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DEVELOPING TECHNOLOGICAL DECISION-MAKING COMPETENCE OF FUTURE ENERGY ENGINEERS THROUGH CDIO AND PROJECT-BASED LEARNING

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Abstract

The article examines the didactic potential of integrating the CDIO approach and project-based learning to develop technological decision-making competence among future energy engineers. In the context of digital transformation, engineering graduates are expected not only to reproduce technical knowledge but also to identify professional problems, design safe and energy-efficient solutions, build digital models, validate prototypes and justify decisions through measurable evidence. The study is conceptual and methodological in nature; it is based on systemic, competence-based, activity-oriented and digital-didactic approaches. The proposed model connects the stages of Conceive, Design, Implement and Operate with energy engineering tasks such as energy audit, electrical supply design, renewable energy system modelling, safety analysis and operational monitoring. The article also proposes assessment indicators for technological decision-making, including problem formulation, engineering calculation, digital modelling, prototype validation, teamwork and reflective justification. The findings show that the CDIO-PBL integration can transform project activity from a creative assignment into a structured engineering methodology for evidence-based technological decision-making. The study contributes to the modernization of energy engineering education by offering a competence-oriented mechanism, an assessment rubric and practical recommendations for integrating virtual laboratories, digital twins, e-portfolios and learning analytics into the curriculum.

Keywords: CDIO; project-based learning; technological decision-making; energy engineering education; digital modelling; engineering thinking; competence-based assessment.

1. Introduction

The modernization of engineering education is closely connected with digital transformation, energy security and the need for graduates who can make technologically justified decisions in complex professional situations. Energy engineering programmes increasingly require students to work with dynamic systems, safety constraints, energy-efficiency indicators, automated control, renewable sources and digital monitoring tools. In this context, the central educational outcome is not the mechanical reproduction of theoretical knowledge but the ability to analyse an engineering problem, model a solution, implement a technically sound prototype and evaluate its operational consequences.

In Uzbekistan, the strategic development of higher education, digital transformation and technological modernization has strengthened the relevance of competence-based engineering education. For energy engineering students, this means that the educational process should integrate fundamental scientific knowledge with project activity, digital tools and industry-oriented assessment. The challenge is to organize learning so that students gradually move from separate disciplinary knowledge to integrated technological reasoning and evidence-based decision-making.

The CDIO approach offers a productive framework for this task because it links education to the life cycle of engineering products and systems: Conceive, Design, Implement and Operate (Crawley et al., 2014). Project-based learning, in turn, creates conditions for students to transform theoretical knowledge into practical solutions, collaborate in teams, test alternatives and defend the selected decision. When these two approaches are systematically integrated, project activity becomes not only a form of active learning but also a methodology for developing technological decision-making competence.

The purpose of this article is to develop and justify a methodological mechanism for forming technological decision-making competence among future energy engineers through the integration of CDIO and project-based learning. The novelty of the article lies in interpreting project work as a structured engineering decision-making process supported by digital modelling, competence indicators and reflective assessment.

2. Literature Review and Theoretical Background

International studies on engineering education emphasize that effective professional preparation requires integration of disciplinary knowledge, design thinking, teamwork, communication, ethical responsibility and system operation. The CDIO framework was introduced as a response to the fragmentation of engineering curricula and remains one of the most applicable models for connecting academic learning with real engineering practice (Crawley et al., 2014). In energy engineering education, CDIO is especially relevant because it naturally corresponds to the sequence of diagnosing an energy problem, designing a technical system, implementing a model or prototype and evaluating operational efficiency.

Project-based learning is widely recognized as a pedagogical strategy that develops problem-solving, collaboration, autonomy and professional reasoning. In engineering education, its value increases when the project is not limited to a presentation or final product but includes specification of requirements, selection of alternatives, calculation, modelling, risk analysis, testing and reflection. Therefore, the CDIO-PBL combination provides a coherent structure for competence formation: CDIO defines the engineering logic of the process, while project-based learning activates student participation and responsibility.

Digital transformation has expanded the methodological possibilities of engineering education. Virtual laboratories, simulation environments, digital twins, learning management systems and analytics platforms allow students to observe processes that are difficult, expensive or risky to reproduce in a traditional classroom. The TPACK framework stresses the need to connect technology, pedagogy and content knowledge rather than using digital tools as isolated instruments (Mishra & Koehler, 2006). Learning analytics also contributes to the monitoring of student progress and timely feedback (Siemens & Long, 2011).

