ISSN 2522-6398 Vol. 9, Issue 9: 20-26, DOI: 10.25236/FER.2026.090903

Governance and Practice Innovation in Integrated Virtual–Physical Experimental Teaching in the Intelligent Era

Li Li[1,2], Li Pan[1,*]

[1]Public Experiment & Service Center, Jiangsu University, Zhenjiang, 212013, China
[2]School of Materials Science and Engineering, Jiangsu University, Zhenjiang, 212013, China
**Corresponding author: panli@ujs.edu.cn*

Abstract: *Against the backdrop of educational development and governance in the intelligent era, this study examines how university-level shared platforms for large-scale instruments can effectively support undergraduate experimental teaching. It addresses unstable access to advanced research equipment, fragmented digital support, shallow curricular integration, insufficient collaboration between faculty and technical staff, and weak evaluation feedback. Drawing on the practice of Jiangsu University's shared-instrument platform in undergraduate open and general-education experiments, the study combines literature analysis, practice-based inquiry, and case synthesis to develop a "three layers, one axis, and one feedback loop" model for integrated virtual–physical reform. The three layers comprise platform governance, teaching scenarios, and literacy development; a learning task chain connects activities before, during, and after class; and data-informed feedback drives continuous improvement. The case indicates that the model can convert advanced instruments from research-support assets into stable teaching resources, broaden students' participation in authentic problems, data, and experimental processes, and strengthen digital and scientific literacy. The model offers a transferable framework for universities with comparable platform infrastructure and interdisciplinary teaching needs.*

Keywords: *Experimental Teaching Innovation, Shared Large-Scale Instrument Platform, Virtual–Physical Integration, Educational Digitalization, Digital Literacy*

1. Introduction

Educational digitalization is reshaping both the resource base and the organizational logic of experimental teaching in higher education. China's Outline for Building a Leading Country in Education (2024–2035) calls for advancing the national strategy for educational digitalization and for developing a more integrated, intelligent, and collaborative education system [1]. The national standard for teachers' digital literacy likewise identifies the application of digital technologies, the use of digital resources, and digitally enabled student development as core dimensions of professional competence [2]. In this context, experimental teaching should no longer be understood as a one-off exercise conducted in a fixed laboratory. It should become a sustained learning process through which students engage with authentic questions, data, and technical systems.

Many universities have established shared platforms for large-scale instruments, yet advanced research resources do not automatically become learning resources that undergraduates can access on a sustained basis. Students may see the equipment without entering the experimental workflow, while courses may nominally use the platform without constructing a coherent chain of problems, methods, data, and communication. This gap between resource ownership and pedagogical conversion is a central challenge for experimental teaching in the intelligent era.

From an educational-technology perspective, shared-instrument platforms already possess much of the infrastructure required for innovation. Unified booking, identity authentication, operational monitoring, data logging, and open scheduling can support not only research services but also learning analytics, process traceability, and resource reuse. Educational digital governance therefore involves more than adopting new tools; it requires a systematic reconfiguration of resources, processes, actors, and evaluation [3]. Research on national experimental-teaching demonstration centers similarly shows that sustainable platforms depend on a stable alignment among resource access, operating mechanisms, and educational objectives [4].

This study consequently asks a more precise question than whether access should simply be expanded: how can a university-level shared platform for large-scale instruments be transformed into an integrated virtual–physical learning environment that protects operational safety while enabling authentic, continuous, and reflective undergraduate experimentation? Building on an established institutional practice, the paper develops a “three layers, one axis, and one feedback loop” framework to explain the relationship among digital technology, teaching-process redesign, and platform governance.

2. Literature Foundation and Problem Definition

Virtual simulation, cloud desktops, remote access, and data platforms have increasingly entered university laboratories. Virtual-simulation project clusters can help students understand procedures and anticipate risks before physical operation [5], while cloud desktops and virtual laboratories enable cross-location access, standardized software environments, and data sharing [6]. Their educational value, however, depends on meaningful integration into authentic tasks. If simulation is reduced to passive pre-class viewing, remote access merely improves administrative convenience, or platform data are used only to count instrument hours, technology is unlikely to change how students learn.

