US-China Education Review A, July 2026, Vol. 16, No. 7, 501-505
doi: 10.17265/2161-623X/2026.07.006

Integrated Undergraduate-Graduate Teaching Reform for Robotics Mechanism Course Under Emerging Engineering Education

ZHAO Yinjun, CHEN Long, QIU Binbin
University of Shanghai for Science and Technology, Shanghai, China
WANG Jieyu*
Shanghai University, Shanghai, China

Traditional teaching in Robotics Mechanism courses often suffers from a disconnect between theory and practice, a gap between undergraduate and graduate content, and a lack of cutting-edge technologies like compliant and soft mechanisms. To address these issues and meet the demand for cross-disciplinary engineering talent, this paper proposes an integrated undergraduate-graduate teaching reform. The reform follows a core logic of "tiered training, continuous practice, and competition-driven learning". At the undergraduate level, we introduce practical modules on robot end-effector gripper design and parallel robot applications, using academic competitions to drive the forward design process. At the graduate level, the curriculum shifts to compliant mechanisms, continuum soft robots, and bionic deployable structures, utilizing flipped classrooms and literature seminars. This creates a progressive system: grounding in rigid bodies, refining through competitions, and exploring flexible frontiers. By bringing real engineering demands and grant application logic into the classroom, the reform successfully bridges the gap between degree levels, providing a replicable model for training top-tier talent in the robotics field.

Keywords: undergraduate-graduate integration, robotics mechanism courses, compliant mechanisms, emerging engineering education

Introduction

Robotics Mechanism is a core course for majors such as Robotics Engineering and Mechanical Engineering (Z. Zhang, A. Zhang, M. Zhang, & Esche, 2019). It serves as the crucial link connecting mechanical design,

Acknowledgements: This work was supported by the National Natural Science Foundation of China (52305122, 52505030), the Internship and Practical Training Base Construction Program at the University of Shanghai for Science and Technology (USST), the Micro-Major Program in Intelligent Robotics (ZYJS-W-251196) at USST, the funding for AI-empowered education and teaching reform at USST, and the Shanghai Pujiang Program (23PJD069).

ZHAO Yinjun, Ph.D., Lecturer, School of Mechanical Engineering, University of Shanghai for Science and Technology, Shanghai, China.

CHEN Long, Ph.D., Professor, School of Mechanical Engineering, University of Shanghai for Science and Technology, Shanghai, China.

QIU Binbin, Ph.D., Lecturer, School of Mechanical Engineering, University of Shanghai for Science and Technology, Shanghai, 200093, China.

WANG Jieyu* (Corresponding author), Ph.D., Associate Professor, School of Mechatronic Engineering and Automation, Shanghai Key Laboratory of Intelligent Manufacturing and Robotics, Shanghai University, Shanghai, China.

motion control, materials science, and intelligent algorithms. As the manufacturing industry rapidly moves toward intelligence, flexibility, and human-machine collaboration, traditional teaching systems—which rely heavily on rigid linkages and classical kinematics—can no longer meet the demand for high-level innovative talent. The "Emerging Engineering Education" initiative clearly calls for cross-disciplinary integration and the alignment of undergraduate and graduate studies (Meehan, 2025; Zhang, S. Wang, Sun, & C. Wang, 2024), urging universities to restructure their knowledge systems (Dart, Young, & Steindl, 2025).

Currently, a clear disconnect exists in how this subject is taught across different degree levels. Undergraduate teaching focuses heavily on complex theoretical formulas, such as D-H parameters and Jacobian matrices (Alwardat & Alwan, 2025). Students may easily solve equations on paper, yet they cannot independently complete the forward design of a small robot body or a complex gripper. The chain from theoretical knowledge to physical engineering is completely broken. Graduate courses, on the other hand, introduce advanced kinematics and optimization but severely lag in international frontier areas like compliant mechanisms (Jagtap, Deshmukh, & Pardeshi, 2021) and continuum soft robots (Shabana, 2018). Because students lack solid physical design experience from their undergraduate years, they lack "engineering intuition" when facing complex spatial multi-loop mechanisms.

Furthermore, traditional teaching lacks strong external motivation. Course experiments are mostly verification-based, missing the complexity of real engineering constraints like weight, cost, and manufacturing limits. High-quality national academic competitions are rarely tied to course assignments, wasting a perfect opportunity to stimulate internal motivation. Without exposure to large-deformation rigid-flexible coupling mechanics or smart material-driven mechanisms, the academic vision of graduate students is limited, making it hard for them to produce high-impact research. To solve these issues, this paper uses the Robotics Mechanism course to build an integrated teaching reform framework, clearing the path from classic rigid mechanism design to advanced compliant and morphing mechanism research.

