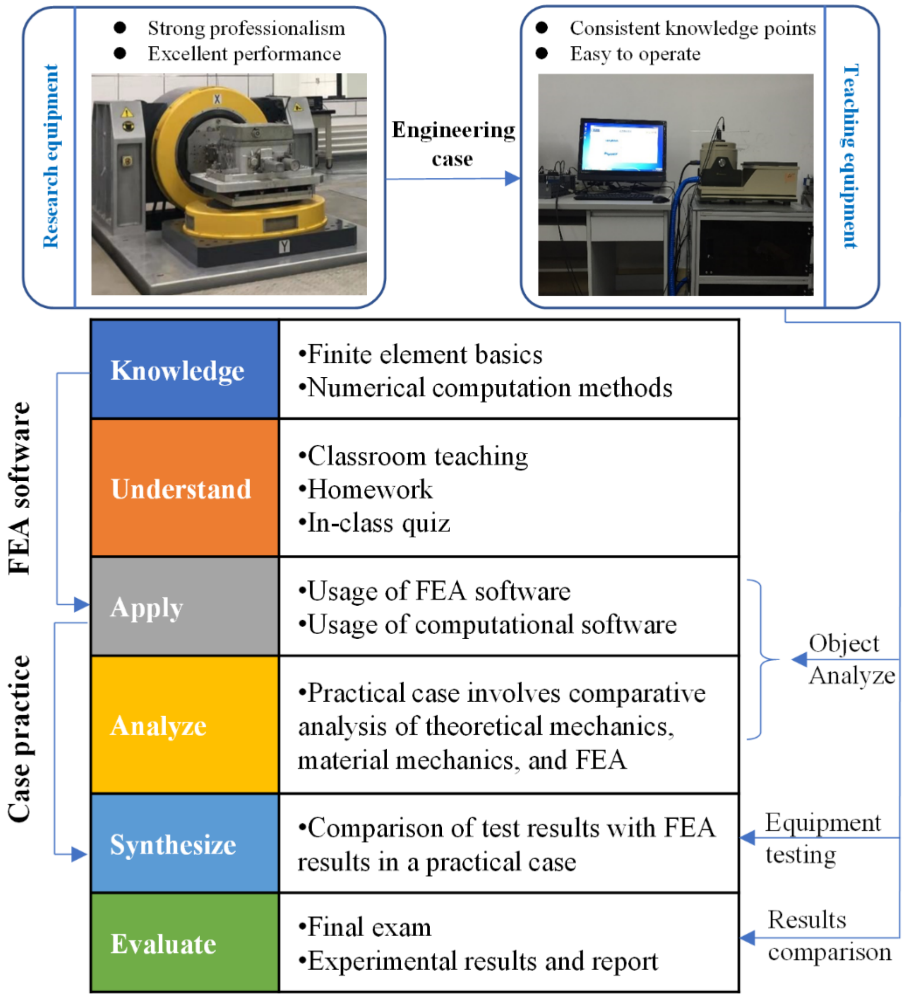

Figure 2: Experimental cases in Engineering Finite Element and Numerical Computation.

During this project, a close relationship was discovered between the integration with the Finite Element Method (FEM). If this project could be implemented in undergraduate education, it would greatly contribute to cultivating students' awareness and capabilities in engineering practice. To achieve this, the teaching team simplified the project while ensuring the principles of the original dynamic experimental platform. The equipment was miniaturized, with a maximum load capacity of 5kg and a sweep frequency design of 3000 Hz. The equipment mainly consists of a dual-axis test platform, a vibration controller, a power amplifier, vibration sensors, and other components. This equipment is used for in-class experiments in the course "Engineering Finite Element and Numerical Computation." To enhance students' understanding, the team replaced the object with small fan blades. Students conduct sweep frequency experiments on the fan blades using this equipment, and then compare the experimental results with the analysis results obtained from FEA software to assess the accuracy of their calculations. This helps students grasp the principles and thought process of the finite element method. Furthermore, it allows students to optimize the structure based on the calculated resonance frequency, providing them with a comprehensive experience of the entire process of finite element analysis and structural design engineering projects.

By comparing the switchgear bottom shell research system and the fan blade sweep frequency system, it can be observed that the principles, functionalities, and experimental procedures of these two sets of equipment are consistent. However, there are slight differences in terms of load-bearing capacity and the selection of control systems. Through this experiment, students acquire a comprehensive understanding of the process of modal testing, finite element analysis, and structural optimization. Additionally, they gain a visual understanding of the practical application of finite element calculations in engineering practice.