International experience with core facilities and remote-analysis infrastructure for large scientific instruments highlights the importance of professional teams, standardized workflows, unified authentication, and shared data environments [7–8]. Undergraduate teaching adds further considerations, including variation in prior knowledge, safety responsibilities, curricular outcomes, and assessment. Research in China has also begun to examine artificial intelligence, virtual–physical integration, and generative AI in laboratory courses. Intelligent tools can support preparation, data processing, and feedback [9]; technical staff can extend their role from equipment maintenance to experimental design, operational guidance, and safety support [10]; and assessment can move from end-product judgment toward process evidence, capability development, and continuous improvement [11].

These studies reveal four connected problems: platform resources exist, but teaching organization remains unstable; digital tools support platform operation more than student learning; instrument use occurs without a complete learning task chain; and process data are collected without systematically informing course improvement.

The empirical setting is Jiangsu University’s university-level shared platform for large-scale instruments, particularly its support for undergraduate open experiments and general-education laboratory teaching. The case was selected because the university has a comparatively complete cross-school sharing system, a sustained process for booking, guidance, logging, and feedback, and projects spanning materials science, chemical engineering, life sciences, medicine, and artificial intelligence. The case is not presented as universally representative; rather, it is a practice sample from a local comprehensive university from which transferable reform principles may be derived.

3. The Integrated Virtual–Physical Reform Model

The proposed model uses three layers to answer three sequential questions: platform governance addresses whether students can enter; teaching scenarios determine how they can participate; and literacy development clarifies what they should ultimately learn. A learning task chain serves as the organizing axis across pre-class, in-class, and post-class activity, while a data-driven feedback loop supports continuous improvement.

3.1. Three Interdependent Layers

The platform governance layer establishes teaching access, coordinated booking, risk classification, and data traceability. Its purpose is not merely to allocate more instrument hours, but to incorporate teaching needs into platform rules and make resource boundaries explicit to faculty, technical staff, and students. High-risk or complex instruments may use a staged pathway: successful online rehearsal, graded on-site authorization, and joint confirmation by the faculty member and technical specialist. As shown in Figure 1, these governance arrangements provide the foundation for an integrated learning environment that connects teaching scenarios, the learning task chain, learning outcomes, and evidence-based feedback.

ISSN 2522-6398 Vol. 9, Issue 9: 20-26, DOI: 10.25236/FER.2026.090903

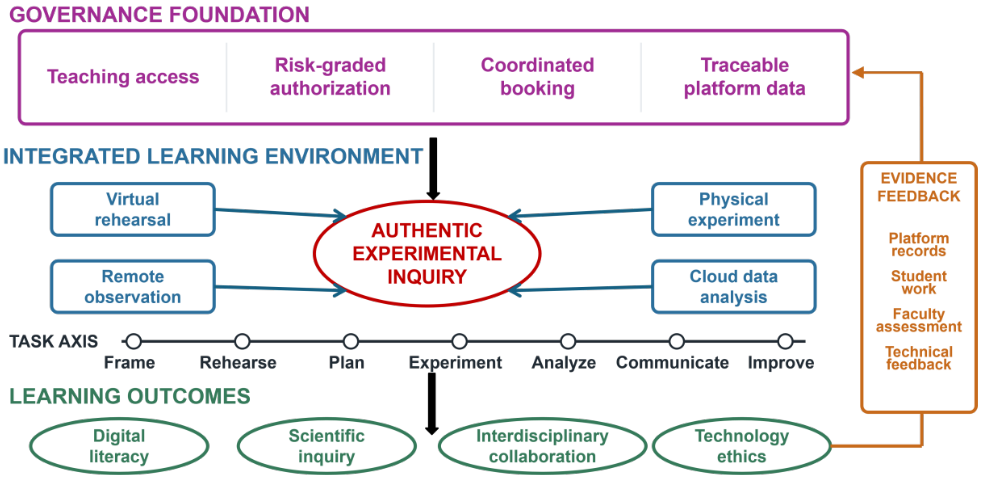

Figure 1: Reform architecture for integrated virtual–physical experimental teaching.

The teaching scenario layer combines modalities according to educational objectives and equipment constraints rather than replacing physical experiments with simulations. Virtual rehearsal builds pre-class understanding of structure, procedures, and safety. Physical experiments support sample preparation, parameter setting, and data acquisition. Remote observation broadens access to crucial operations when all students cannot be present. Cloud analysis supports post-class data processing, interpretation, and collaboration. This design draws on project-based learning's emphasis on authentic problems, sustained tasks, and public outcomes [12], while giving particular attention to the safety and accessibility constraints of advanced equipment.

