Article

Developing a Framework for Innovative Engineering Practice Competence in Electrical Engineering Education in the Context of New Quality Productive Forces

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Abstract: To address gaps in the continuity of competence development, sustained mentoring, the integration of industry needs, and assessment in electrical engineering practical education, this study proposes a five-level framework for developing innovative engineering practice competence. The framework considers the requirements associated with new quality productive forces and the educational objectives of electrical engineering programs at regional agricultural universities. It encompasses five interconnected levels: understanding and applying engineering knowledge, designing and developing solutions, investigating complex engineering problems, integrated engineering application, and community engagement and application of project outcomes. Course-based experiments, practical training, course design projects, and extracurricular innovation activities are coordinated to align competence objectives, practical tasks, and assessment evidence. Stage-specific mentoring and university–industry collaboration driven by authentic projects are incorporated to translate digitalization, intelligent technologies, and green development requirements into task specifications and engineering constraints. A multidimensional assessment approach combines process performance with the quality of project outcomes, while assessment feedback informs subsequent teaching arrangements. The resulting framework integrates practical learning content, instructional support, and assessment-informed improvement. Its applicability and educational effectiveness remain to be evaluated through subsequent implementation.

Keywords: new quality productive forces; electrical engineering; innovative engineering practice competence; practical education framework; university–industry collaboration

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1. Introduction

Innovation-driven industrial development places increasing demands on engineers' ability to apply knowledge, develop technologies, and solve practical problems. Electrical engineering connects energy conversion, equipment control, and information processing, and engineering tasks in this field frequently require knowledge from multiple disciplines. As production processes become increasingly digitalized and intelligent, students must be able to apply disciplinary principles to design, commission, and improve engineering solutions. Translating coursework into the ability to address engineering problems therefore remains a central concern in electrical engineering education. The development of new quality productive forces reinforces this need and calls for practical education to extend beyond isolated skills training toward the development of integrated competence.

Previous studies have examined students' innovation capabilities and reforms in electrical engineering practical education from several perspectives. Guo proposed a four-dimensional framework comprising learning modes, learning resources, learning environments, and learning organizations to support students' innovation capabilities in the context of new quality productive forces [1]. Lu et al. proposed an integrated

educational model combining industry engagement, teaching, practical training, and competitions, emphasizing coordination among practical education, university–industry collaboration, and innovation and entrepreneurship education [2]. Yang et al. incorporated authentic engineering projects and product development into practical education, integrating knowledge, skills, and awareness and using competence assessment to inform instructional improvement [3]. Song et al. explored approaches to connecting curricular and extracurricular practice and integrating innovation education with disciplinary education [4]. Drawing on engineering education accreditation requirements, Yang et al. investigated a progressively structured practical education framework for electrical engineering [5]. These studies indicate that developing innovative engineering practice competence requires coordinated learning content, appropriate instructional support, and suitable assessment mechanisms.

For regional universities, these reform approaches must be translated into specific tasks that reflect program objectives and available teaching resources. Laboratory work, practical training, competitions, and capstone projects each serve distinct purposes, but completing these activities does not necessarily result in continuous competence development. Educational planning must therefore clarify how tasks are sequenced, what sustained guidance students require, and how changes in their competence will be assessed. Moreover, competition awards and project outputs capture only part of students' learning. The development of solutions, resolution of problems, and individual contributions should also inform assessment. Requirements related to digitalization, intelligent technologies, and green development must be incorporated into project content and assessment criteria to establish meaningful connections with students' practical work.

This study proposes a five-level framework for developing innovative engineering practice competence, taking into account the educational objectives of electrical engineering programs at regional agricultural universities. The framework organizes otherwise dispersed practical learning activities around progressively developing competence. It specifies the requirements of each level and the connections between them, supported by stage-specific mentoring, university–industry collaboration, and multidimensional assessment. The proposed design aligns learning activities, instructional guidance, and assessment evidence, establishing a basis for subsequent implementation and evaluation.

