Educational Innovation Research, 2026, Volume 4, Issue 6
https://bbwpublisher.com/journal/EIR
Online ISSN: 3029-1852
Print ISSN: 3029-1844

Construction of an Undergraduate Practical Teaching System Empowered by Research Platforms: A Case Study of a Multiphase Flow Testing Technology Platform Cluster

Yang Yang, Chao Zhang, Jiaqi Chen, Xiangrui Dong, Mingxu Su*

School of Energy and Power Engineering, University of Shanghai for Science and Technology, Shanghai 200093, China

Author to whom correspondence should be addressed.

Abstract: Develop good teaching materials for undergraduates based on the research results to promote the integration of science and education and nurture new-generation talents. Based on the project "Construction of an undergraduate practical teaching system empowered by multiphase flow testing technology research platform cluster" at the School of Energy and Power Engineering, University of Shanghai for Science and Technology, this paper explores how to develop undergraduate laboratory teaching materials by integrating various research resources such as ultrasonic testing, optical testing, image analysis, and numerical simulation, through the two main research platforms: China Machinery Industry Federation Key Laboratory of Multiphase Flow Measurement and Research Center for Intelligent Measurement and Computation of Particle and Multiphase Flow. According to the whole-process framework of systematic research resource inventory, pedagogical transformation design, tiered experimental project development, teaching resource package construction, and course operation optimization, a teaching system with seven research-oriented experimental modules has been established to serve more than 200 undergraduate students each year. Based on the above experience, the effect of empowering undergraduate practical teaching with research platform clusters can be considered the combination of platform resources, the systematic character of transformation paths, and the coherence of cultivation models. It can offer some references for the actual teaching reform of other engineering courses.

Keywords: Research-empowered teaching; Practical teaching; Multiphase flow testing; Integration of science and education; Experimental teaching reform

Online publication: June 26, 2026

1. Introduction

Application of knowledge at the undergraduate level can help students develop their engineering abilities and creative thinking. Laboratory education in many technical areas is out of touch with the times and does not match the demands of modern industrial engineering. At the same time, many good academic institutions and research bases have collected high-end equipment, advanced research results, and various empirical evidence, but the path to applying these excellent resources in teaching remains obstructed. One of the main problems of the current reform of higher technical education is how to reduce the gap between research and teaching and effectively use research results to support undergraduate hands-on learning.

Around the world, integrating the academic resources of different departments into undergraduate courses has begun to spread among high-end engineering education reform. Research institutions around the world believe that students' participation in original research is a good way to train creative talents. In 1969, MIT set up the Undergraduate Research Opportunities Program (UROP) to have students participate more actively in professors' research, and now, more than 4,000 undergraduates across the country are engaged in advanced study under the guidance of professors through UROP and have constructed an effective system for turning academic resources into teaching materials [1]. The Undergraduate Research Experience Program at Stanford University is a place for new students to do research, and a development mentorship system has been established to help them with their studies and independent research [2]. The University of Cambridge has added practical research topics to the undergraduate thesis work and senior-year tasks of all its laboratory areas to create a single "research-learning-teaching" system [3]. All the above cases show that to improve undergraduate teaching through investigative forums, it is necessary to build formal transformation pipelines and hierarchical participation models.

Many excellent Chinese institutions have also been studying this locally. Beihang University has begun the "Research Classroom" TOP project to use its excellent core laboratories for various purposes and has turned high-quality research institutions into numerous courses, giving students more frequent opportunities to use important laboratories at the provincial or ministerial level and above [4]. A system for the development of undergraduate practical teaching instruments has been built at the Analysis and Testing Center of Southwest Jiaotong University [5]. The above work has produced some good regional cases of research-oriented teaching.

However, a large-scale study of the application of this method around the world and in China has not yet been carried out. The departments are focusing on building their own kinds of industrial bases and scholarly interests, and at present, there is a lack of particular theoretical analysis and empirical evidence on how to construct organized and reproducible methods for transforming scholarly assets into high-quality practical training based on academic profiles and facility attributes. Based on the above, this paper will take the initiative to select the "Construction of a Practical Teaching Framework Enriched by a Multiphase Flow Testing Technology Research Platform Cluster" project in the Energy and Power Engineering Department of the University of Shanghai for Science and Technology as the case study, systematically explore how research infrastructure can improve undergraduate laboratory education, what results have been achieved, and provide generalizable knowledge and ideas for other technical majors.