The literacy development layer moves learning beyond procedural operation. Intended outcomes include the responsible use of digital resources, data-analysis competence, scientific-evidence awareness, interdisciplinary communication, and technology ethics. General-education and interdisciplinary practice studies suggest that engagement with authentic problems and complex evidence helps students connect scientific methods with societal issues [13–14]. Data produced by advanced instruments are often open to interpretation and uncertainty; they therefore show students that scientific conclusions emerge from methodological choices, parameter control, evidence comparison, and reasoned argument rather than a single standard answer.

3.2. One Task Axis and One Improvement Loop

The learning task chain organizes a continuous sequence of problem framing, virtual rehearsal, plan discussion, physical experimentation, data analysis, outcome communication, and reflective improvement. The feedback loop integrates booking data, rehearsal records, on-site observations, student work, faculty assessment, and technical-staff feedback. Platform data thus become evidence for pedagogical diagnosis and resource optimization rather than remaining administrative statistics. Table 1 summarizes how the major elements of the proposed model respond to the practical problems identified above and translate them into corresponding design strategies and expected contributions.

Table 1: Alignment between the reform model and practical problems.

Model element	Problem addressed	Key design	Expected contribution
Platform governance layer	Unstable teaching access and unclear safety boundaries	Project admission, instrument risk grading, coordinated booking, and traceable data	Stable conversion of platform resources into teaching resources
Teaching scenario layer	Separation of digital tools from the learning process	Virtual rehearsal, physical experiments, remote observation, and cloud analysis	Accessible and participatory learning scenarios
Literacy development layer	Objectives confined to procedural operation	Digital-resource use, evidence interpretation, interdisciplinary collaboration, and technology ethics	Development of integrated literacy and scientific inquiry
Learning task chain	Fragmented and shallow course experiences	Problem framing, plan discussion, experimentation, analysis, and communication	A continuous inquiry process centered on instrument use
Feedback loop	Process data do not inform improvement	Platform records, student work, faculty assessment, and technical-staff feedback	Continuous optimization of courses and the platform

ISSN 2522-6398 Vol. 9, Issue 9: 20-26, DOI: 10.25236/FER.2026.090903

4. Implementation Through Open Experimental Projects

4.1. Resource Inventories and Tiered Access

The first step is a teaching-oriented resource inventory. Beyond equipment names, the inventory should identify relevant topics, output data types, operations in which students may participate, risk level, opening times, and technical-support requirements. Instruments with highly visual outputs, manageable risks, and interdisciplinary value can be prioritized for general-education and open projects. Equipment with complex operations, strict environmental requirements, or costly sample consumption may be used through instructor demonstrations, student rotation, remote observation, or analysis of provided data.

Tiered access makes openness operational. Before entering the laboratory, students complete virtual rehearsal, safety learning, and interpretation of key parameters. On site, their permitted role—observation, assisted operation, or independent operation—is defined by instrument risk. After the experiment, students submit data records and reflections through the platform. This process protects laboratory safety while ensuring a shared baseline of understanding.

4.2. Connecting Virtual Rehearsal with On-Site Operation

Virtual rehearsal should mirror the critical steps of the physical experiment rather than pursue animation complexity for its own sake. In materials-characterization experiments, for example, pre-class resources may cover instrument structure, sample-stage installation, vacuum-system risks, interpretation of representative spectra, and diagnosis of abnormal conditions. Because foundational procedures are learned in advance, on-site time can focus on parameter selection, data-quality judgment, and discussion. Evidence from integrated virtual–physical zoology laboratories similarly suggests that pre-class virtual training combined with physical operation reduces risk and improves procedural understanding [15].

Open-project cohorts often include students from different disciplinary backgrounds. Rehearsal provides a common entry point, enabling non-specialists to understand what an instrument does, what its data mean, and how those data answer a question. This does not lower standards; it makes explicit the operational logic that otherwise remains tacit in the experience of teachers and technical staff.

4.3. Reconstructing the Course around a Learning Task Chain

Advanced instruments become learning resources only when embedded in a coherent task chain. In an open project on energy-material testing and characterization, students begin with the question of how material structure and morphology affect performance and what evidence is needed to support a judgment. They then study instrument principles and safety through the platform; observe samples, set parameters, and acquire data under joint guidance; and subsequently interpret images, spectra, or response curves before presenting a group conclusion.

