

Exploration and Practice of OBE-enabled Teaching Reform: A Case Study of Robot Innovation Design Practice Course

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Abstract: The rapid development of intelligent manufacturing, artificial intelligence, and robotics has generated an urgent need for innovative engineers with interdisciplinary expertise. However, practical courses frequently suffer from insufficient alignment between learning objectives and industry requirements, a disconnect between instructional content and industrial practice, and limited diversity in teaching and assessment. Guided by outcome-based education (OBE), this study explores teaching reform in the robot innovation design practice course. First, intended learning outcomes are specified in relation to program educational objectives and enterprise needs, and explicit mappings are established between course objectives and industry competency requirements. Then, instructional content is reorganized around an engineering workflow comprising requirements analysis, conceptual design, system implementation, and presentation of project outcomes, resulting in a practical teaching framework driven by project tasks. Next, project-based learning, task-oriented instruction, teamwork, and ongoing guidance are integrated to strengthen student agency and encourage self-directed learning and collaborative innovation. Finally, a multidimensional assessment framework evaluates disciplinary knowledge, engineering practice, innovative design, teamwork, and communication of project outcomes, enabling learning to be monitored and assessed throughout the course. Teaching practice indicates that the OBE-based reform was associated with improvements in students' practical engineering skills, innovative design capabilities, and teamwork, together with a shift in emphasis from knowledge transmission toward competency development and learning outcome attainment. These findings may provide a reference for reforming robotics courses and comparable practical engineering courses.

1. Introduction

With rapid advances in artificial intelligence and intelligent manufacturing, robotics is evolving

toward greater intelligence, flexibility, and system integration, with applications across industrial production, medical rehabilitation, logistics and transportation, and public services, making it an important technological enabler of industrial upgrading and new quality productive forces. The rapid growth of the robotics industry raised higher demands for engineering talent and challenged conventional approaches to engineering education. To address complex engineering tasks, contemporary engineers need not only a sound disciplinary foundation but also the ability to integrate interdisciplinary knowledge, analyze and solve complex engineering problems, design and implement systems, innovate, collaborate, and continue learning. Translating industry needs into course objectives and integrating the development of knowledge, skills, and professional attributes through practical teaching have therefore become important priorities for teaching reform under the Emerging Engineering Education (EEE) initiative.

The robot innovation design practice (RIDP) is an important practical course for robotics and related engineering programs. Its integrative, practical, and innovative character makes it a key component of education in robotic system design, development, and innovation. The course draws on mechanical design, sensing technologies, actuation and control, embedded systems, software development, and system integration, reflecting the interdisciplinary nature of robotics education. Students synthesize knowledge acquired in multiple courses and complete an engineering workflow covering requirements analysis, conceptual design, system implementation, testing and optimization, and presentation of outcomes to develop robotic systems that combine functionality with innovation. The RIDP course thus supports both the integrated application of disciplinary knowledge and the development of practical engineering skills, innovative design competence, teamwork, and complex problem-solving capabilities.

However, the conventional RIDP course remains insufficiently aligned with industrial development and EEE requirements, limiting its capacity to prepare innovative engineers with interdisciplinary expertise. First, course objectives are largely oriented toward theoretical knowledge acquisition and standardized experiment completion, while their contribution to program educational objectives and graduation requirements remains unclear. Second, instructional content is typically divided into relatively independent modules, resulting in fragmented knowledge structure, which constrains the development of systems thinking and complex problem-solving abilities. Third, teaching remains predominantly instructor-centered, relying on lectures, demonstrations, and prescribed tasks, thereby limiting students' active engagement in design, problem solving, self-directed learning, and collaborative innovation. Finally, assessment relies mainly on laboratory reports, completed products, and final grades, with insufficient consideration of learning processes and competency development.

Outcome-based education (OBE) centers on learning outcome attainment and employs backward design to align course objectives, content, activities, and assessment with program educational objectives, while using assessment evidence to support continuous improvement. Its emphasis on student-centeredness, outcome orientation, and continuous improvement aligns with the shift from knowledge transmission to competency development in EEE. For integrative, project-based engineering courses, OBE translates industry needs and program objectives into explicit, observable, and assessable learning outcomes, offering a theoretical basis for systematic curriculum redesign. As engineering program accreditation has advanced, OBE has increasingly informed university education and course reform, although practical courses still require further exploration of how to translate industry needs into course learning outcomes and align these outcomes with project tasks, learning activities, and assessment.