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3.2. Conducting "Initial Experience" Research Activities in conjunction with CDIO

The implementation process of research projects/engineering projects and CDIO follows a similar pattern, which involves five stages: topic selection, data collection, problem identification, problem solving, and summarization. However, research projects often possess a strong professional and theoretical nature, which can lead students to feel intimidated and uncertain about how to proceed. Therefore, when formulating CDIO project topics, teachers need to extract simplified modules from research work to help students build their confidence. The specific guidance process is illustrated in Figure 3.

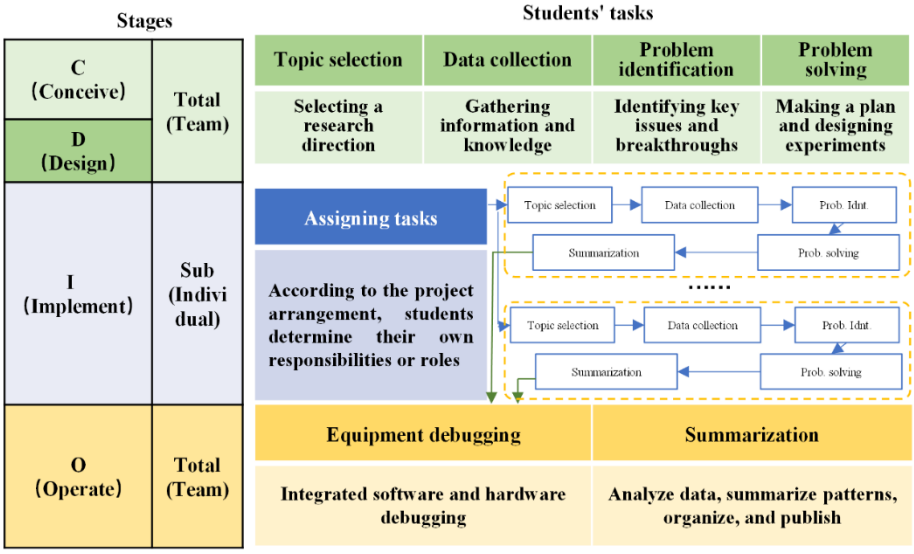

Figure 3: CDIO implementation method diagram.

During the execution of CDIO, teachers employ a graduate education approach to guide undergraduate students. Starting from literature research, students receive guidance on how to approach problem-solving. Subsequently, the teacher assists in task allocation within the team, dividing the students' work in a manner that mirrors a research team. This ensures that each student takes responsibility for different aspects of the project, providing them with training in engineering skills. Finally, students integrate their individual work with the team project to complete equipment assembly and debugging. Throughout this process, students engage in CDIO projects organized in a team-individual-team manner, allowing them to gain an "initial experience" in research activities.

In the 2015 edition of the teaching syllabus at the School of Mechanical Engineering, Xi'an Jiaotong University, six CDIO courses related to research projects were introduced for senior students, aiming to cultivate their research awareness. An example of one of these CDIO courses is "Equipment Control and Fault Diagnosis," which focuses on the study of misalignment faults in wind power equipment[21], as illustrated in Figure 4.

(1) Background and research status investigation of the project. In the study of misalignment fault diagnosis in wind power equipment, it is known that there are three types of misalignment conditions, but the fault characteristic frequencies are consistent. The existing diagnostic approach involves identifying the fault, stopping the equipment for diagnosis to determine the fault type, and then making adjustments to the equipment, resulting in long maintenance time. If it is possible to differentiate the misalignment conditions based on vibration signals and predict the fault type in advance, it would reduce the downtime.

(2) Individual student research. After clarifying the project objectives, students identified four aspects to focus on: experimental platform, data acquisition, diagnostic algorithms, and software programming. Each student initially divided tasks based on their interests. The student responsible for the experimental platform conducted research on the elastic connection in wind power systems and designed a replaceable coupling type elastic support experimental platform. They successfully built the experimental platform. The student in charge of data acquisition found through investigation that various methods such as dial indicators and laser alignment tools can be used for precise measurement of misalignment in existing systems. They selected a laser alignment tool to accurately measure the misalignment on the experimental platform. Meanwhile, the student involved in software programming used LabVIEW to develop a

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vibration signal acquisition system, which successfully achieved real-time data acquisition of vibration signals. The student focusing on diagnostic algorithms conducted in-depth research and introduced two statistical parameters for analyzing the vibration signals.