The objective is not for every student to operate every instrument independently, but for each student to experience an integrated chain of questions, methods, and evidence. Research in chemistry education indicates that students' understanding of what scientists do depends substantially on opportunities to engage with authentic research questions and evidential reasoning [16]. The educational value of advanced equipment therefore lies not only in its technical sophistication but in its capacity to connect abstract theory, real samples, data interpretation, and scientific communication.

4.4. Faculty–Technical Staff Collaboration

Teaching with advanced instruments requires joint work by course faculty and platform specialists. Faculty members understand educational objectives, knowledge structures, and student differences; technical staff understand instrument capabilities, operational risks, and data-quality control. Before class, the two groups jointly define objectives, access boundaries, and assessment criteria. During class, faculty guide questions, concepts, and discussion, while technical staff supervise critical procedures, safety, and data quality. After class, they jointly review student reports, platform records, and feedback.

This mechanism also addresses the marginal position that technical staff may occupy in teaching. Recognizing their contributions to course design, experimental guidance, and resource development in teaching-reform outputs and performance evaluation can sustain a genuine experimental-teaching community. Figure 2 illustrates how the learning task chain unfolds across the pre-class, in-class, and post-class stages, with faculty guidance, technical-staff support, and platform data providing

ISSN 2522-6398 Vol. 9, Issue 9: 20-26, DOI: 10.25236/FER.2026.090903

complementary support throughout the process.

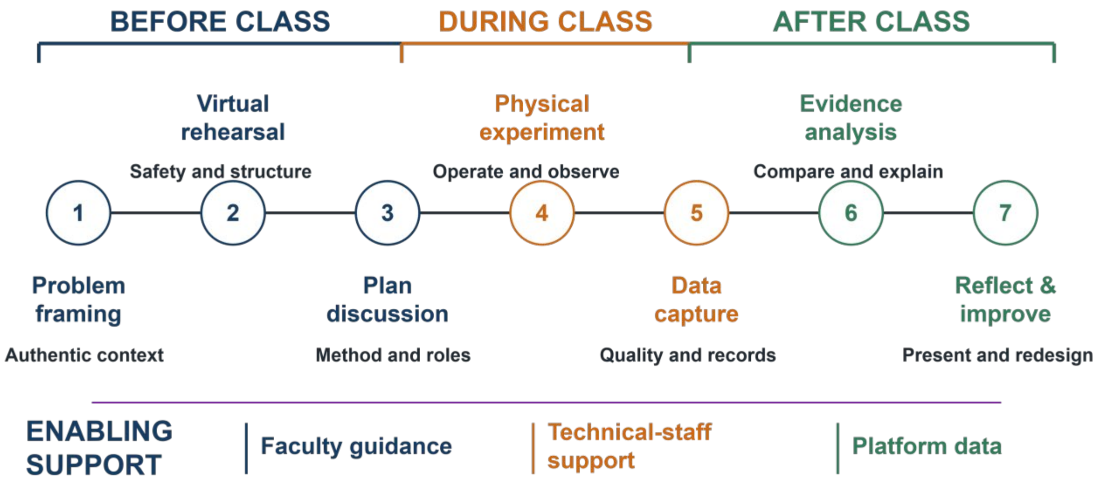

Figure 2: Learning task chain and staged implementation process for integrated virtual–physical experimental teaching.

4.5. Process Assessment for Continuous Improvement

Assessment limited to report format and result correctness overlooks much of students' actual learning. The model therefore covers pre-class, in-class, and post-class performance, including appropriate use of digital resources, plan development, interpretation of experimental data, and teamwork. Curriculum-reform research in medical education likewise emphasizes linking an evaluation framework with learning evidence and feedback rather than relying on a single end-of-course judgment [11].

Platform data are important evidence but cannot replace professional judgment. A booking record confirms participation, not conceptual understanding; a rehearsal score indicates preparation, not necessarily on-site competence. A defensible evaluation therefore triangulates platform records, faculty observations, technical-staff feedback, laboratory reports, and group presentations. Accordingly, Table 2 presents a process-oriented assessment framework that links each assessment dimension with its observation focus, evidence source, and use for subsequent improvement.

Table 2: Process-oriented assessment framework.