This study uses RIDP course as a setting for teaching reform guided by OBE, addressing the requirements of EEE and the core competencies needed in robotics occupations. The reform encompasses course objectives, instructional content, teaching approaches, and assessment. By

establishing a teaching framework organized around learning outcomes, it redirects attention from knowledge delivery and task completion to competency development and outcome attainment. It seeks to strengthen students' abilities in complex engineering problem solving, innovative robot design, and teamwork, providing a reference for improving robotics education and related practical engineering courses.

2. Theoretical Background

2.1. Foundations of Outcome-enabled Education

OBE is an educational philosophy centered on student learning outcomes, shifting emphasis from what teachers teach to what students can do after learning. Grounded in program educational objectives and graduation requirements, it specifies intended course learning outcomes that guide the backward design of course objectives, content, activities, and assessment. This alignment connects knowledge acquisition, competency development, and outcome attainment within an integrated framework supported by ongoing feedback. Its central principles can be summarized as student-centeredness, outcome orientation, and continuous improvement, providing a theoretical foundation for engineering education reform under the EEE initiative.

2.2. Characteristics of the RIDP Course

The RIDP course is a core, interdisciplinary, project-based practical course in robotics engineering. It integrates mechanical design, electrical control, software development, and system integration. The course focuses on innovative design, complex engineering problem solving, and teamwork, aligning with the robotics industry's demand for highly capable engineers with interdisciplinary expertise. The practical and integrative nature of the course is well suited to OBE. Using backward design, intended learning outcomes can be defined in relation to graduation requirements and industry competencies and then used to coordinate course objectives, project tasks, and classroom activities. This approach supports a transition from the passive completion of standardized experiments to the active solution of authentic, complex engineering problems.

3. OBE-enabled Course Framework Designing

3.1. OBE-based Course Objectives Redefining

Guided by the OBE principles of outcome orientation and backward design, this study redefines the intended learning outcomes in line with robotics engineering program objectives, engineering education requirements, and core occupational competencies, as shown in Figure 1.

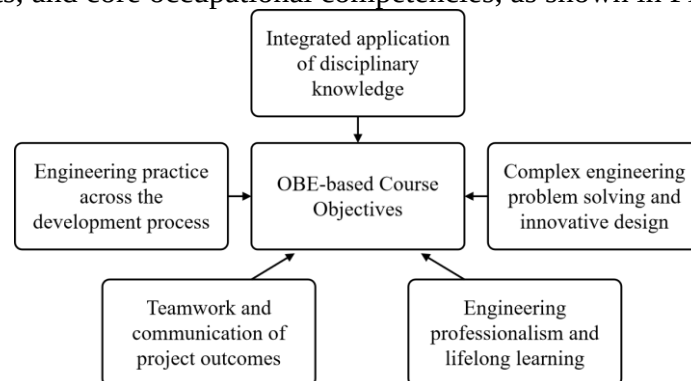


Figure 1: Illustration of OBE-based Course Objectives.

(1) Integrated application of disciplinary knowledge. Students could master foundational knowledge in mechanical design, electronics, sensing and measurement, control principles, and software development. They could analyze the requirements of robotic systems, decompose system functions, develop overall architectures, and design key functional modules.

(2) Engineering practice across the development process. Students could design and implement robotic systems according to project tasks and engineering requirements, completing conceptual design, hardware construction, and software development. They could master basic engineering methods for system debugging, performance testing, and parameter optimization.

(3) Complex engineering problem solving and innovative designing. Students could identify complex problems arising during robot design, development, and debugging, analyze their causes in practical contexts, and propose viable solutions. Through technical justification and experimental testing, they could refine system designs, developing capabilities in complex problem solving and engineering innovation.

(4) Teamwork and communication of project outcomes. Students could demonstrate coordination and appropriate division of responsibilities, and effective communication to jointly complete project tasks and resolve development problems. They could clearly explain design concepts, implementation plans, and project outcomes through technical reports, demonstrations, and oral project defenses.

(5) Engineering professionalism and lifelong learning. Students could understand advances in robotics, intelligent manufacturing, and intelligent control to meet project needs. They could apply this learning in practice, demonstrate awareness of safety and engineering standards, and develop self-directed learning capabilities needed to adapt to technological change and occupational demands.

3.2. Projects-driven Instructional Content Reorganizing

In accordance with course objectives and the robotic system development workflow, instructional content is reorganized into five interconnected stages, as shown in Figure 2. These stages form a complete project sequence covering requirements analysis, conceptual design, system implementation, debugging and optimization, and outcome presentation.

