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Exploration and Practice in the Construction of Electrical and Electronic Laboratories

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Abstract: This paper delves into the development of electrical and electronic laboratories in higher education institutions, elucidating their significance for talent cultivation and disciplinary advancement. It analyzes current challenges such as outdated equipment, imperfect practical teaching systems, and backward laboratory management models. A series of targeted strategies are proposed, including advancing equipment modernization, improving practical teaching systems, strengthening faculty development, and establishing open-access platforms. Implementation steps and effectiveness evaluation methods are introduced to create high-quality electrical and electronic laboratories that meet new-era demands, thereby enhancing university teaching, learning, and research standards.

Keywords: Electrical and electronic engineering; Laboratory development; Practical teaching

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1. Introduction

With the rapid advancement of technology, electrical and electronic engineering has found widespread application across various fields, driving an increasing demand for specialized professionals. As vital hubs for talent cultivation, universities face challenges in their electrical and electronic laboratories, which directly impact teaching quality and students' practical skills development. Many institutions currently struggle with outdated equipment, limited functionality, and closed management systems, making it difficult to meet modern teaching and research demands. Therefore, exploring effective approaches to laboratory construction is crucial for enhancing teaching quality and fostering students' innovation and practical abilities [1]. This paper examines the necessity of laboratory development, existing challenges, construction strategies, implementation, and evaluation methods, aiming to provide reference for the development of electrical and electronic laboratories in higher education institutions.

2. The necessity of university electrical and electronic laboratory development

2.1. A key support for talent development

Electrical and electronic laboratories provide students with practical operation platforms, enabling them to apply theoretical knowledge learned in the classroom to real-world scenarios. This integration of theory and practice allows students to gain a deeper understanding of circuit principles, electronic device characteristics, and related content. Through hands-on laboratory work, students develop practical skills, problem-solving abilities, and analytical capabilities. This fosters innovative thinking and teamwork spirit, laying a solid foundation for future careers in related fields [2].

2.2. Vital assurance for disciplinary advancement

State-of-the-art electrical and electronic laboratories furnish essential conditions for universities to conduct research. Within these facilities, faculty and researchers pursue cutting-edge technological studies and explore innovative applications of electrical and electronic technologies across diverse fields. The quality of laboratory development directly impacts a discipline's research output and academic influence, playing a pivotal role in advancing university-level academic programs [2].

2.3. A powerful foundation for serving society

Leveraging their technological and talent advantages, university electrical and electronic laboratories can engage in industry-academia-research collaborations with enterprises. By providing technical support and solving practical engineering problems for businesses, they facilitate the transformation of research outcomes into practical applications, contributing to local economic development. Simultaneously, these collaborations offer students opportunities to engage with real-world production demands, enhancing their social adaptability [3].

3. Challenges in developing university electrical and electronic laboratories

3.1. Lagging equipment updates

Electrical and electronic technology is advancing rapidly, with new experimental equipment and techniques continually emerging. However, many universities face slow laboratory equipment upgrades due to limited funding and cumbersome procurement processes. Outdated equipment often lacks timely maintenance, calibration, and repairs, leading to diminished measurement accuracy and frequent malfunctions. This not only undermines the effectiveness of experimental teaching but also hampers research activities, ultimately affecting the overall efficiency of laboratories [3].

3.2. Incomplete practical teaching system

Currently, practical teaching in electrical and electronic engineering at some universities still relies heavily on verification-based experiments with insufficient exploratory experiments; it features numerous single-knowledge-point experiments but lacks interdisciplinary comprehensive experiments; and it emphasizes fixed-process experiments over self-designed experiments, resulting in a shortage of comprehensive, design-oriented, and innovative experiments. Teaching methods remain relatively monotonous, predominantly involving teacher demonstrations followed by student imitation, leading to superficial understanding of experimental principles and failing to fully unleash students' initiative and creativity [4]. Grading primarily relies on lab reports and final data, overlooking the critical thinking, hands-on skills, and teamwork demonstrated by students during experimental design, debugging processes, and troubleshooting.

3.3. Need to enhance faculty practical skills

While some instructors possess solid theoretical knowledge, they often lack practical engineering experience and application backgrounds. When guiding student experiments, they struggle to integrate real-world engineering case studies into instruction. This disconnects between teaching content and practical demands hinders the development of students' practical skills and innovative thinking.

3.4. Outdated laboratory management models

Traditional laboratory management models primarily rely on closed-door management, opening only to specific classes during scheduled lessons while remaining largely idle the rest of the time. This restrictive approach severely limits academically capable students from utilizing their free time for independent research or subject competition preparation, stifling their innovative spirit. The absence of clear equipment maintenance protocols and accountability systems often leads to a "use-only, no-maintenance" approach, with repairs only undertaken after malfunctions occur. This not only shortens equipment lifespan but also disrupts normal teaching operations. The lack of scientific information management tools makes it difficult to achieve efficient and precise management in areas such as equipment usage, maintenance, and consumables management [5].