Content Restructuring: From Rigid Bodies to Compliant/Soft Bodies

The reform follows a clear philosophy: build a solid foundation with rigid bodies for undergraduates, and elevate with flexible frontiers for graduates. We have restructured the teaching content to ensure a seamless transition of skills.

Undergraduate Level: Foundation and Practical Innovation

The core goal for undergraduates is to ensure they can independently design and build a physical robot for a specific task. We reduce pure mathematical derivation and emphasize the application of theory through modern design tools. Students are taught to use kinematics software for virtual simulation, interference checking, and trajectory optimization. To put theory into practice, we introduce two core practical modules. First is the robot end-effector gripper design. Students design linkage grippers, gear-rack systems, and underactuated compliant grippers. They must complete the full process: calculate grasping force, select drive motors, and design the 3D structure to adaptively wrap around fragile objects.

The second module focuses on parallel robot innovative design. We break away from teaching only serial arms by using parallel robots to train spatial mechanism design skills. Students analyze classic configurations like the Delta high-speed sorting robot and then move to low-DOF parallel mechanisms. They target specific applications, such as medical micro-motion platforms, and complete type synthesis and workspace analysis. By using genetic algorithms, students optimize mechanism parameters to achieve the largest singularity-free workspace.

Graduate Level: Compliant Advancement and Complex Systems

Building on the undergraduate experience, graduate courses shift entirely to “non-traditional” mechanism frontiers, integrating mechanics, bionics, and control science. We start with compliant mechanisms and rigid-flexible coupling. By exploring the micro-design principles of flexure hinges and large-deformation mechanics, students elevate their understanding from discrete rigid joints to continuous elastic deformation.

The curriculum then moves to soft robots and continuum mechanisms. We introduce designs driven by fluids, Shape Memory Alloys, and Dielectric Elastomer Actuators. Students learn Constant Curvature Kinematics and the spatial deformation control of soft arms for multi-target grasping in unstructured environments. Finally, we introduce high-end engineering cases, such as flexible morphing aircraft wings designed specifically for precise fluid field adaptation rather than simply maintaining fixed aerodynamic characteristics. Students also study origami-inspired deployable mechanisms for deep space antennas, training them to extract key scientific problems from geometric topology.

Innovative Teaching Models: Competitions and Seminars

To drive engagement and practical application, the reform completely overhauls the traditional classroom delivery method, moving away from pure theory toward hands-on realization and peer review.

Competition-Driven Simulation and Physical Prototyping

Traditional assignments often become mere formalities because they lack real constraints. This reform binds undergraduate course assignments directly to high-level national competitions, such as the National Undergraduate Mechanical Innovation Design Competition and RoboMaster. While the course reform does not involve the construction of new dedicated laboratory platforms, it heavily emphasizes providing students with opportunities for virtual simulation and physical prototyping.

Students must use existing campus manufacturing resources and simulation software to turn their ideas into reality. They first conduct virtual interference checking and trajectory optimization. Once the virtual design is verified, they manufacture their physical prototypes—such as complex grippers or low-DOF parallel robots—to meet the strict constraints of the competitions, including limits on size, weight, motor power, and budget. At the end of the term, we hold a campus design exhibition. To ensure professional engineering communication, students are required to document their designs rigorously. When presenting their work, they must use clean, white-background components for the professional rendering of scientific figures in their reports, strictly rejecting AI-generated text or cluttered backgrounds in their visual layouts. Outstanding teams are sent directly to national competitions.

The “Research-Driven” Flipped Classrooms

For graduate students, we abandon the traditional passive lecture format and introduce a dynamic, dual-track training system centered on high-level academic writing and rigorous peer review. In this immersive environment, students form collaborative research groups to deeply dissect the narrative logic and methodological frameworks of seminal papers from top-tier journals like Science Robotics and Mechanism and Machine Theory. Beyond mere reading, they are expected to critique experimental designs and replicate theoretical derivations. These insights are then presented in academic seminars conducted entirely in English or bilingually, where students engage in heated debates on complex topics such as compliant mechanism optimization and soft micro-robots, fostering a truly international research mindset.

As a preliminary exploration of digital transformation, we have begun to integrate AI-empowered parametric simulation into the curriculum to bridge the gap between theoretical concepts and engineering validation. In this module, students leverage intelligent algorithms and modern computational tools to conduct rapid parametric modeling, moving beyond static analysis to explore dynamic performance verification. This hands-on training not only significantly enhances the efficiency of their design iterations but also allows them to visualize complex mechanical behaviors that are difficult to capture analytically. By optimizing their designs in real-time based on AI-generated feedback, students learn to appreciate the power of data-driven engineering. At the end of the term, they must submit a comprehensive course paper featuring a clear, original mechanism innovation that is robustly backed by this rigorous simulation data.

Competency-Oriented Evaluation System

A successful teaching reform requires a grading philosophy that reflects its goals. We replaced the traditional “one final exam decides everything” model with a diverse evaluation system focused on engineering translation and original innovation.