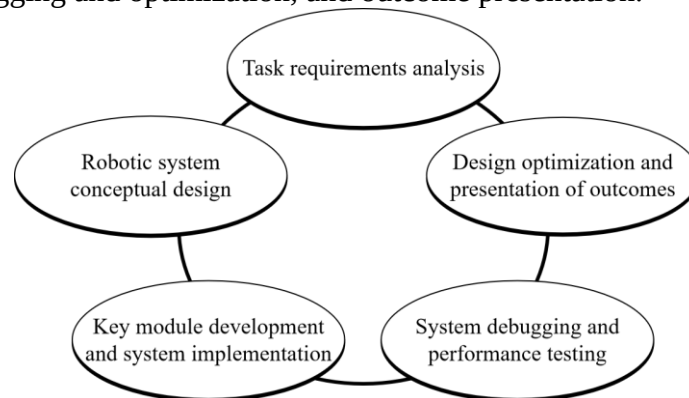


Figure 2: Projects-driven Instructional Content.

(1) Task requirements analysis. Teachers design projects from practical scenarios, such as intelligent material-handling robots, inspection robots, service robots, and robots for specialized operations. Students analyze engineering problems, specifying task objectives, operating requirements, and functional constraints, and define system functions and performance specification. This stage connects mechanical, electronic, control, and software knowledge with engineering problems, developing integrated knowledge application and awareness of engineering requirements.

(2) Robotic system conceptual designing. Based on the requirements, students develop an overall design covering structural configuration, actuation, sensing, and control architecture. They compare alternative solutions on functional requirements, technical feasibility, cost, reliability, and originality, then select an implementation plan, thereby promoting interdisciplinary knowledge application, system design, decision-making, and innovation awareness.

(3) Key module development and system implementation. Students design, fabricate, and integrate key modules based on the selected design. Teachers provide stage-specific guidance according to project progress and student needs, using questions, technical advice, and feedback to help students resolve practical problems without supplying complete solutions. This stage emphasizes self-directed learning and teamwork while translating course objectives from conceptual understanding into engineering application.

(4) System debugging and performance testing. Students debug and test robotic systems against project requirements, examining response speed, obstacle avoidance, and task efficiency. They diagnose anomalies through experimental analysis, data comparison, and troubleshooting, and propose targeted improvements. Through iterative cycles of testing, analysis, improvement, and retesting, students apply engineering methods to complex design problems, problem-solving, and iterative optimization.

(5) Design optimization and presentation of outcomes. Based on testing results, students refine robot structures, control parameters, and software algorithms to improve functionality and performance. Project outcomes are presented through technical reports, physical demonstrations, and oral defenses, in which students articulate project requirements, technical approaches, implementation processes, innovations, and test results, and respond to questions. This stage assesses project outcomes and course objective attainment while strengthening technical communication.

3.3. Multiple-integrated Teaching Approaches Innovating

The course applies the OBE principles of student-centeredness and outcome orientation to establish an integrated approach combining project-based learning, progressively demanding tasks, teamwork, and redefined teacher and student roles, as shown in Figure 3. It shifts the organizing focus from teacher-led delivery toward student learning outcome attainment and aligns teaching with the interdisciplinary competencies required by EEE.

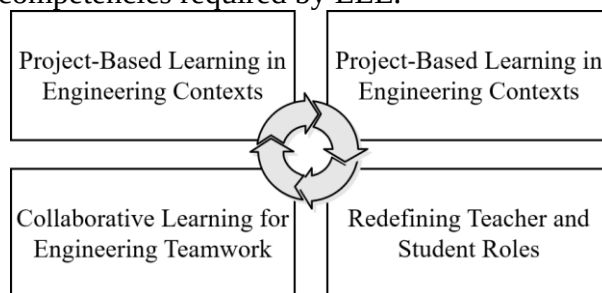


Figure 3: Multiple-integrated Teaching Approaches.

(1) Project-Based Learning in Engineering Contexts. The course integrates theoretical modules into robot design projects, using projects to organize learning and tasks to translate objectives into action. Rather than teaching topics in isolation, the course centers on integrated design projects (e.g., autonomous obstacle-avoiding mobile robots and intelligent sorting systems), in which students independently conduct requirements analysis, mechanical design, motion-control programming, and path-planning debugging. Working toward project outcomes, they identify knowledge gaps and learn the required content, thereby addressing fragmentation, passive

participation, and difficulties in translating knowledge into capability.

(2) Progressively Demanding Tasks for Diverse Learning Needs. To accommodate individual differences, the course establishes three progressively task levels. Foundational tasks develop core skills such as motor-drive debugging and basic Robot Operating System (ROS) programming. Integrated tasks combine mechanical design, simultaneous localization and mapping (SLAM), and autonomous navigation to support the design, construction, and debugging of complete robotic systems, as shown in Figure 4. Innovative tasks engage students with emerging technologies encouraging functional extension, algorithm improvement, and adaptation to new scenarios. These three levels accommodate diverse developmental needs and support progression from basic operations through integrated design to innovative development.

