Article

Exploring the Articulation Pathway between Undergraduate Foundations and Graduate Specialization – A Case Study of the Course "Theory and Measurement Techniques of Gas–Liquid Two-Phase Flow"

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Abstract: Good coordination of undergraduate and graduate education is needed to improve the overall quality of high-end talent cultivation. For example, the graduate course "Theory and Measurement Techniques of Gas-Liquid Two-Phase Flow" in the department of energy and power engineering has studied the problems that currently exist in the articulation of graduate courses and undergraduate foundation courses systematically, such as disconnection in teaching content, lack of capability transformation and misalignment of assessment focus. Therefore, the reform path of education builds upon the foundation provided by undergraduate education and focuses on developing abilities. Specifically, the following measures will be taken to better align the knowledge points of undergraduates with the direction of graduate specialisation in a "correspondence matrix plus articulation handbook"; a three-tiered gradient training objective of "foundation transformation - specialisation deepening - innovative application" will be set; teaching links that promote knowledge transfer will be designed; and all-encompassing "formative + summative" assessment will be carried out. The first tests have shown that this reform path can strengthen students' ability to transfer knowledge and specialise in applying skills, so it is a suitable imitation model for reforms in the articulation teaching of similar graduate courses.

Keywords: undergraduate-graduate articulation; curriculum reform; capability transformation; graduate education; gas-liquid two-phase flow

Received: 21 June 2026
Revised: 09 August 2026
Accepted: 24 August 2026
Published: 31 August 2026

1. Introduction

Undergraduate and graduate education are two different stages of higher education in China; they are independent but also work together. However, in the current curriculum, teaching at both the undergraduate and graduate levels in the same field is still in a phase of simple repetition and lack of coordination. Curricular disconnection is now one of the serious problems facing universities; for example, there is an inconsistency in the development of content, a mismatch between the goals of courses and their actual contents, and a division between courses and research training [1].

Energy and Power Engineering is a typical representative subject; therefore, the undergraduate course "Measurement and Control Technology in Power Engineering" has been organised with the following three basic units: sensor principles, flow measurement and automatic control. At the same time, the graduate course "Theory and Measurement Techniques of Gas-Liquid Two-Phase Flow" also covers the basic theory of two-phase flow and some measurement methods. There is a close connection between the two courses, and the special topics in gas-liquid two-phase flow measurement, such as pressure measurement, flow-rate measurement and void fraction measurement, are based on the fundamental knowledge gained at the undergraduate level, including sensor

principles, signal processing and error analysis. However, many graduate courses for teachers still start from scratch and do not use the foundation laid during their undergraduate studies. Therefore, students need to repeatedly review basic knowledge before they can be introduced to specialised learning, which is inefficient for teaching and disrupts their learning.

From the students' perspective, many graduate students are confused by the gap between undergraduate knowledge and graduate-level specialisation. Some graduate courses have too much material and are difficult to learn in a short time. This poor expression will have an adverse impact on the teaching of graduate courses and fail to help students master what they have learned in college. Thus, one of the problems in the reform [2] of graduate curricula is how to build an effective articulation path for undergraduate foundational courses and graduate specialised courses.

2. Theoretical Foundations and Reform Approach

2.1. Theoretical Basis for Undergraduate-Graduate Integrated Curriculum Development

The purpose of the integrated undergraduate-graduate training model is to cultivate excellent innovative talents by integrating the education of undergraduates, graduates and doctoral students, coordinating high-quality educational resources, and building an effective and integrated continuum of education. The Courses are prerequisites for the graduate school curriculum. One of the purposes of the new integrated curriculum system for undergraduates and graduates is to coordinate the teaching of these two levels. The integrated undergraduate-graduate courses should have the basic theories and applications of undergraduate courses, and gradually add advanced knowledge, interdisciplinary and cutting-edge theories, and innovative applications of graduate courses. It will help to build an orderly system and harmony in the cultivation of professional knowledge, meet the demands of high-level research output, and nurture excellent innovative talents [2, 3].

The specific articulation path is as follows: First, teach the basic knowledge points; next, increase the breadth and depth of the content; finally, carry out projects and practice [4]. Other scholars have pointed out that universities should be driven by the demands of students, focus on cultivating innovation awareness and ability, give different weights to courses at different times, and strengthen the links among these courses. In college, we will focus on learning the basics and basic abilities; after graduation, we will study specialized professional knowledge and learn how to apply it innovatively [5]. The above studies provide some theoretical support for the articulation reform in this paper.

2.2. Basic Reform Approach

Based on the theoretical foundation above, we have taken the course "Theory and Measurement Techniques of Gas-Liquid Two-Phase Flow" as an example and proposed the reform idea of "building on undergraduate foundations and focusing on capability transformation". The basic idea is to start with the knowledge system of the undergraduate course "Measurement and Control Technology in Power Engineering", systematically map the corresponding relationships among the core knowledge points of undergraduates and the specialisation requirements for graduates, restructure the content structure and teaching links of graduate courses, build a tiered cultivation path of "undergraduate foundation - specialisation extension - research application", and finally help students effectively transfer their undergraduate knowledge into graduate-level specialised abilities.