The author’s previous research provides an important foundation for the present study. Ismoilov (2020) demonstrated the importance of scientific cognition methods and research-based content in physics education. Tursunov and Ismoilov (2016) analysed the essence and role of models in learning physics, which is directly related to digital modelling in engineering education. Ismoilov (2021) examined the management of students’ learning processes in a methodological system and highlighted the role of professional activity, design and research tasks. More recent works by Ismoilov (2026a, 2026b) focus on methodological modelling, artificial intelligence, PhET simulations, formative assessment and learning analytics. These studies support the idea that engineering competence is formed when scientific cognition, modelling, software tools and assessment are organized as a unified didactic system.

Despite the existence of extensive research on CDIO, project-based learning and digital education, the issue of technological decision-making competence in energy engineering remains insufficiently systematized. In particular, there is a need to connect energy-related professional situations, digital modelling, safety criteria, prototype validation and competence-based assessment into a single pedagogical mechanism.

3. Research Methodology

The research is conceptual and methodological. It is based on systemic, competence-based, activity-oriented, integrative and digital-didactic approaches. The systemic approach makes it possible to consider technological competence as an integrated result of goals, content, methods, tools, assessment and outcomes. The competence-based approach shifts the focus from the amount of knowledge acquired to the student's ability to solve a professional task in a justified, safe and efficient way. The activity-oriented approach interprets competence as a product of purposeful student action in professional and quasi-professional situations.

The methodological procedures included content analysis of engineering education literature, comparative analysis of CDIO and project-based learning, pedagogical modelling, design of competence indicators, expert interpretation of energy engineering tasks and construction of a rubric-based assessment matrix. The content of energy engineering education was analysed through the following professional contexts: electrical supply systems, renewable energy systems, heat-energy processes, automation, energy audit, operational diagnostics and safety management.

Technological decision-making competence was operationalized through six indicators: (1) formulation of an energy-related problem; (2) engineering calculation and selection of parameters; (3) construction and interpretation of a digital model; (4) implementation and validation of a prototype or simulation; (5) teamwork and communication of technical decisions; and (6) reflective evaluation of risks, limitations and improvement strategies. These indicators were connected with CDIO stages and project tasks. The visual profile presented in the article is illustrative and rubric-based; it is intended to demonstrate the logic of assessment and should be tested through a full pedagogical experiment in future research.

4. Results and Discussion

The integration of CDIO and project-based learning creates a gradual pathway for developing technological decision-making competence. At the Conceive stage, students learn to identify an energy-related problem, analyse user needs, formulate technical requirements and define constraints. At the Design stage, they develop schemes, parameters, algorithms, safety requirements and alternative solutions. At the Implement stage, students construct a digital model, simulation, mini-stand or prototype and perform calculations. At the Operate stage, they test the solution, analyse reliability, evaluate efficiency and formulate improvement recommendations.

This sequence changes the role of the student from a passive receiver of information to an active participant in engineering activity. The student does not simply solve a ready-made problem; instead, he or she defines the problem, justifies the method, compares alternatives, validates the result and defends the decision. This is essential for energy engineering, where a technically correct decision must also be safe, economically reasonable, environmentally responsible and operationally sustainable.