2. Requirements and Existing Challenges in Developing Innovative Engineering Practice Competence in Electrical Engineering in the Context of New Quality Productive Forces

2.1. Competence Requirements Associated with New Quality Productive Forces

Engineering problems in renewable energy generation, smart grids, and intelligent agricultural production commonly involve electrical equipment, control methods, information acquisition, and data processing. Students must understand the relationships among these technical components and apply their knowledge in relation to an overall task objective. Developing innovative engineering practice competence should therefore emphasize connections across courses, enabling students to examine individual functions from a systems perspective and recognize how module-level design choices affect overall performance [6]. Digitalization and intelligent technologies have also changed how engineering analysis and design are conducted. Modeling, simulation, data acquisition, and programming tools should be used in relation to specific problems. Students need to justify their selection of tools, understand their conditions of applicability, and use experimental results to examine the validity of their analyses and designs. Autonomy in innovative practice is reflected primarily in the ability to identify problems, formulate feasible approaches, and revise solutions in response to validation results. Learning tasks should therefore allow sufficient scope for exploration, enabling students to compare methods, explain discrepancies, and refine solutions while developing evidence-based engineering judgment. Engineering assessment should also address green development

and practical use. Beyond achieving the required functionality, students must consider energy efficiency, operational safety, implementation costs, and maintenance requirements, including trade-offs among these objectives. Teamwork, technical communication, and professional responsibility are integral to this process. These requirements should be expressed through explicit task conditions and assessment criteria rather than remaining general statements of educational intent.

2.2. Insufficient Continuity in Competence Development Across Practical Learning Activities

Electrical engineering programs include course-based experiments, specialized practical training, course design projects, academic competitions, innovation and entrepreneurship projects, capstone projects, and internships. Although each activity has its own learning objectives, organizing activities independently by course or event can obscure the continuity of competence development. Without coordinated planning, students may accumulate substantial practical experience yet struggle to transfer their knowledge and skills to unfamiliar engineering tasks. Effective progression requires attention to task difficulty, student autonomy, and expected outputs. Introductory experiments usually provide clearly defined procedures and emphasize conceptual understanding and standard operating practices. Subsequent design tasks require students to analyze needs, select methods, and validate results independently. Without appropriate intermediate tasks, students may continue to rely on reference solutions and find it difficult to make the judgments required for independent design. Repeated basic operations across courses, combined with insufficient training in design justification, system commissioning, and integrated analysis, can also limit the educational value of practical teaching hours. Addressing these issues requires explicit specification of the prior competence needed for each activity and the performance expected upon completion. As students become proficient in basic operations, tasks should become more open-ended and require greater integration of knowledge. Later tasks should also draw on earlier outputs, allowing students to test and extend their learning in new problem contexts [3,7].

2.3. Insufficient Continuity of Guidance and Alignment with Industry Needs

Students undertaking open-ended practical work may encounter difficulties at any stage, including topic selection, solution development, testing and commissioning, and refinement of project outcomes. When guidance is concentrated around a small number of milestones, such as competition preparation or final assessment, problems may not be discussed promptly, and continuity of support across activities may be lost. Students also differ in their prior knowledge and practical experience, making uniform tasks and guidance schedules unsuitable for all learners. Educational planning must therefore address both access to essential practical training and individual development needs. Incorporating industry requirements into teaching also requires deliberate adaptation. Industrial problems are often constrained by schedules, equipment availability, and operational safety, and their complexity may exceed undergraduate students' preparation. Introducing such problems without instructional adaptation may prevent students from undertaking substantive work. Conversely, limiting engagement to site visits or demonstrations provides insufficient opportunities for problem analysis and solution validation. Reusing fixed project content over extended periods can further restrict students' understanding of changes in professional technologies and industrial applications. Sustained mentoring and university–industry communication should therefore focus on specific tasks. Academic staff and industry practitioners need to jointly identify work that students can reasonably undertake, divide engineering problems into clearly defined and assessable tasks with appropriate workloads, and adjust guidance in response to student progress.

2.4. Limited Comprehensiveness of Competence Assessment

Laboratory reports, project artifacts, and competition awards provide useful assessment information, but each captures only part of students' performance. Reports

document experimental procedures and results, yet direct observation may still be needed to establish whether students can complete tasks independently. Artifacts demonstrate final functionality but do not necessarily reveal how solutions were developed or problems were resolved. Competition results are also influenced by participation opportunities, team resources, and supervisory input. Consequently, no single type of output can fully represent innovative engineering practice competence. Identifying individual competence is particularly important in team projects. A shared artifact may involve solution design, programming, hardware commissioning, and documentation. Assessing only the collective output can conceal differences in individual contributions. Disconnected assessment criteria across practical activities can also make stage-specific grades poor indicators of continuing competence development, reducing their usefulness for instructional improvement. Assessment should consider both how students complete a task and the extent to which they meet its objectives. In addition to final acceptance testing, evidence should include design justifications, test records, progress presentations, and individual oral defenses. Such evidence allows problem analysis, design refinement, and collaboration to inform subsequent training and mentoring priorities.