4. Strategies for developing electrical and electronic laboratories in higher education institutions

4.1. Advancing equipment modernization

4.1.1. Develop scientific equipment renewal plans

Institutions should formulate long-term and short-term equipment renewal plans based on technological trends and teaching/research needs. Conduct regular assessments to identify equipment requiring updates or additions. Prioritize technologically advanced, stable, and representative equipment while considering compatibility and scalability to accommodate future technological developments.

4.1.2. Strengthen equipment management and maintenance

Establish comprehensive equipment management protocols, clearly defining procedures and responsible parties for procurement, acceptance, usage, maintenance, and decommissioning. Enhance routine maintenance by conducting regular inspections, calibrations, and repairs to ensure optimal operational condition. Utilize information technology to create a laboratory equipment management system, enabling real-time tracking of usage status and maintenance records to improve management efficiency.

4.2. Enhancing the practical teaching system

4.2.1. Optimizing experimental content

Increase the proportion of comprehensive, design-oriented, and innovative experiments while reducing verification-based experiments. Develop challenging experimental topics based on real-world engineering cases and research projects, such as communication circuit design or equipment electronic system fault diagnosis, to guide students in applying knowledge for independent design, analysis, and problem-solving, thereby cultivating systematic thinking and innovation capabilities.

4.2.2. Innovate teaching methods

Employ diverse pedagogical approaches such as project-driven learning, inquiry-based teaching, and collaborative group learning. Use projects as learning vehicles, enabling students to actively acquire knowledge and explore concepts while developing self-directed learning skills and teamwork spirit. For example, instructors can assign real-world electronic product design projects in class, where students complete the entire process, from conceptual design and circuit fabrication to debugging and optimization in groups [6].

4.2.3. Refine practical teaching assessment systems

Establish scientifically sound practical teaching assessment frameworks to comprehensively evaluate students' hands-on competencies. Assessment criteria should encompass experimental skills, report quality, project completion, and innovative contributions. Combine formative and summative evaluations, emphasizing process-oriented feedback to provide timely guidance.

4.3. Strengthening faculty development

4.3.1. Enhancing faculty practical competence

Encourage faculty to participate in industry internships and arrange regular visits to relevant enterprises to learn about the latest technologies and production processes, accumulating engineering experience. Support faculty involvement in research projects and laboratory development to enhance their research capabilities and practical guidance skills. Simultaneously, invite industry experts and technical leaders to deliver lectures and training sessions at the university, imparting real-world engineering expertise to faculty.

4.3.2. Optimize faculty structure

To meet the laboratory's developmental needs, we will strategically recruit professionals with extensive engineering experience and advanced academic qualifications to strengthen our faculty and elevate the laboratory's overall teaching and research capabilities. We will establish a regular training and exchange system, organizing periodic workshops focused on "cutting-edge technologies, advanced teaching methodologies, major instrument operation, and laboratory safety" to empower faculty in tracking academic frontiers [7]. Implement a "mentor-apprentice" system by pairing young faculty with experienced mentors who excel in both teaching and research. These mentors will provide comprehensive guidance in project applications, course design, experimental development, and student supervision, accelerating the professional growth of junior faculty.

4.3.3. Establish faculty incentive mechanisms

Establish a teaching and research incentive system to recognize and reward faculty members who achieve outstanding results in experimental teaching reform, scientific research innovation, and guiding student competitions. Implement a "Representative Achievements" Evaluation Mechanism: Shift away from the single-dimensional evaluation model focused solely on publications and academic titles. High-quality teaching designs, successfully commercialized scientific achievements, case studies addressing real-world industrial challenges, and the effectiveness of cultivating outstanding students should all be regarded as equally important "representative achievements" and incorporated into performance evaluations and promotion systems. While adhering to syllabus requirements, encourage faculty to personalize reforms in experimental course content, teaching methods, and assessment approaches. Support their integration of the latest research findings into experimental teaching and the development of distinctive advanced inquiry-based experimental projects [8].

4.4. Building an open-sharing platform

4.4.1. Implementing an open laboratory system

Break away from traditional closed management models by adopting an open laboratory system. Extend laboratory operating hours, allowing students to independently access facilities during non-class hours for experimental research based on their interests and needs. Develop comprehensive open laboratory management protocols, clearly defining accessible resources, reservation procedures, safety protocols, and other matters to ensure orderly operations [9].