2. Theoretical foundations for empowering undergraduate practical teaching with research platforms

2.1. Resource transformation logic under the integration of science and education

The main idea of integrating science and education is to combine research activities with educational training so that students can gain knowledge in an exploratory way and develop through the process of actual research. Based on the above evidence, many studies have put forward converting scientific knowledge into laboratory teaching modules to better integrate it with school education and improve students' learning results [6]. At the level of resource conversion, a basic logic sequence of "resource discovery—content adaptation—instructional redesign—performance assessment" needs to be established to improve undergraduate education through research infrastructure. Among the excellent research results, some should be selected, condensed, and then planned for educational use in accordance with the intellectual abilities and growth needs of college students.

2.2. Practical implications of constructivist learning theory

According to constructivist pedagogy, students actively build knowledge in actual situations. Authentic research environments, advanced equipment, original empirical data from academic platforms, and other resources can all be provided for students' "real-world research studies." When students themselves use research-grade instruments and follow research-oriented laboratory procedures to process the obtained data, their motivation to learn and the depth of their thinking will generally be higher than what is achieved in traditional verification-focused laboratory activities. Therefore, the goal of research-enhanced teaching is not to spread research materials, but rather to create an environment of "pseudo-research" experience that can attract students' attention and motivate them to learn by asking questions and exploring.

2.3. Articulation needs for bachelor's-to-master's continuum

The Effective combination of undergraduate and postgraduate education is required to nurture excellent innovative talents. Adding a scholarly atmosphere to undergraduate teaching can help students get familiar with research tools and learn how to conduct research; thus, they will be better prepared for graduate school studies later on. The sequence of "undergraduate application—research creativity—master's progression" can help reduce the adjustment period after leaving university for graduate school and improve the cohesion and structure of human resource development.

3. Practical exploration of empowering undergraduate practical teaching with the multiphase flow testing technology research platform cluster

3.1. Platform foundation: A multi-technology integrated research resource cluster

The Energy and Power Engineering Department of Shanghai University of Science and Technology has two main research bases: the Machinery Industry Federation Key Laboratory of Multiphase Flow Measurement and the Research Center for Intelligent Measurement and Computation of Particle and Multiphase Flow; it has built a complete facility network covering all stages of multiphase flow measurement. The first equipment in the laboratory is an ultrasonic multi-parameter synchronous detection system, which consists of a Panametrics PR5800/PR5910 ultrasonic probe and a 24-channel ultrasonic tomography device; Next is a Raman spectroscopy analysis station, an environmental optical sensing platform, a spray test set-up, an oil-gas-water multiphase flow rig, a microscopic flow field observation station, and an experimental frame for droplet temperature measurement and defocusing imaging. There are many kinds, such as ultrasonic detection, optical imaging, image processing, flow pattern recognition, multi-sensor integration, numerical modeling, etc.

Director Su Mingxu of the platform is a councilor to the Chinese Society of Particuology and a committee member of the Multiphase Flow Division in the Chinese Society of Engineering Thermophysics.

After more than 20 years of research on the assessment of multiphase flow, he has led over 30 research projects, published more than 200 papers, obtained over 20 patents, written two specialized books, and won two Second Prizes at the Shanghai Natural Science Award and one Second Prize at the Shanghai Technological Invention Award (as the main inventor). The team members have continued to carry out teaching and research on multiphase flow evaluation, accumulating rich experience in the development of experimental teaching materials, practical guidance, and computational model education. Recently, the institution has achieved some good research results, such as ultrasonic two-phase flow monitoring, electromagnetic flow sensing of oil-water mixtures, and optical identification of multiphase contaminants, and these have provided rich intellectual resources for educational reform [7–11].

3.2. Transformation pathway: A five-stage process from research resources to teaching resources

The five usual steps for changing scholarly resources into teaching materials have been established.