3. Development of the Framework for Innovative Engineering Practice Competence in Electrical Engineering

3.1. Overall Framework Design

The proposed framework comprises five interconnected competence levels: understanding and applying engineering knowledge, designing and developing solutions, investigating complex engineering problems, integrated engineering application, and community engagement and application of project outcomes. Each level specifies practical learning objectives, task requirements, and expected outputs. These specifications guide the coordination of seven types of activity: course-based experiments, specialized practical training, course design projects, academic competitions, innovation and entrepreneurship projects, capstone projects, and internships. Stage-specific mentoring and university–industry collaboration provide organizational and resource support, while assessment feedback informs judgments about objective attainment and adjustments to educational arrangements. Practical content is selected according to the competence students are expected to develop. Objectives should describe work that students can perform rather than merely list courses or activities. As students acquire knowledge and experience, tasks progressively require broader integration and provide greater opportunities for choosing solutions and making independent decisions. Authentic industrial problems can establish meaningful needs and engineering constraints, helping students understand the conditions under which disciplinary methods are applicable [3]. Digital tools, intelligent control methods, and green design requirements should be incorporated where relevant to the task. Progression across the five levels primarily reflects an expansion in learning emphasis and problem scope; it does not imply that competencies are isolated or that each activity corresponds to only one level. A course design project may support solution development and, with additional experimental analysis, problem investigation. An internship may introduce engineering standards while also supporting application feedback and technical improvement. The competence level supported by a task should therefore be determined by its substantive requirements rather than its course title or placement within a particular academic year.

3.2. Development of Practical Learning Content Across Five Interconnected Levels

3.2.1. Understanding and Applying Engineering Knowledge

The first level helps students connect disciplinary principles with physical engineering systems. Experiments and introductory practical training associated with circuit analysis, electronics, electrical machines and drives, automatic control, and sensing and measurement should include circuit interpretation, instrument use, data acquisition, and analysis of results. Following verification of basic principles, tasks may introduce parameter adjustments, measurement error analysis, or simple fault identification,

requiring students to explain observations and assess the plausibility of their results. Standard operating practices and analytical habits should be developed together. Students need to record test conditions and raw data, compare theoretical calculations with measurements, and explain possible sources of discrepancies. Safe and standardized operation, verification of results, and technical communication thus become routine expectations that support subsequent independent design.

3.2.2. Designing and Developing Solutions

The second level requires students to propose and implement technical solutions that meet specified objectives. Course design projects and comprehensive practical training can provide functional requirements and relevant constraints while leaving students responsible for task decomposition, component selection, software development, and functional verification. Compared with introductory experiments with prescribed procedures, this level introduces more decisions that students must make independently. Students are expected to justify their choice of technical methods and provide evidence that allows their designs to be evaluated. Motor speed control, environmental monitoring, and equipment operation control are possible task areas. Projects should allow alternative implementation pathways so that students can compare functionality, cost, energy consumption, and implementation difficulty. During progress discussions, instructors should examine whether students have correctly interpreted the requirements, whether their proposed solutions are feasible, and whether the tests adequately support their design conclusions.

3.2.3. Investigating Complex Engineering Problems

The third level emphasizes in-depth investigation of key problems through open-ended tasks associated with innovation and entrepreneurship projects, research training, and academic competitions. Tasks should contain issues that require dedicated analysis, such as discrepancies between models and physical systems, interacting factors, or competing performance objectives. Students must review relevant literature, develop models, and design experiments to formulate and validate their approaches. Training focuses on problem definition, hypothesis formulation, experimental design, and interpretation of results. For example, a task concerning data stability in environmental monitoring may require students to investigate error sources under multiple disturbances and resource constraints, compare processing methods, and determine the range of conditions over which an improved solution remains applicable. Whether a task supports the investigation of complex engineering problems depends on its analytical depth, interacting constraints, and demands for knowledge integration. Routine calibration or parameter comparison does not satisfy this level merely because it forms part of a competition or innovation project.

3.2.4. Integrated Engineering Application

The fourth level extends practical work from individual problems to complete systems. Comprehensive practical activities, capstone projects, and suitable industrial projects can require students to integrate sensing, control, actuation, and communication modules. Students must address internal module functions as well as relationships among interfaces, operating logic, and fault handling, and determine whether the components collectively meet overall requirements. Implementation should begin with the decomposition of system objectives into technical specifications, followed by the selection of integration procedures and test plans. Students need to examine system operation under different conditions and analyze relationships among functionality, reliability, energy consumption, and maintenance requirements. Design documents, software, prototypes, and test reports should be consistent and collectively explain how the system was implemented, how its performance was verified, and which issues remain unresolved.