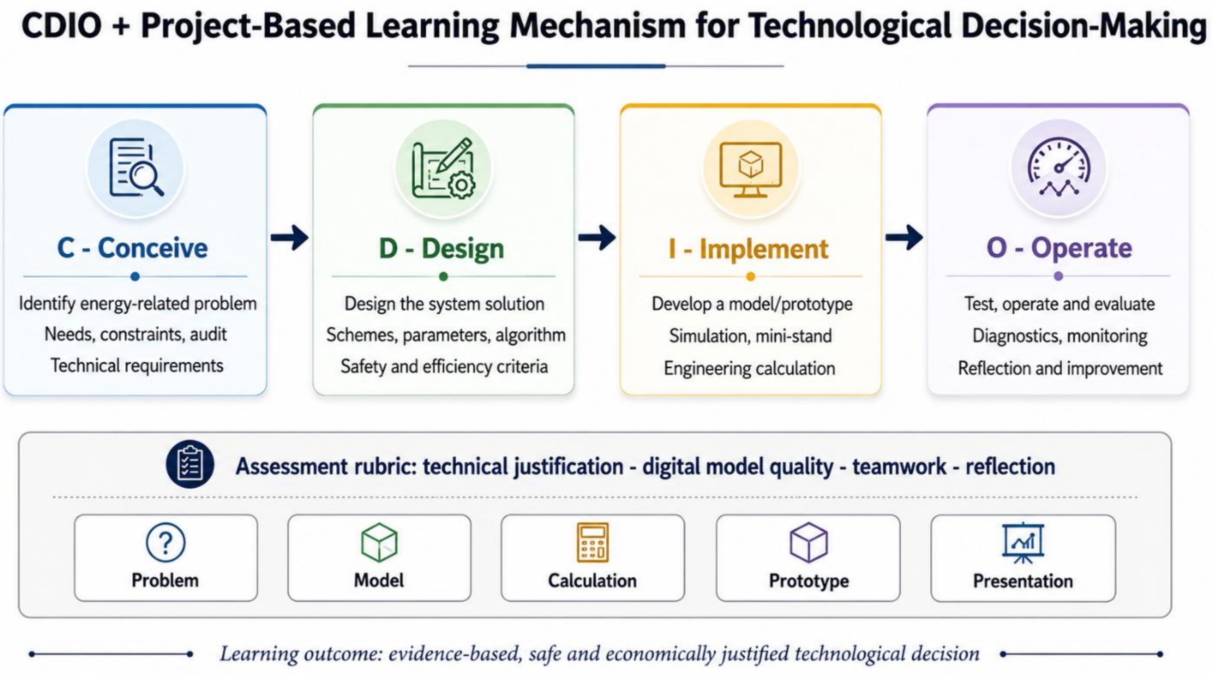


Figure 1. CDIO-PBL mechanism for developing technological decision-making competence in energy engineering education.

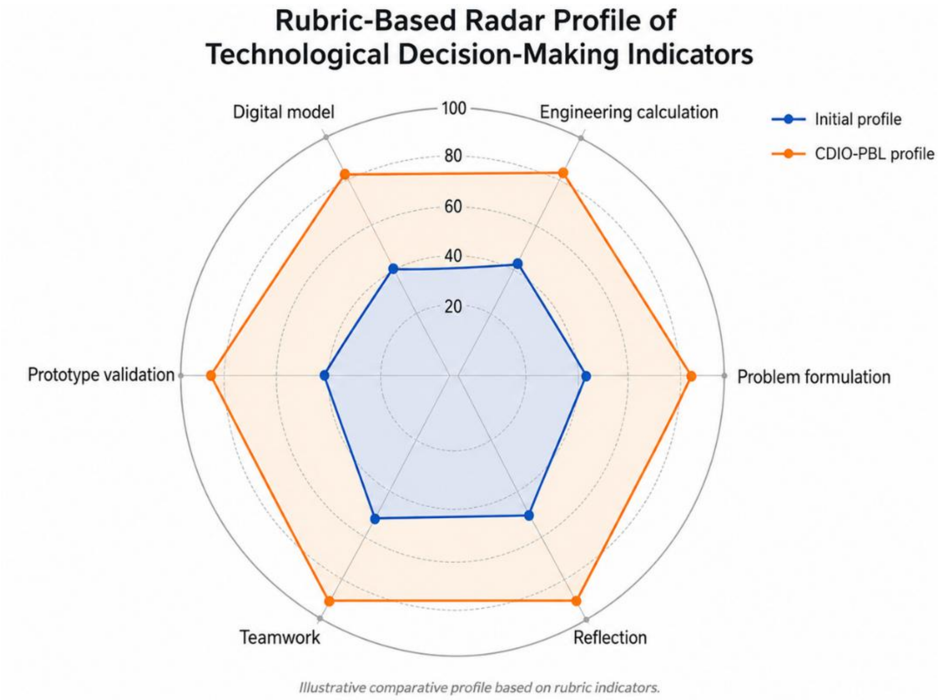
Table 1 presents the relationship between CDIO stages, energy engineering learning activities and assessment indicators. The table shows that each stage should be evaluated not only by the final answer but also by the quality of reasoning, modelling, justification and reflection.

Table 1. CDIO stages, student activity and assessment indicators.