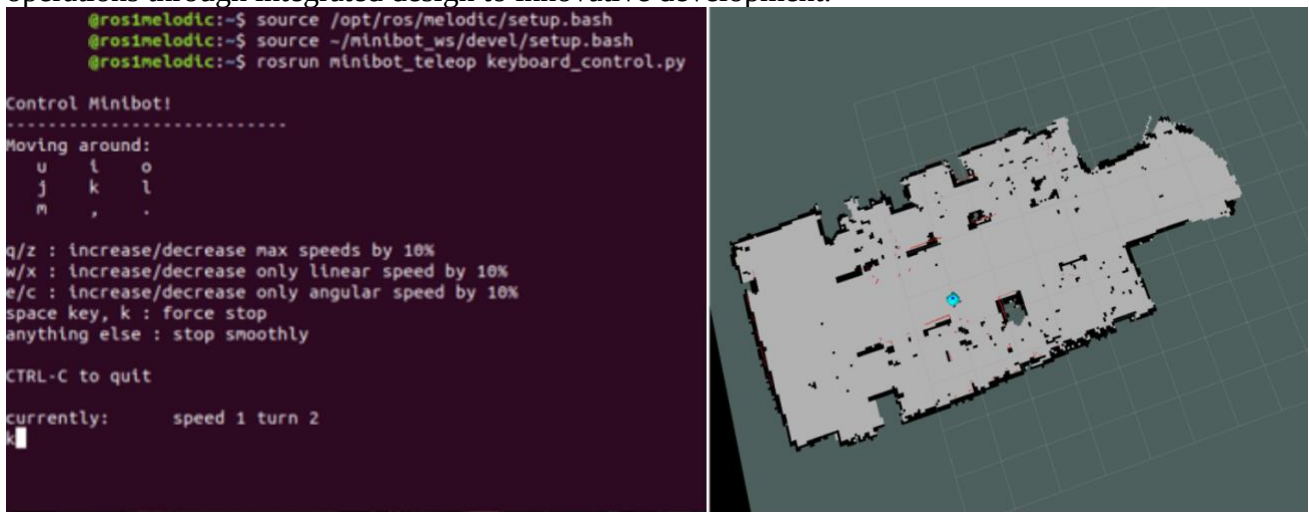


Figure 4: Tasks of ROS Programming and SLAM.

(3) Collaborative Learning for Engineering Teamwork. The course adopts collaborative group learning informed by industrial project management practices. Teams assign responsibilities for conceptual design, hardware construction, software implementation, and system testing and optimization according to project requirements. To address free-riding, limited individual participation, and uneven contributions, the course combines individual task logs, interim progress presentations, and assessment of separate deliverables, using project records, milestone reviews, and individual oral defenses to track each student's performance and contribution. These measures support project delivery while developing teamwork, communication, coordination, and project management capabilities relevant to industrial practice.

(4) Redefining Teacher and Student Roles. The course redefines teachers from knowledge transmitters to designers of learning activities, facilitators of learning, supporters of project work, and monitors of outcome attainment. Their responsibilities include designing authentic projects and differentiated tasks aligned with industry needs and course objectives; translating intended outcomes into stage-specific objectives and competency criteria; providing technical guidance, resources, and feedback to address engineering challenges; and monitoring progress through milestone reviews, discussions, and reflection while adjusting strategies based on outcome evidence. These roles enhance student agency in independent inquiry, critical thinking, and innovative practice.

4. Multidimensional Course Assessment Method Developing

Traditional course assessment depends largely on final results, lacks process monitoring and cannot capture knowledge construction or competency development across the learning cycle.

Guided by OBE, the course establishes a multidimensional framework integrating formative assessment, summative assessment, and continuous improvement, with intended learning outcomes guiding evaluation of both process and results and of individual and team performance.

Formative assessment tracks learning trajectories to inform ongoing instructional improvement. It covers classroom performance, project progress, and teamwork. Classroom performance reflects understanding of robot design principles and adherence to debugging procedures. Project progress evaluates milestone completion and identifies problems for timely instructional adjustment. Teamwork assessment examines participation and communication effectiveness. These dimensions help teachers diagnose learning needs, provide differentiated guidance.

Summative assessment evaluates disciplinary knowledge and competency attainment at course completion through project product presentation and oral defense. Students demonstrate final outcomes via robot operation videos and articulate design originality, technical implementation, and application value, rendering system design capabilities observable, as shown in Figure 5. The defense assesses depth of understanding, rigor of reasoning, and professionalism of engineering communication. These methods enable judgment of intended learning outcome attainment and inform subsequent teaching improvement.