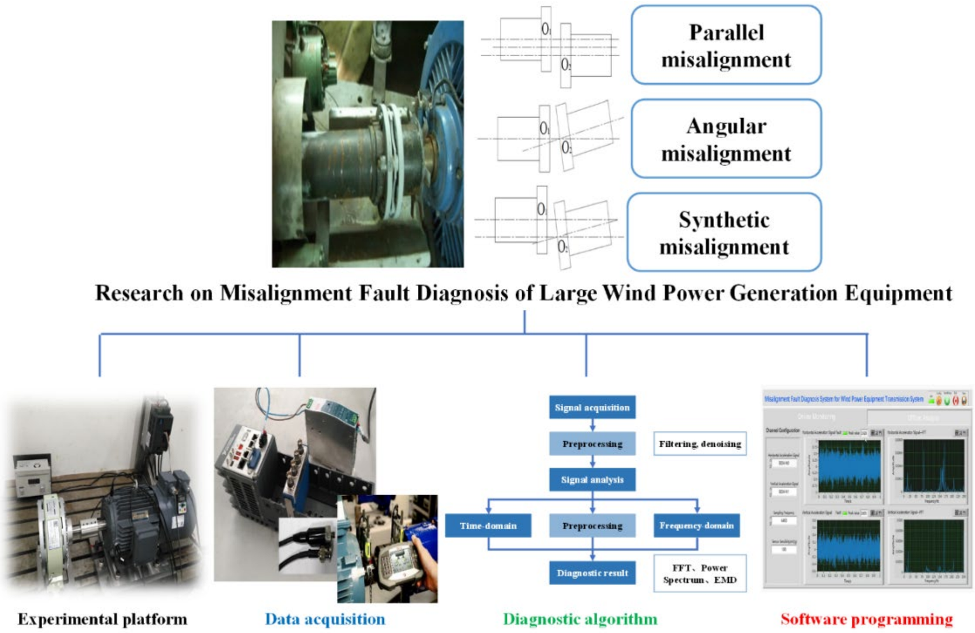

Figure 4: Case studies in Equipment Control and Fault Diagnosis.

(3) Project summary. On the experimental platform, a total of 96 sets of experimental data were collected, involving three types of couplings, nine operating conditions, and two fault types. Through signal analysis, it was observed that the amplitude of the harmonics varied for different couplings under different conditions. This finding provides a basis for the detection of misalignment faults in rotating machinery.

3.3. Promoting Research through Teaching: Providing Pre-research for Project

Research activities and competitions both require innovation and a pioneering spirit. However, research activities have continuity as they build upon the accumulated results over multiple years, emphasizing the aspect of inheritance. On the other hand, competitions are often discrete in nature, subject to changes in students and annual competition themes, making it challenging to maintain continuity. To address this, the author has explored the combination of competitions, CDIO projects, and research topics to ensure the continuity of undergraduate projects, as illustrated in Figure 5.

The author has integrated students' creative ideas from competitions into the "Mechanical Innovation Design" CDIO project and undergraduate thesis. By combining the themes of competitions with cutting-edge research, preliminary research is provided for research projects. This approach allows students to smoothly transition into research teams after graduation. While the prototypes may be relatively rough, students gain valuable experience in relevant projects and research. Ensuring continuity is key during this transition process. As teachers are involved in practical courses, they have direct access to undergraduate students, facilitating iterative improvements of students' work and ensuring continuity.

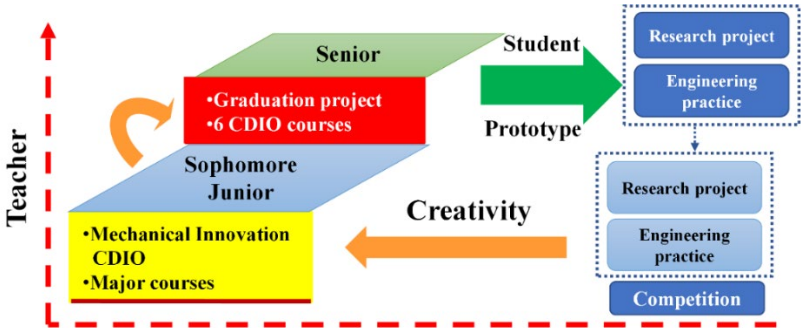

Figure 5: Schematic illustration of promoting research through teaching.

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In 2015, the author supervised students in the completion of the BayMini structure design for the National College Student Digital Design Competition for Mechanical Products. This project involved the use of adhesion principles to enable the robot to crawl. The adhesion mechanism consisted of two main components: a centrifugal fan and a deflector plate. Following the completion of this project, from 2016 to 2018, a climbing robot topic was continuously included in the "Mechanical Innovation Design" CDIO project. Students applied the adhesion method for crawling during the CDIO project. They also delved deeper into the control system of the climbing robot, dividing it into three modules: sensors, air pumps, and motor control. Initially, a lightweight climbing robot was developed using lightweight materials to achieve basic functionality. Subsequently, through further component selection, a load-bearing climbing robot was successfully developed. This series of explorations laid the foundation for the research on an airborne engine field inspection robot project and provided feasibility verification for the design and development of climbing robots in the project, as shown in Figure 6.