Phase 1: Investigation of Asset Accumulation and Recognition. Conduct a full-coverage audit of the equipment in the facility area, collect data, learn about the procedures and functional norms, build a scholarly asset directory, etc. The Infrastructure Cluster has organized the results of almost five years of multi-stage fluid simulation studies, more than ten comprehensive academic trial schemes, complete instrument user guides and calibration standards, etc., to provide rich fundamental materials for the development of the following education.

Phase 2: Pedagogical Evolution Framework Construction. According to the resources in the database and considering the intellectual level and academic goals of undergraduate students, some materials and forms for transforming research assets into teaching materials will be selected. The three general directions of this reform are to simplify and modify research topics, regularise the operation of research tools, and reduce the technical hurdles in data analysis; thus, the revised teaching materials will keep up with the trends and truthfulness of research while also being more practical and reliable for education.

Phase 3: Experimental Program Implementation and Laboratory Manual Preparation. Based on the selection of academic materials, some practical problems have been identified, and the "Undergraduate Hands-on Training Guide for the Multiphase Flow Testing Technology Research Platform Cluster" has been published to elaborate on the function standards and cross-technique data analysis pipelines of the seven laboratory initiatives.

Phase 4: Development of Teaching Case Repositories and Video Materials. At all three levels, research-based case archives have been established for the purposes of basic validation, general planning, and creative exploration; in combination with a set of essential instrument-use tutorials, a special resource bundle ready for teaching has been prepared.

Phase 5: Curriculum Pilot Introduction and Optimization. Implement the practical tasks that have been developed in the relevant classes, collect learner feedback, optimize the instructional materials and implementation methods, and finally determine the educational results.

3.3. Curriculum system: Research-oriented experimental modules aligned with core courses

The four main courses are Power Engineering Measurement and Control Experiments, Power Engineering Measurement and Control Technology, Computer Software Practice for Energy and Power Engineering C, and Energy and Environment (Bilingual), and each has the following seven research-based practical units listed below:

3.3.1. Power engineering measurement and control experiments

This course has four research-oriented experimental modules:

(1) Research on morphology and pressure drop characteristics of multiphase flow. A triphasic oil-air-liquid facility and a high-resolution imaging system are employed to observe changes in flow configuration under various operating conditions, learn how to calculate multiphase pressure drop, and obtain friction coefficient data for all kinds of flow.

(2) Imaging and analysis of multiphase flow fields [11]. A micro-flow field test facility and a spray experiment device are employed to observe the irregular flow pattern of a particulate two-phase stream under different conditions and learn how to present parameters such as velocity fields and particle dispersion, etc.

(3) Determination of annular flow rate experiment using electromagnetic flowmeters [7]. According to the ideas of electromagnetic sensing and annular fluid dynamics, this section will teach students how to use electromagnetic sensing technology for monitoring various conditions in multiphase flow, operate an electromagnetic flowmeter to accurately determine the rate of annular flow, and perform basic data analysis and error checking.

(4) Ultrasonic fluid layer thinness assessment experiment [8]. This part will introduce the main ideas of ultrasonic testing generally and explain how ultrasonic echoes, absorption, and the thinness of the liquid layer are related. Learn how to use and calibrate a simple ultrasonic detection device, understand the general method of analyzing ultrasonic waveforms and reconstructing the thin-film structure of fluids, and be able to carry out all steps of the experiment and preliminary data analysis independently.

3.3.2. Power engineering measurement and control technology

The above module will offer full cognitive support for the cluster of research platforms in multiphase flow testing technology. The contents include equipment arrangement, roles of people operating equipment, basic operating instructions for necessary test and measurement instruments, general information on research ethics and procedural rules, etc., all of which aim to help students establish a good mindset for laboratory research.

3.3.3. Computer software practice for energy and power engineering C

Both COMSOL simulation and experiments are employed to study multiphase flow in this paper [9]. First, introduce the general steps of using the COMSOL Multiphysics calculation tool; then, based on the multiphase flow test environment in real life, construct a multiphase flow model, carry out numerical calculations and display the results; finally, compare the simulation results with the actual experimental data to determine why there are differences and adjust the numerical model accordingly.