Figure 5: Action Demonstration of the Designed Innovative Robot.

Effective utilization of assessment results is pivotal to OBE-based continuous improvement. Formative and summative evidence are integrated into iterative instructional refinement. Analysis identifies weaknesses in specific knowledge or skills, enabling targeted reinforcement and remediation. Student feedback and assessment findings inform improvements to project design and collaborative learning. Reflection on assessment criteria and implementation supports more systematic indicators and reduces subjectivity. The resulting cycle of assessment, feedback, improvement, and reassessment supports the sustained enhancement of teaching quality.

5. Teaching Implementation Outcomes and Analysis

To verify the effectiveness of the curriculum reform based on the OBE concept, this study analyzes the feasibility and educational effectiveness of the reform plan from the aspects of learning behavior, comprehensive ability, academic achievement and quality growth, combined with multidimensional data such as the evaluation of the achievement of curriculum objectives, student surveys, practical results, competition performance and teacher evaluation.

In terms of learning behavior and engineering capabilities, the reform facilitated a transition from passive, standardized experiments to active engagement in requirements analysis, design justification, system development, and iterative optimization. Students integrated mechanical, sensing, actuation, and control modules, thereby fostering systems thinking and enhancing complex problem-solving and system integration capabilities. Differentiated projects promoted alternative solutions, experimentation, and critical thinking, while role assignment, milestone reviews, and project defenses improved collaboration, communication, and adherence to engineering conventions. Individual contribution tracking mitigated free-riding and reinforced participation and responsibility.

In terms of academic performance, the results suggest that the OBE-based reform was associated

with improvements in knowledge transfer and application capabilities. Following the systematic reorganization of content, diversification of teaching approaches, and introduction of assessment throughout the learning process, both the proportion of excellent grades and the pass rate increased. Descriptive results showed a higher mean course grade and a lower standard deviation after the reform. These findings suggest improvements in knowledge application and practical engineering capabilities alongside narrower performance differences among students. Combining formative and summative assessment may also have helped students identify and address weaknesses promptly and consolidate core knowledge in mechanical design, motion control, and programming, thereby strengthening their knowledge structures.

In terms of innovative design and educational outcomes, changes in project quality and disciplinary competition performance provided preliminary evidence of the reform's value. Following implementation, student projects showed advances in structural originality, control design, functional integration, and practical usability. Some teams proposed designs with engineering potential and research value, suggesting progress in innovative thinking and engineering creativity. Competition outcomes offered further evidence: the competition award rate increased, and several teams achieved strong results in demanding events such as the Undergraduate Robotics Competition of China. The integration of advanced technologies, authentic engineering cases, and open-ended design projects may have broadened students' technical perspectives and strengthened their ability to address complex engineering problems and undertake innovative design.

In terms of teamwork and broader professional attributes, the introduction of collaborative projects with differentiated tasks was associated with improvements in teamwork and project management capabilities. Projects required students to manage work through division of responsibilities, milestone reviews, and concentrated problem solving, thereby developing coordination, communication, and collaborative innovation. Most students perceived improvements in their teamwork and recognized its value for future engineering practice and research. Overall, the findings suggest coordinated development in disciplinary learning, engineering professionalism, and broader attributes, providing a practical reference for preparing innovative robotics engineers with interdisciplinary expertise.

6. Conclusions

Using the RIDP course as a case, this study explored systematic OBE-guided teaching reform to address weak alignment between course objectives and industry requirements, fragmented instructional content, and limited assessment diversity. The main conclusions are as follows.

(1) Redefining course objectives. Course objectives were designed backward from program educational objectives and industry needs, with intended learning outcomes specified across knowledge, capabilities, and professional attributes, thereby shifting emphasis from knowledge transmission to learning outcome attainment.

(2) Reorganizing instructional content. Content was restructured around a full engineering workflow-requirements analysis, conceptual design, system implementation, testing and optimization, and outcome presentation. The resulting project-driven framework connected previously isolated knowledge modules and fostered systems thinking.

(3) Renewing teaching approaches. An integrated model combining project-based learning, progressively tasks, teamwork, and redefined teacher-student roles enhanced student agency, practical engineering skills, innovative design capabilities, and collaboration.

(4) Reforming assessment. A multidimensional framework combined process and outcome assessment, team and individual assessment, and teacher assessment complemented by peer assessment. Analysis of course objective attainment informed continuous improvement,

strengthening the role of assessment in supporting and guiding competency development.

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