Dimension	Observation focus	Evidence source	Improvement use
Pre-class preparation	Completion of rehearsal; recognition of key risks and parameters	Platform records, quizzes, and task sheets	Revise preparatory resources and access criteria
Plan design	Coherence among the question, method, and expected data	Discussion records and faculty observation	Refine problem framing and task difficulty
Operational compliance	Adherence to safety rules and understanding of operational boundaries	On-site observation and technical-staff feedback	Strengthen guidance and risk prompts
Data analysis	Interpretation of conclusions supported by spectra, curves, or images	Reports, data files, and group presentations	Improve data templates and analytic training
Collaboration and communication	Appropriate division of work, clear communication, and specific reflection	Presentations, peer review, and reflection logs	Improve team tasks and assessment criteria

5. Outcomes, Discussion, and Transferability

The case was examined in terms of teaching organization, student participation, data-informed feedback, and transferability. In 2025, Jiangsu University implemented 22 undergraduate open experimental projects through the university-level shared-instrument platform. Projects originated from materials science, chemical engineering, life sciences, medicine, artificial intelligence, and other fields. The figures should be interpreted as evidence from a local comprehensive university rather than as a universal institutional pattern.

ISSN 2522-6398 Vol. 9, Issue 9: 20-26, DOI: 10.25236/FER.2026.090903

5.1. From Ad Hoc Coordination to Advance Planning

Platform-supported teaching has gradually shifted from temporary equipment borrowing toward project-based, task-oriented, and digitally coordinated organization. Previously, the use of advanced instruments depended heavily on gaps in research schedules and repeated negotiation among course times, bookings, and technical support. Under the reformed arrangement, equipment availability, technical support, safety clearance, and data archiving are considered when projects are proposed and implemented. The platform can assess whether project requirements match operating conditions, while faculty can design tasks around the equipment and data that will actually be available.

This change is more consequential than administrative convenience. Advanced instruments become stable elements of the course rather than optional experiences, and their use is connected to problem framing, experimental design, observation, data analysis, and communication. Dependence on incidental research downtime decreases, while the predictability of teaching and continuity of participation improve.

5.2. From Watching Experiments to Conducting Inquiry

In conventional visits or demonstrations, contact with advanced equipment often remains observational. Combining virtual rehearsal, group rotation, remote observation, and cloud analysis allows students to contribute to question discussion, parameter interpretation, data comparison, and explanation even when they cannot independently operate the instrument throughout. General-education laboratories do not require non-specialists to master every procedural detail; they should help students understand how contemporary science and technology produce evidence, explain problems, and respond to social needs.

5.3. Using Platform Data to Improve Teaching

Participation in open experimental teaching increased from 2,926 student attendances in 2023 to 7,314 in 2025, indicating a substantial expansion in the platform's undergraduate reach. More importantly, operational and learning-process data can help identify inadequate preparation, periods of high demand for technical support, and instruments with strong potential for pedagogical conversion. Growth in participation does not by itself establish educational effectiveness; future evaluation should collect evidence of changes in question formulation, data interpretation, report writing, and interdisciplinary collaboration. Generative AI can assist resource organization, data analysis, and feedback generation, but its use must remain subject to faculty judgment and academic-integrity standards [9].

5.4. Transferability and Boundaries

The model has three principal areas of transferability. Universities with shared-instrument platforms can increase educational contribution through resource inventories, tiered access, and task-chain design. Cross-school, multi-campus, or large-cohort teaching can extend access through remote observation and cloud analysis. Programs in emerging engineering, medicine, agriculture, and interdisciplinary fields can introduce authentic samples, data, and problems to strengthen openness and inquiry.

The model also has clear limits. Not every advanced instrument should be directly opened to undergraduates, and not every experimental step should be moved online. Equipment involving high hazards, extremely narrow operating windows, or stringent environmental stability should remain under technical-staff leadership. International core-facility experience similarly demonstrates that sharing depends on stable governance, professional personnel, and sustained service capacity [7]. The aim is therefore neither "total openness" nor "everything online," but an appropriate combination based on educational objectives, equipment risk, and student readiness.

6. Conclusions and Recommendations

Reform of university experimental teaching in the intelligent era is not achieved by adding equipment or layering digital tools onto existing classes. It requires an operational and improvable system that coordinates resource access, technical support, curricular tasks, professional collaboration, and evaluative feedback. The "three layers, one axis, and one feedback loop" model explains how a shared platform for large-scale instruments can be transformed from research infrastructure into an experimental learning environment. The case suggests positive contributions to resource accessibility, scenario expansion, process participation, and digital-literacy development.