4.4.2. Promote laboratory resource sharing

Strengthen collaboration between universities and between universities and enterprises to facilitate the sharing of electrical and electronic laboratory resources. Establish shared platforms to enable the pooling of equipment, faculty, experimental projects, and other resources, thereby improving resource utilization efficiency. For example, universities can collaborate with neighboring institutions to conduct cross-campus experimental teaching programs, sharing high-quality experimental teaching resources; or partner with enterprises to co-build laboratories, jointly undertaking research projects and talent development initiatives.

4.4.3. Strengthen laboratory safety management

Establish comprehensive safety management systems for laboratories, enhancing oversight of electrical equipment, electronic components, and other critical assets. Equip facilities with necessary safety devices and infrastructure, conduct regular safety training and emergency drills to heighten awareness and response capabilities among faculty and students. Leverage information technology for real-time monitoring and early warning systems to ensure laboratory safety operations [10].

5. Implementation and evaluation of university electrical and electronic laboratory development

The implementation of electrical and electronic laboratory construction should follow a scientific process. First, conduct requirements analysis and design proposals to clarify construction objectives and specific content. Next, procure equipment and perform installation and debugging to ensure performance and quality. Then, complete laboratory renovation and environmental setup to create a conducive experimental atmosphere. Finally, establish management systems and provide personnel training to ensure efficient laboratory operation.

Effectiveness evaluation of laboratory construction is a critical component in ensuring construction quality. Evaluation metrics should encompass equipment performance, availability of experimental projects, utilization efficiency, and student satisfaction. Assessment methods may include questionnaires, expert reviews, and data analysis. Based on evaluation results, promptly adjust and optimize the laboratory construction plan to continuously enhance the construction standards and utilization effectiveness of the laboratory.

5.1. Systematic implementation of laboratory construction

The implementation of laboratory construction is an interconnected dynamic process where each phase requires meticulous planning and execution.

5.1.1. Thorough needs analysis and forward-looking design form the foundation of success

At the requirements analysis level, it is essential not only to clarify current foundational experimental teaching needs, such as the number of experimental benches and basic instruments required for courses like Circuit Theory, Analog Electronics, and Digital Electronics, but also to proactively consider disciplinary development trends. This includes integrating cutting-edge content like FPGA, embedded systems, and power electronics; reserving innovative practice spaces for undergraduate electronic design competitions and innovation/entrepreneurship projects. Simultaneously, laboratories must be capable of supporting faculty research projects and student development. Ultimately, a comprehensive Demand Analysis Report should be produced as the foundational basis for all subsequent work.

At the design level, based on clearly defined requirements, develop a Comprehensive Laboratory Construction Plan. This plan should specifically include:

Equipment Selection and Technical Specifications: Detailed listing of required instruments (e.g., oscilloscopes, signal generators, multimeters, soldering stations) including performance parameters, brands, quantities, and rationale for selection, achieving optimal balance between precision, reliability, and budget.

Spatial Layout and Environmental Design: Scientifically plan functional zones such as high-voltage experimentation areas, low-voltage experimentation areas, innovation fabrication zones, and discussion areas. Design must fully consider ergonomics, safety standards (grounding resistance, leakage protection, emergency lighting, firefighting facilities), network coverage, power distribution (including three-phase power requirements), and environmental requirements like anti-static measures, ventilation, and lighting to create a safe, comfortable, and efficient experimental environment.

Software and Digital Platform Planning: Provide essential circuit simulation software (e.g., Multisim, PSpice, MATLAB/Simulink), PCB design software (e.g., Altium Designer, KiCad), and a laboratory information management system to enable digital management of equipment reservations, consumable requisitions, and safety access.

5.1.2. Standardized equipment procurement and meticulous installation/commissioning are core quality assurances

Strictly adhere to national government procurement and institutional bidding procedures to select suppliers with excellent qualifications and reliable after-sales service. When signing contracts, clearly define equipment technical specifications, acceptance criteria, training content, and after-sales response times. Upon equipment arrival, laboratory managers must conduct unpacking inspections to verify model numbers, examine physical condition, and check accessories. During installation and commissioning, test each unit's basic functions and key performance indicators to ensure compliance with design specifications. This process must generate detailed Equipment Acceptance Reports and Equipment Archives, laying the foundation for subsequent asset management and maintenance.

5.1.3. Professional laboratory renovation and human-centered environmental design embody an educational atmosphere

Construction must ensure the quality of concealed works like plumbing, electrical systems, ventilation, and networking, utilizing wear-resistant, corrosion-resistant, fire-retardant, and eco-friendly materials. Environmental design should transcend basic functional requirements to emphasize cultural education. For instance, display the history of electrical and electronic disciplines, profiles of renowned scientists, safety protocols, outstanding student projects, and cutting-edge technological developments on walls. Install tool walls, component display cabinets, and project showcase areas to cultivate a rich culture of engineering practice and innovation, subtly stimulating students' curiosity and sense of accomplishment.