3.3.4. Energy and environment (Bilingual)

One module is a photomural assessment exercise of ecological multiphase fluid pollutants [10]. With the help of an ambient optical assessment device, students will be able to learn to sense light, obtain information on the concentration of pollutants in multiphase currents, and be introduced to applications of light-based diagnostic technology in ecological monitoring.

3.4. Distinctive innovations: Four mechanisms ensuring transformation effectiveness

First, we will introduce the whole-platform cluster integration. This is to address the limitations of individual technical paths; full pedagogical evolution has been achieved for all kinds of tests—such as ultrasonic, optical, imaging, spectroscopic, and others—to help students gain all-round knowledge of multiphase flow measurement.

In addition, there are practical problems with the use of scholarly assets. Undergraduate students can use good equipment and hardware freely, learn from the academic laboratory's protocols, numerical analysis methods, and research materials, and thus gain experience in real science. In this way, all research topics will be covered in the lectures, activities, and other creative works.

Thirdly, the combination of virtual and real teaching can help the students gradually understand the concepts. The goal of using the COMSOL Multiphysics modeling tool to build the teaching sequence named "simulation-based preliminary trials—empirical verification—model refinement" is to enable students to learn the basic ideas of complex fluid dynamics through simulation, compare the results of these simulations with those obtained in laboratory experiments, and then improve the computational model based on experimental data; thus, they can develop systematic thinking and modeling abilities.

Fourth, the transition from undergraduate to graduate school advances the study of scholars. The students with the highest scores will be allowed to join the research laboratory for their final projects or continue their studies at the graduate school, thus forming an uninterrupted training path of "undergraduate education—research creativity—graduate studies."

3.5. Coverage scale and initial outcomes

The main users of this project are third- and fourth-year undergraduates in Energy and Power Engineering, and it also covers related areas such as Process Equipment and Control Engineering, Energy Storage Science and Engineering, and New Energy Science and Engineering; there are over 200 participants each year. In terms of the construction of resources, the Practical Teaching Guide for the Research Platform Cluster of Multiphase Flow Testing Technology, a research and experimental case repository, and a series of core instrument operation videos have been built. Talent Training: Every year, we will organize 3–5 undergraduate innovation projects (with 3–5 participants per project) and aim to achieve the production of 2–3 student innovation results annually, such as scholarly articles, utility patents, and professional competition awards. A Scalable and Transferable Model of Research-Resource-to-Teaching Conversion has been established.

4. Reflections and implications

4.1. Platform resource integration as a prerequisite for empowerment

No single instrument or specific technical route can lead to all the changes in education; rather, a group of platforms covering all areas of technology should be built to provide rich resources and various choices for teaching. Therefore, the platform cluster for testing the technology of multiphase flow will have seven laboratory modules to integrate all kinds of technology in one place, such as ultrasonic, optical, imaging, and simulation; thus, a complete chain from hardware to software and from practical tests to simulations will be established. The above case shows that the basis of research-based platform-driven teaching is to organize platform resources reasonably and to discover transformation opportunities in the direction of technology at various times.

4.2. Adaptability design as the key to transforming research into teaching resources

Not all research topics are suitable for direct application in undergraduate teaching at present. In light of the three guiding principles of "streamlining and modifying the research subjects, formalizing apparatus operation procedures and making data analysis techniques transparent," all-weather adaptation of research materials has been achieved in this study. Streamlining and modification refer to breaking down the difficult research problems into several small parts that are suitable for a single class; formalization is the establishment of specific operating rules for equipment designed for undergraduates to ensure laboratory safety and data accuracy; transparency means presenting the complex computational algorithm in an easy-to-understand and logical way for teaching. The above ways of conducting research are still suitable for teaching and safe for the students.

4.3. Institutionalization as the basis for sustainability

Investigation-based pedagogy should not be a temporary project but should be carried out in an organized way by institutions. The three ways to carry out inquiry-based teaching in the regular structure of school life are: curriculum integration (adding practical content to training plans), project promotion (using undergraduate research projects as carriers), and facility accessibility (allowing students frequent access to research institutions). An institutional case of promoting the sustained health and stability of research-oriented teaching is how to incorporate the results of research into curriculum development, introduce new project supervision and facility management systems, etc.