3.2.5. Community Engagement and Application of Project Outcomes

The fifth level focuses on the fit between technical outcomes and user needs. Internships, application-oriented activities, and technical service projects can provide

opportunities to engage with users and operational settings. Under the guidance of academic staff or industry practitioners, students examine operating practices, environmental conditions, and maintenance requirements, determine whether their designs are suitable for actual use, and propose adjustments based on feedback. Field testing, user interviews, assessments of application conditions, and the preparation of operating instructions can all serve as practical activities at this level. Commercialization is not a prerequisite. Instead, assessment should establish whether students understand the limitations of technical applications and can make reasonable judgments that account for safety, cost, and available resources. This level extends learning into application contexts and professional responsibility, while awareness of these issues should also inform earlier design and investigation activities.

3.3. Development of Stage-Specific Mentoring

Sustained guidance requires clearly assigned responsibilities and defined forms of participation. The proposed scheme uses student groups as the basic organizational unit, with academic mentors monitoring learning and project progress and planning guidance according to students' preparation, interests, and current tasks [8]. Additional academic specialists and industry practitioners may participate when projects involve particular technical areas or industrial applications. Routine guidance, milestone reviews, and feedback on outcomes should be connected rather than concentrated at final assessment. The emphasis of mentoring varies by stage. During foundational training, mentors help students develop an understanding of the discipline, establish standard working practices, and identify areas of practical interest. Short tasks can reveal students' learning characteristics. During design and investigation, discussions focus on topic justification, comparison of solutions, and experimental results, with students regularly reporting progress and difficulties. The integrated application stage introduces greater attention to engineering conditions, system testing, and user feedback, with academic and industry mentors contributing according to their expertise. The level of guidance should change as students become more autonomous. Students with limited preparation may need task decomposition and demonstrations. As their competence develops, they should be given broader choices and greater responsibility for justification and validation. Mentors can support judgment by questioning assumptions and discussing alternatives while preserving opportunities for independent analysis and correction of errors. Role rotation within groups can also broaden exposure to technical tasks and reduce uneven competence development arising from fixed assignments.

3.4. Development of University–Industry Collaboration and Project Continuity

University–industry collaboration should center on engineering problems that can be adapted for teaching. In regional agricultural universities, agricultural environmental monitoring, electrical equipment control, and renewable energy utilization can provide relevant project areas [9]. Academic staff and industry practitioners should jointly assess the educational value of candidate problems, considering their links to course knowledge, the workload students can undertake, available equipment, and safety requirements. These considerations define the scope of participation and expected outputs. Before industrial problems are introduced into teaching, they require instructional adaptation. Instructors should identify needs suitable for student investigation, divide system-level work into related subtasks, and specify their difficulty and acceptance criteria. Where field implementation is not feasible, simulation, laboratory platforms, or historical data may be used. However, the issues that these approaches can validate and their differences from actual operating conditions should be made explicit. An agricultural environmental monitoring and control system illustrates how tasks may be connected. Foundational training may cover sensor calibration and signal acquisition, followed by the design of monitoring terminals and actuation modules. Students can then investigate selected measurement, communication, or control problems before undertaking system integration and testing. Where conditions permit, field validation or an assessment of application suitability can follow. The stages share a common engineering context, with

data, software, and design records maintained for reuse and revision. Project continuity should not result in repeated submission of the same output. Course design projects, innovation and entrepreneurship projects, and capstone projects should each specify new problems and additional work, ensuring that every extension involves identifiable technical content and competence objectives. Industry feedback can help evaluate existing outputs and update project requirements, maintaining links between practical learning and real-world applications.

4. Implementation Pathways and Assessment Mechanisms

4.1. Staged Implementation of Practical Tasks

For instructional organization, the five competence levels can be implemented through three stages: foundational training, design and investigation, and integrated application. Foundational training primarily supports understanding and applying engineering knowledge. Design and investigation address solution development and the investigation of complex engineering problems. Integrated application emphasizes system implementation, community engagement, and the application of project outcomes. The three stages organize tasks and resources, whereas the five levels describe competence objectives. Their alignment should reflect course prerequisites and student readiness rather than rigid assignments to academic years. Before implementation, existing practical content should be reviewed to identify the knowledge required, intended competencies, and acceptance criteria for each task. Repeated training and insufficiently supported objectives can then be identified, providing a basis for a project task repository. Each project should specify its background, technical conditions, workload, and expected interim outputs, together with suitable extension options. Data acquisition, modeling and simulation, and control programming should be selected according to project needs, while energy efficiency, safety, and cost should inform solution comparisons and test requirements. Task specifications and progress records can support process management. Students submit needs analyses and role assignments at the outset, report design and testing progress at key milestones, and consolidate outputs and unresolved issues at completion. Instructors use this information to plan discussions and support, while laboratory access and equipment booking should accommodate task schedules. Projects extending across courses also require checks on the completeness and usability of existing materials and clear specification of additional work to prevent missing records or duplicated objectives from disrupting continuity.