3. Practical Exploration of the Articulation Pathway

3.1. Restructuring the Specialised Content System Based on Undergraduate Foundations

The first step of articulation reform [6] is content reorganization. The teaching team systematically reviewed the teaching system of the undergraduate course "Measurement and Control Technology in Power Engineering", clarified the main knowledge points, teaching requirements and competence goals of each chapter, and created a complete

"undergraduate knowledge points inventory". Then, by cross-referencing all the chapters of the graduate course "Theory and Measurement Techniques of Gas-Liquid Two-Phase Flow", the team analyzed the foundation knowledge for all the specialisation topics at the undergraduate level and created a "Correspondence Matrix of Undergraduate Knowledge Points and Graduate Specialisation Extensions".

According to the above matrix, we will organise the graduate courses. An "Introductory Lecture on the Articulation between Undergraduate Measurement and Control Fundamentals and Two-Phase Flow Specialisation" (2 credit hours) has been added to the beginning of the course to systematically connect the main content of undergraduate studies with the requirements of graduate-level specialisation and help students build an all-encompassing cognitive system based on undergraduate measurement and control technology for specialised two-phase flow measurement. In each chapter, there was a section called "Review of Undergraduate Fundamentals and Specialised Applications"; before presenting the specialised content, students are asked to recall relevant undergraduate knowledge, and then the specialised theory and application cases are introduced, achieving a "review the old to learn the new" effect.

In addition, the teaching team has compiled an Articulation Guidance Handbook that specifies the undergraduate knowledge points to be evoked in each chapter, the extension ideas and application cases, etc., to provide teachers and students with a clear reference for foundational support. Based on the general idea of "articulation needs" in the "matrix plus handbook" articulation model, specific and practical "teaching action guides" have been developed to improve the accuracy of articulation teaching.

3.2. Setting Tiered Training Objectives Focused on Capability Transformation

The Goals of the course will affect the Planning of teaching activities and students' learning directions. The traditional objectives of graduate courses are to achieve the acquisition of specific knowledge and the cultivation of research ability; however, they do not address the transition and transformation from undergraduate basic competencies to graduate-level specialised competencies [7, 8]. Thus, the three levels of the gradient training objective system in this paper are: foundation transformation, specialisation deepening and innovative application.

The purpose of the foundation transformation stage is to have students skillfully apply the basic measurement and control principles, equipment operation and data processing skills they have learned at the undergraduate level to solve simple special problems in the field of gas-liquid two-phase flow. For example, based on their undergraduate knowledge of sensors, students can be introduced to the features of special two-phase flow sensors, such as optical fibre probes and capacitance sensors, in comparison with traditional sensors, how they work, etc.

The purpose of the specialisation and deepening tier is to help students extend their undergraduate knowledge and gain an in-depth understanding of the flow theory of gas-liquid two-phase flow and the rules for special measurement techniques, as well as develop the ability to design measurement schemes for two-phase flow parameters independently using conventional measurement and control equipment. Using your undergraduate knowledge of the principles of flowmeter measurement, solve a specific problem in two-phase flow measurement and design a scheme for measuring the phase flow rates of gas-liquid two-phase flow.

The purpose of the new application tier is to help students integrate the foundation of undergraduate measurement and control with specialized knowledge at the graduate level, participate in research projects on gas-liquid two-phase flow, obtain some research experience, and learn how to propose improvements for special measurement techniques and analyze complex experimental data. The three levels are progressively higher, and at each stage [9], both the level of ability and the emphasis of learning change.

3.3. Designing Adaptive Teaching Links to Promote Knowledge Transfer

The Design of Teaching Links is to achieve the goals of the course. To solve the problem of directly presenting specialised theories in graduate teaching without building

upon the knowledge points established in undergraduate teaching, this paper puts forward three types of adaptive teaching links.

The first is the articulation introduction. At the beginning of each chapter, a few undergraduate knowledge points will be presented briefly in a problem-oriented way to stimulate cognitive conflict and interest in learning [10]. For instance, before teaching "Flow Rate Measurement in Gas-Liquid Two-Phase Flow", the question "Why can't we directly apply the conventional flowmeters you learned at the undergraduate level to the measurement of two-phase flow?" is posed. Therefore, students need to actively recall the working principles of flowmeters they learned in college and consider the particular problems of two-phase flow measurement; thus, they will be naturally led to learn about this specific topic.

Secondly, there is the case-based extended teaching. A number of special cases have been built upon the foundation of undergraduates. Based on the study of differential pressure flowmeters in college, this paper will present correction methods for using differential pressure flowmeters to measure gas-liquid two-phase flow and design an application case for building a simple data acquisition system for gas-liquid two-phase flow based on undergraduate data acquisition experiments. The first few are basic knowledge points for undergraduates, and then they are gradually expanded in the graduate level to guide advanced studies.