CDIO stage	Learning and professional activity	Assessment indicator
Conceive	Identifying an energy problem; defining needs, constraints and technical requirements	Accuracy of problem formulation and technical justification
Design	Developing schemes, parameters, algorithms and safety requirements	Correctness of calculation and consistency of the digital model
Implement	Creating a simulation, mini-prototype or practical project product	Functionality, efficiency, economic reasonableness and reliability
Operate	Testing, monitoring, diagnosing, reflecting and improving the solution	Quality of result analysis, risk evaluation and decision defence

A second result of the study is the structure of technological decision-making competence. It includes five interrelated components. The motivational-value component reflects the student’s professional interest, responsibility and orientation toward safety and energy efficiency. The cognitive component includes knowledge of physical laws, energy processes, system parameters and digital modelling principles. The operational-technological component concerns calculations, modelling, prototyping and testing. The communicative-collaborative component reflects teamwork, documentation and presentation of decisions. The reflective-analytical component includes error analysis, comparison of alternatives, evaluation of risks and formulation of improvement strategies.

The illustrative rubric-based profile in Figure 2 shows how CDIO-PBL activities may increase the quality of technological decision-making indicators when compared with a traditional initial profile. The profile is not presented as final experimental evidence; rather, it is a methodological visualization of expected competence growth that should be verified through future empirical research.



Rubric-Based Radar Profile of Technological Decision-Making Indicators

Illustrative comparative profile based on rubric indicators.

Figure 2. Illustrative rubric-based profile of technological decision-making indicators.

5. Assessment Rubric for CDIO-PBL Projects. For practical implementation, assessment should be based on transparent criteria. Table 2 proposes a three-level rubric that can be adapted for energy engineering courses, virtual laboratories, digital-twin tasks and project defence.

Table 2. Rubric for assessing technological decision-making competence in CDIO-PBL projects.

Criterion	Low level	Medium level	High level
Problem formulation	The problem is described generally; constraints are unclear.	The problem and main constraints are identified but not fully justified.	The problem, needs, constraints and criteria are formulated precisely and professionally.
Engineering calculation	Calculations are fragmented or contain serious errors.	Basic calculations are correct but alternatives are weakly compared.	Calculations are accurate, justified and used to compare alternatives.
Digital model	The model is incomplete or poorly connected with the real process.	The model reflects the main parameters but requires additional validation.	The model is coherent, interpretable and validated through data or simulation results.
Prototype or simulation	The product is mostly demonstrative and lacks testing.	The product functions but testing and reliability analysis are limited.	The product is tested, improved and evaluated according to technical indicators.
Decision defence	The decision is presented descriptively without evidence.	The decision is explained with partial evidence and reflection.	The decision is defended with evidence, risk analysis and improvement strategy.

6. Practical Recommendations. First, energy engineering courses should include a bank of professional situations related to electricity supply, energy audit, renewable energy, automation, safety and operational diagnostics. Each situation should require students to pass through the CDIO cycle and produce evidence: a problem statement, calculation, model, prototype or simulation, and reflective report.

Second, digital tools should be selected according to didactic purpose. Simulation platforms, PhET-based demonstrations, MATLAB/Simulink, AutoCAD Electrical, ETAP-like modelling environments, spreadsheets, LMS tools and e-portfolios should not be used as separate technologies; they should support a clear decision-making task. This corresponds to the TPACK idea that content, pedagogy and technology must be integrated rather than mechanically combined.

Third, assessment should move from a final mark to a formative and analytical system. Learning analytics, rubric-based peer review, teacher feedback and e-portfolio evidence can help identify individual growth trajectories. Such monitoring is particularly important for students who need support in calculation, modelling, communication or reflection.

7. Conclusion

The development of technological decision-making competence among future energy engineers requires an integrated educational system that combines professional content, digital tools, project tasks and competence-based assessment. The CDIO approach provides the engineering logic of the learning process, while project-based learning creates conditions for active student participation, collaboration and responsibility for the final technical decision.

The proposed CDIO-PBL mechanism shows that technological competence is formed through a sequence of actions: identifying an energy problem, designing a solution, implementing a model or prototype, testing the result and reflecting on improvement. In this system, digital technologies are not merely illustrative tools; they become instruments for modelling, diagnosing, validating and justifying engineering decisions.

For future research, the proposed mechanism should be tested through a pedagogical experiment with control and experimental groups. Statistical analysis of student outcomes, normalized gain indicators, expert evaluation and learning analytics data would make it possible to determine the real effectiveness of the model in energy engineering education.

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