4.2. Multidimensional Assessment Combining Process and Outcomes

The assessment framework comprises five dimensions: knowledge application and problem analysis, solution design and innovative improvement, practical operation and system implementation, teamwork and individual contribution, and engineering standards and application value. Knowledge application is assessed using needs analyses, explanations of models, and discussions of data to determine whether students understand the task and its key problems. Solution design emphasizes the justification for comparing alternatives and the validation of improvements. Practical operation is assessed through observed performance, commissioning records, and test results, with attention to working practices and functional attainment. Teamwork assessment requires evidence of assigned responsibilities and actual contributions. Engineering standards and application value concern the reasonable treatment of safety, energy efficiency, cost, and user needs. The same framework applies across the competence levels, with specific criteria and emphases adjusted accordingly. Process assessment should retain evidence of how solutions evolve. Students need to explain the basis of key decisions and document testing problems and their resolution, allowing assessors to determine whether independent analysis and effective revision have occurred. Outcome assessment examines functionality, performance, and technical documentation against task objectives; substantial process effort does not in itself justify lowering expectations for final results. When a project fails to meet its targets, outcome attainment and learning performance

should be assessed separately, acknowledging technical limitations while using documented evidence to evaluate analysis, experimentation, and reflection. Assessment is coordinated by academic staff and incorporates input from industry practitioners, student self-assessment, and peer assessment as appropriate [10]. Academic staff primarily evaluate knowledge application, investigative methods, and competence attainment. Industry practitioners focus on engineering feasibility and alignment with needs, while student assessment adds information about task fulfillment and collaboration within the team. All judgments should be supported by evidence. Team-level scores should be supplemented by individual records and oral defenses to distinguish contributions, and substantial disagreements can be reviewed through further questioning or examination of documentation. Assessment weights and criteria should be disclosed before tasks begin. Foundational training emphasizes conceptual understanding, standard operating practices, and analysis of results; design and investigation place greater weight on solution justification and innovative improvement; integrated application focuses on overall performance and engineering constraints. Competition awards, publications, and patents may provide supplementary evidence, but their relevance to the task and the student's contribution must be verified, and they should not replace other forms of assessment.

4.3. Assessment Feedback and Continuous Improvement

Assessment should lead to explicit decisions about subsequent learning. Mentors can use performance across the assessment dimensions to recommend specific training. For example, students who are proficient in module development but less capable in systems analysis may need additional interface checking and integrated commissioning tasks. Those with well-developed design ideas but insufficient supporting evidence may require further training in experimental design and data analysis. Feedback should therefore influence later tasks rather than consist only of scores or general comments. Program-level improvement requires evidence from multiple practical activities. Periodic reviews of objective attainment, recurring difficulties, and industry feedback can identify issues that are not apparent within a single project. When similar weaknesses recur, prerequisites, task design, mentoring input, and equipment conditions should be examined before changes are determined [3]. New industry requirements should also be assessed for educational suitability. Content aligned with undergraduate objectives and feasible under available conditions can be incorporated into the task repository, with its effects reviewed during subsequent teaching. The framework requires continuing evaluation, potentially using evidence on prior preparation, task participation, and outcome quality from different classes or successive cohorts. Assessment criteria should be kept as consistent as possible, supported by shared scoring exemplars and cross-checking among instructors. Comparisons between groups should account for prior competence, project difficulty, and mentoring conditions rather than attributing all changes in performance to the educational framework. Competence assessment, project evidence, and student feedback should be considered together to support informed revision.

5. Conclusions

This study proposes a five-level framework for developing innovative engineering practice competence in electrical engineering, informed by the requirements of new quality productive forces and the educational objectives of regional agricultural universities. Practical tasks are organized around knowledge application, solution development, problem investigation, integrated engineering application, and community engagement and application of project outcomes, with explicit links between competence objectives and assessment evidence. Stage-specific mentoring and university–industry collaboration support implementation, while multidimensional assessment combining process performance and outcome quality informs competence evaluation and instructional feedback. Requirements related to digitalization, intelligent technologies, and green development are incorporated into project content, design constraints, and

acceptance criteria. The study establishes a proposed educational framework and associated implementation mechanisms; evidence from teaching practice is still needed to determine its effectiveness. Subsequent work should examine the appropriateness of task levels and assessment criteria using student development data and application feedback, while refining the resources required for implementation.

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