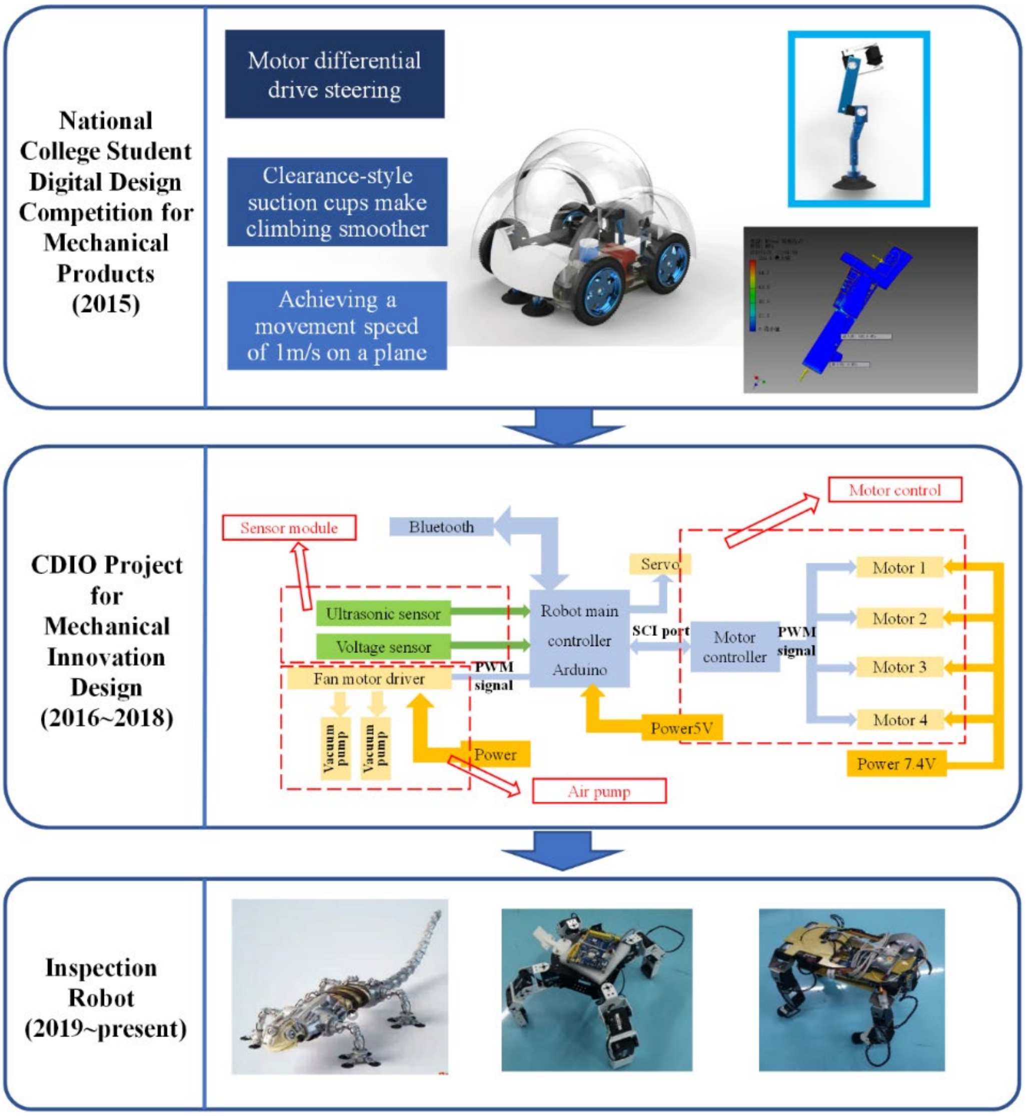

Figure 6: Iterative illustration of climbing robot.

4. Conclusions

During the exploration of integrating education and research, solutions were proposed for three different aspects: in-class experiments, CDIO experiments, and open innovation experiments. In the in-class experiment phase, advanced technologies were introduced into experimental teaching using equipment as carriers, allowing students to experience projects that resemble real engineering tasks. In the CDIO experiment activities, simple research topics were conducted, and based on the characteristics of both research and CDIO, students were organized in a research-oriented manner, providing them with

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an initial experience of research. At the same time, through teaching and guiding, students' competition topics were continuously followed up and iterated, providing preliminary research for the teachers' projects, thereby offering prior knowledge for research activities. Through these three pathways, with engineering projects and research topics as auxiliary tools, students' engineering awareness and innovative capabilities were continuously enhanced.

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