Three priorities can deepen the reform. First, universities should build teaching-oriented experimental data repositories that preserve representative samples, procedures, raw data, analysis templates, and high-quality student work as reusable resources. Second, intelligent learning-support tools can provide operational reminders, anomaly alerts, and individualized feedback without replacing faculty judgment. Third, institutional evaluation should recognize the teaching contributions of technical staff in course development, student guidance, and resource creation. With these conditions in place, shared large-scale instruments can become durable infrastructure for experimental-teaching innovation and digital-literacy development.

Acknowledgements

This research was supported by the Basic Research Program of Jiangsu (Grant No. BK20250853) and the Education Special Program of Zhenjiang Science Applied Research (Grant No. 2026JY218).

References

[1] Communist Party of China Central Committee and State Council. Outline for Building a Leading Country in Education (2024–2035) [Z]. 2025. (in Chinese).

[2] JY/T 0646–2022. Digital Literacy of Teachers [S]. (in Chinese).

[3] Zhu, Z. T., & Du, R. Integrating principles and instruments: A systemic framework and mechanism study of intelligent governance for educational digitalization [J]. China Educational Technology, 2026(1), 1–12. (in Chinese).

[4] Li, Y., Yang, H. J., & Qi, G. J. Sustainable development of national experimental teaching demonstration centers [J]. Research and Exploration in Laboratory, 2025, 44(2), 117–122. (in Chinese).

[5] Xu, L., Wang, H. P., Gao, Z. Y., et al. Construction of virtual-simulation experimental teaching project clusters in comprehensive universities [J]. Research and Exploration in Laboratory, 2021, 40(12), 187–190. (in Chinese).

[6] Jiang, Y., & Chen, S. J. Construction of computer virtual laboratories based on cloud desktops [J]. Research and Exploration in Laboratory, 2025, 44(7), 224–228. (in Chinese).

[7] Gagnon, M., Côté, A., Costantino, S., et al. Laboratory management models in core facilities [J]. Journal of Biomolecular Techniques, 2023, 34(2), 40–52.

[8] De Vita, R., Rind, O., Benjamin, D., et al. The creation and evolution of the US ATLAS shared analysis facilities [J]. EPJ Web of Conferences, 2024, 295, 07013.

[9] She, Y., Zhuang, Q. X., Zhang, H. R., et al. Generative AI-supported experimental courses in materials science in the era of digital intelligence [J]. Polymer Bulletin, 2025, 38(6), 958–966. (in Chinese).

[10] Li, Y., Ke, Y., Jiang, J. Y., et al. The teaching role of experimental technical staff in laboratory courses [J]. Research and Exploration in Laboratory, 2017, 36(6), 263–266. (in Chinese).

[11] Alwadei, A. Utilizing evaluation and development frameworks to engineer a college-wide evaluation and reform of an undergraduate dental curriculum [J]. Advances in Medical Education and Practice, 2023, 14, 145–156.

[12] Wang, C. L., Guan, H., & Jiang, J. W. Interdisciplinary practical activities: Concept, teaching value, and implementation strategies [J]. Chinese Journal of Chemical Education, 2025, 46(23), 11–18. (in Chinese).

[13] Yan, Z., Yang, J., Xiong, L., et al. Integrating research-project outcomes into general-education courses [J]. Journal of Biology, 2024, 41(2), 126–130. (in Chinese).

[14] Yang, T. H., Li, R. D., He, Y. G., et al. Exploration and practice of the general-education course Energy, Environment and Sustainable Development through a values–critical thinking–systems thinking framework [J]. Research in Higher Education of Engineering, 2023(S1), 98–101. (in Chinese).

[15] Chen, Y. B., Du, K., Fu, Y. Y., et al. Integrated virtual–physical teaching in a general zoology laboratory course [J]. China Poultry, 2022, 44(2), 117–120. (in Chinese).

[16] Martinez, B. L., Roche Allred, Z. D., & Underwood, S. M. A qualitative investigation of higher education chemistry students' perceptions of what scientists do [J]. Journal of Chemical Education, 2024, 101(10), 4071–4082.