4.4. Virtual-physical integration as an effective means to overcome bottlenecks

The academic system is often expensive and difficult to manage, so not many students have access to it. Therefore, the teaching plan of "simulation first and then experimental verification" can be introduced to interest students and help them learn about basic physics in an economical way. The combination of virtual and real teaching is a practical way to overcome the problems of scarce equipment and high operating costs in the development of similar research institutions.

5. Conclusion

Strengthening undergraduate laboratory teaching on the basis of research platforms is an urgent task to promote the integration of science and education and nurture creative talents. Based on the research platform network for multiphase flow experiment technology, the Energy and Power Engineering Department of the University of Shanghai for Science and Technology has developed a good plan to convert academic resources into practical teaching materials by organizing resource maps, flexibly adjusting content, planning hierarchically, and building a continuous cultivation system. Therefore, the main direction of research-integrated teaching is to build a full-circle system covering the discovery of research materials, the actual process of teaching, all forms of integration in courses and other activities, as well as linking undergraduate education with graduate studies. In the future, with the progress of this initiative, more research and optimization will be conducted to address the problems in assessing the results of pedagogical transformation, continually improve and develop teaching materials, expand the monitoring of students' inventive abilities, and provide a stronger foundation for practical educational reform in other engineering fields.

Funding

The authors express their great thanks to the Graduate Teaching Project of the University of Shanghai for Science and Technology for financial support.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Xiong H, Liang J, 2013, Experience and Enlightenment of UROP in MIT. Chongqing Higher Education Research, 1(2): 99–103. https://doi.org/10.15998/j.cnki.issn1673-8012.2013.02.015

[2] Stanford University, 2026, Undergraduate research and independent projects. https://undergradresearch.stanford.edu/

[3] Healey M, Jenkins A, 2009, Developing Undergraduate Research and Inquiry. https://doi.org/10.1080/14703291003718976

[4] Wang J, Liu G, Jin T, 2026, Exploration and Practice of the "Research Class" Model for Undergraduates Using Key Laboratories: TOP Program of Beihang University. Experimental Technology and Management, 43(1): 289–294. https://doi.org/10.16791/j.cnki.sjg.2026.01.036

[5] Wei F, Fang W, 2025, Reflections and Practices on Leveraging University Large-scale Research Instruments for Undergraduate Experimental Teaching from the Perspective of Research-Education Integration: A Case Study of the Analysis & Testing Center at Southwest Jiaotong University. Sichuan University of Arts and Science Journal, 35(2): 113–116. https://read.cnki.net/web/Journal/Article/DXSZ202502016.html

[6] Boyer EL, 1990, Scholarship Reconsidered: Priorities of the Professoriate. Princeton University Press, New Jersey.

[7] Tang Y, Ha W, Ma L, et al., 2025, Gas–Liquid Two-Phase Flow Measurement by Ultrasonic Method Based on the Phase-Isolation and Dual-Fluid Model. Physics of Fluids, 37(7): 73302. https://doi.org/10.1063/5.0272745

[8] Yang Y, Ha W, Zhang C, et al., 2022, Measurement of High-Water-Content Oil-water Two-Phase Flow by Electromagnetic Flowmeter and Differential Pressure Based on Phase-Isolation. Flow Measurement and Instrumentation, 2022(84): 102142. https://doi.org/10.1016/j.flowmeasinst.2022.102142

[9] Yang Y, Yang B, Wang G, et al., 2025, Theoretical Model of Electromagnetic Flowmeter under Annular Conductivity Distribution Based on Annular Domain Weight Function. Measurement, 2025(253): 117538. https://doi.org/10.1016/j.measurement.2025.117538

[10] Chen Z, Wang M, Venables DS, et al., 2026, Measurement of Gas-Phase Naphthalene with Deep-UV Broadband Cavity-Enhanced and Integrated Absorption Spectroscopy. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 127964. https://doi.org/10.1016/j.saa.2026.127964

[11] Yang Y, Hu H, Wang H, et al., 2024, Study on Characteristics of Phase-Isolation Caused by Different Classic Axial Flow Swirlers in Upward Vertical Gas-Liquid Two-Phase Flow. Experimental Thermal and Fluid Science, 2024(150): 111031. https://doi.org/10.1016/j.expthermflusci.2023.111031