Undergraduate Evaluation: Focus on Practical Output

For undergraduates, 50% of the overall grade is based on the major project practice (the gripper or parallel mechanism assignment). This grade focuses heavily on the rationality of the 3D assembly, manufacturability assessment, and the physical prototype’s actual performance, rather than just correct math. Daily performance and virtual simulation reports account for 20%, while a final written exam testing the rapid application of core concepts makes up the remaining 30%.

Graduate Evaluation: Focus on Academic Thinking

For graduates, the evaluation strictly focuses on academic rigor. Literature seminars account for 30% of the grade, evaluating critical reading and presentation skills. Another 40% is based on the innovative design report, assessing the rigor of theoretical derivation for complex continuum mechanisms and the ability to propose novel topological prototypes. The final 30% evaluates their paper writing, strictly assessing the accuracy and logical consistency of their scientific problem extraction.

Reform Results and Future Outlook

Practical and Academic Achievements

Since its pilot implementation, this integrated teaching reform has achieved remarkable results. The phenomenon of undergraduate “armchair engineers” has essentially been eliminated. Over half of the students can now independently complete the 3D forward design of complex mechanical systems, and the first-time success rate of physical prototyping has surged. Projects incubated from course assignments have won multiple national prizes in core engineering competitions, greatly boosting students’ professional confidence.

Among graduate students, apprehension toward frontier topics like compliant mechanisms has dropped significantly. Their academic enthusiasm has been fully ignited, leading to a noticeable increase in publications in top robotics conferences and journals, showcasing strong original innovation capabilities.

Future Outlook in the AGI Era

In the era of Artificial General Intelligence, future robotics mechanism teaching will move toward deeper digital and intelligent integration. Our next steps include exploring Embodied AI. We will study the co-evolution of physical morphology and AI models, investigating how to use generative AI to automatically generate novel compliant mechanism topologies that meet specific task requirements.

We will also deepen industry collaboration by partnering with leading enterprises. By bringing real-world bottleneck engineering problems into the classroom as advanced challenges, we will ensure our curriculum remains at the cutting edge. By continuously optimizing this integrated model—from rigid basics and competition trials to flexible frontier innovation—we aim to build a world-class robotics education hub, providing a steady stream of highly qualified talent for the intelligent manufacturing industry.

Conclusion

In summary, the integrated undergraduate-graduate teaching reform for the Robotics Mechanism course successfully addresses the critical disconnect between theoretical instruction and real-world engineering practice. By implementing a progressive framework, the curriculum smoothly guides students from foundational rigid-body mechanics to advanced frontier research. The undergraduate phase leverages academic competitions to drive the physical prototyping of end-effector grippers and parallel robots, effectively bridging the gap between mathematical derivation and physical manufacturing. Transitioning into the graduate phase, the focus shifts toward original innovation in compliant mechanisms, soft robotics, and complex bionic deployable structures—such as morphing aircraft systems designed for precise fluid field adaptation. Furthermore, by substituting traditional lectures with flipped classrooms centered on top-tier literature and grant proposal logic, the program cultivates rigorous academic thinking and professional scientific communication. Ultimately, this tiered approach—grounded in rigid fundamentals and elevated by flexible, cutting-edge exploration—provides a highly replicable model for emerging engineering education. It ensures that students are not only adept at solving complex equations but are fully equipped to design, prototype, and innovate the next generation of intelligent robotic systems.

References

Alwardat, M. Y., & Alwan, H. (2025). Geometric jacobians derivation and kinematic singularity analysis for 6-DOF robotic manipulator. *International Journal of Advanced Research in Computer Science, 16*(1), 6-20.

Dart, S., Young, A., & Steindl, E. L. (2025). Systematic literature review of the factors influencing development of engineering education researchers. *Journal of Engineering Education, 114*(4), e70030.

Jagtap, S. P., Deshmukh, B. B., & Pardeshi, S. (2021). Applications of compliant mechanism in today's world—A review. *Journal of Physics: Conference Series*, 012013.

Meehan, D. N. (2025). The National Academy of Engineering and engineering professional societies: "Linking Engineering Leadership to National Service". *Engineering Education Review, 3*(2025). https://doi.org/10.54844/eer.2025.1021

Shabana, A. A. (2018). Continuum-based geometry/analysis approach for flexible and soft robotic systems. *Soft Robotics, 5*(5), 613-621.

Zhang, W., Wang, S., Sun, J., & Wang, C. (2024). Global evolutionary trends of the discipline of engineering education and their empirical implications. *Engineering Education Review, 2*(4), 145-160.

Zhang, Z. Zhang, A. Zhang, M., & Esche, S. K. (2019). Project-based robotics courses for the students of mechanical engineering technology. In *2019 ASEE Annual Conference & Exposition*, Tampa, Florida, United States.