The third is the experimental introduction. Based on the existing undergraduate measurement and control experimental equipment, some extended experimental projects will be carried out. For example, the undergraduate sensor experimental platform can be employed to carry out the experiment "Pressure Fluctuation Measurement of Gas-Liquid Two-Phase Flow with Conventional Pressure Sensors". This Design will help us make more effective use of the experimental resources over time, reduce reform costs, strengthen the link between experimental skills in "undergraduate operations" and "graduate studies", etc [11].

3.4. Establishing an Integrated Assessment System to Guide Comprehensive Knowledge Application

The evaluation system will change how the teachers teach. The old ways of testing graduate courses focus on specialisation and research ability; they do not cover the application of undergraduate core competencies and thus fail to determine how well students integrate knowledge from "undergraduate foundation - graduate specialisation". Therefore, the two types of assessments in this study will be used together.

Foundation-application assignments will be added to the formative assessment; an example is that students need to write a comparative analysis report on specialised two-phase flow sensors based on their undergraduate studies in sensors, as well as foundation-specialisation articulation lab reports. Assessments of students' ability to apply their undergraduate knowledge in specific situations are included in the 30% of the overall grade.

A certain proportion of the "foundation-specialisation integrated questions" will be added to the final examination for summative assessment, such as "Based on undergraduate automatic control theory, design a stability control scheme for a gas-liquid two-phase flow measurement system", to evaluate students' integration of knowledge at all levels. The course paper should show how to use the basic knowledge of undergraduate measurement and control in the specific research topic and counts for 40% of the total score.

In addition, the teaching team has set up all-round feedback channels through questionnaires, student interviews and analysis of homework and test papers to regularly collect students' opinions on the clarity of teaching and adjust teaching content and methods accordingly.

4. Practical Effects and Reflection

4.1. Preliminary Practical Effects

The reform plan mentioned above was introduced in the teaching of the course "Theory and Measurement Techniques of Gas-Liquid Two-Phase Flow" during the first semester of the 2024-2025 academic year. Based on the first round of feedback, there have been some improvements.

Students' Knowledge Transfer Abilities have risen. With the help of the correspondence matrix and the introductory articulation lecture, students can better understand the basic connections between their undergraduate knowledge and graduate-level specialisation content and reduce confusion during the transition from undergraduate to graduate study. Students were more willing to apply their undergraduate knowledge in the course discussion to solve particular problems.

The students learn well. Build specialised teaching on the foundation of undergraduate studies to reduce the time lost on redundant review of basic knowledge and allow students to enter in-depth specialised learning sooner. According to the analysis of homework and test data, students' understanding of specialised content has improved over time, and they are now better at handling integrated questions that require combining undergraduate knowledge with specialised knowledge.

The students were doing well. By the end of the semester, most students had felt that the "foundation-specialisation" division design had reduced the difficulty of the course and improved their learning efficiency; they had given positive evaluations to both the "articulation introduction" and the "case-based extension teaching" links.

4.2. Reflection and Outlook

Although the above indicators show some good initial results, some problems were also found during the actual operation.

First, students have different undergraduate backgrounds. Some students have not grasped the undergraduate course "Measurement and Control Technology in Power Engineering" well, and therefore find it difficult to recall relevant undergraduate knowledge. How to provide good remedial assistance for those with weak foundations and meet the needs of the majority is still an open question.

Second, articulation teaching requires more from the teachers. Teachers should have a good command of the specialised content at the graduate level, be well-versed in the knowledge system and teaching demands of the undergraduate course, and be able to design effective articulation teaching links. How to strengthen the articulation teaching ability of teachers through team collaboration, collective lesson planning and other ways is an important guarantee for the continuous development of the reform.

Thirdly, the quantity of the results of the reform should be increased. At present, most of the assessment methods are in-class performance, homework and test scores, questionnaires, etc.; more organised pre- and post-comparative studies and long-term follow-up data are lacking. In the future, a control group will be added, a stricter quasi-experimental design will be used, and how well it promotes reform will be investigated further.

5. Conclusion

The link between undergraduate studies and graduate specialisation needs to be strengthened to enhance the quality of postgraduate education. The course "Theory and Measurement Techniques of Gas-Liquid Two-Phase Flow" in this paper is a typical case of the reform path for articulation that "builds upon the foundation of undergraduate education and focuses on capability transformation". Based on the above practice, it has been determined that by accurately aligning the knowledge points of undergraduates with the direction of graduate specialisation through a "correspondence matrix and articulation handbook", various tiered training goals can be gradually set for their abilities; effective knowledge transfer via adaptive teaching links can be promoted, all-round knowledge application guided by an integrated assessment system can be carried out, and thus, the problem of disconnection between graduate courses and undergraduate

foundations can be solved effectively, and students' knowledge transfer ability and specialised application competence can be enhanced.

The reform experience in this paper can be used as a reference for other graduate specialisation courses based on undergraduate foundations at the same institution, and some ideas for similar courses can also be obtained by other domestic universities. Of course, the system of projects for reforming the undergraduate-graduate joint-teaching curriculum has many links, such as training programs, curriculum systems, teaching methods and assessments, etc., and further research should be carried out to advance this work from a broader perspective.

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

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