5.1.4. Robust institutional frameworks and systematic personnel training are vital for sustainable operation

Establish a management system characterized by "clear responsibilities, defined processes, safety assurance, and open access". Core regulations should include: Student Experimentation Guidelines, Laboratory Safety and Hygiene Management System, Instrument Operation and Maintenance Standards, Hazard Response Protocols, Equipment Borrowing and Damage Compensation Procedures, and Laboratory Access Management Policies.

Personnel training should be tiered and comprehensive: Laboratory managers receive in-depth training on equipment operation, daily maintenance, and troubleshooting to become "technical experts". Instructors undergo training on new equipment and platforms to ensure effective guidance in experimental teaching. Students must complete mandatory safety education and access assessments, receiving specific equipment safety instructions before each experiment. Systematic training is crucial for preventing safety incidents, enhancing equipment utilization, and improving experimental teaching outcomes.

5.2. Comprehensive effectiveness evaluation and continuous improvement of laboratory development

Laboratory completion marks not the end of the project but the beginning of value creation. A scientific, comprehensive evaluation system serves as the engine driving continuous laboratory evolution and service quality enhancement. Evaluation should establish a multidimensional, quantifiable indicator system covering the following key aspects:

Equipment Performance and Operational Status: Core metrics include equipment integrity rate ($\geq 95\%$ is excellent), equipment failure rate, and average maintenance response and completion times. These directly reflect the reliability of the hardware infrastructure.

Experiment Program Offerings and Teaching Quality: Key indicators are experiment program implementation rate (actual programs offered/programs required by syllabus) and the proportion of comprehensive/design-based/innovative experiments. The latter serves as a key gauge of experimental teaching depth and the intensity of fostering students' innovative capabilities.

Resource Utilization and Management Efficiency: Focuses on equipment utilization rate (machine-hour utilization), laboratory open-access rate (support for extracurricular innovation activities), and the standardization and cost-effectiveness of consumables management.

User Feedback and Educational Outcomes: Subjective perceptions regarding experimental content, instructional quality, and environmental facilities are gathered through student satisfaction surveys. More importantly, objective educational achievements are tracked, such as student awards in relevant academic competitions, graduation projects/theses completed using laboratory platforms, and published patents or academic papers.

To obtain objective data for the above metrics, a diversified assessment approach is required, incorporating data analysis, questionnaires/interviews, and expert review. Data analysis involves retrieving log data from the laboratory management system to statistically analyze equipment operating hours, reservation status, and fault records. Questionnaires and interviews entail distributing anonymous surveys to students and faculty, supplemented by in-depth interviews with representative users to gather qualitative feedback. Expert review involves periodically inviting peer experts from within and outside the university, as well as industry engineers, to conduct "diagnostic" evaluations in the laboratory through on-site inspections, document reviews, and classroom observations, providing professional and authoritative recommendations for improvement.

The ultimate purpose of evaluation is to "promote development and reform through assessment". Therefore, a closed-loop linkage mechanism must be established between evaluation results and subsequent decision-making. Based on evaluation reports, the university and departments should: Affirm strengths, summarize best practices, and promote successful models; For identified issues (e.g., aging equipment, uneven utilization rates, safety vulnerabilities), develop explicit Action Plans for Improvement Measures specifying responsible parties, deadlines, and allocated resources (e.g., maintenance funds, equipment upgrade budgets, management optimization plans). Through this spiral-up cycle of "planning-implementation-evaluation-feedback-optimization", electrical and electronic laboratories can dynamically adapt to evolving technological advancements and talent development needs. This ensures their sustained advancement and vitality, ultimately establishing them as premier platforms supporting high-quality innovation in talent cultivation and scientific research.

6. Conclusion

The development of electrical and electronic laboratories in higher education institutions constitutes a complex and long-term systematic endeavor, holding critical significance for cultivating high-caliber innovative talent and advancing academic disciplines. In response to the numerous challenges encountered during the current construction process, universities should prioritize addressing these issues. This requires implementing a series of measures, including optimizing resource allocation, advancing equipment modernization, refining practical teaching systems, strengthening faculty development, and establishing open-access sharing platforms, to continuously elevate the standards of electrical and electronic laboratory construction. Concurrently, universities must closely monitor industry trends and continuously refine laboratory development to better align with the demands of education, teaching, and research in the new era.

Disclosure statement

The authors declare no conflict of interest.

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