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Authentic Learning in Physics Laboratories: A Case Study from Beijing Institute of Technology

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Abstract: Authentic learning is designed for second-year undergraduates majoring in science and engineering at Beijing Institute of Technology (BIT). Students form teams to investigate diverse topics rooted in fundamental physical phenomena observed in nature, daily life, or industrial applications. The learning process involves literature review, experimental design, setup construction, data analysis, and final report writing. Over a semester, students significantly improve their abilities to analyze and solve complex problems. This paper outlines the content, methodology, assessment, and outcomes of the authentic learning approach implemented at BIT, aiming to provide a reproducible model for physics laboratory education reform in Chinese universities.

Keywords: Authentic learning; Physics experiment; Innovative capacities; CUPT; BJUPEC

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1. Introduction

Undergraduates majoring in science and engineering at Beijing Institute of Technology (BIT) are required to complete a University Physics Experiment course in their second year. These basic experiments cover mechanics, electricity, optics, and atomic/molecular physics, with typical examples including measuring Young's modulus, determining the heat capacity ratio of air, investigating the Hall effect, using a Michelson interferometer, and conducting the Franck-Hertz experiment [1,2]. These are primarily verification-based experiments with predetermined outcomes, designed to enhance students' practical skills and deepen their understanding of relevant theories through hands-on operation. When performing these experiments, students follow step-by-step instructions and typically complete each task within a few hours. While valuable for foundational training, traditional experimental approaches and teaching methods have notable limitations in fostering students' innovative capabilities [3,4].

To address this gap, authentic learning—an approach that immerses students in open-ended investigations mirroring the practices of professional researchers—offers a promising solution [5]. We have therefore developed and implemented an authentic learning elective course for interested students. The topics of this course are derived from the problems of the China Undergraduate Physics Tournament (CUPT) and the Beijing Undergraduate Physics Experiment Competition (BJUPEC), which consistently supply open-ended, real-world tasks suitable for authentic learning [6]. Students are divided into teams of two or three to focus on one topic over a semester, with their performance evaluated through comprehensive assessments. The course aims to prepare students for outstanding academic and research careers. This paper details the course objectives, content design, implementation workflow, evaluation criteria, and educational outcomes.

2. Content of authentic learning

The topics selected for the authentic learning course fully embody the characteristics of authentic experimentation: they are open-ended, with no predefined research ideas or methods. Consequently, there is no single "correct" answer to each topic; instead, solutions are distinguished by the ingenuity of their approach, breadth of perspective, comprehensiveness, rationale, and depth of investigation.

Furthermore, the topics cover both physics related to natural and daily-life phenomena and physics applied in industrial contexts. Below are two representative examples from everyday experiences:

Crazy suitcase: When one pulls along a two-wheeled suitcase, it can, under certain circumstances, wobble so strongly from side to side that it can turn over. Investigate this phenomenon. Can one suppress or intensify the effect by varying the packing of the luggage? (CUPT 2016)

Earth's physical parameters: Set up an experimental device to measure the physical parameters of Earth. (BJUPEC 2016)

These topics are closely tied to students' daily experiences, making it easier to stimulate their research interest and enthusiasm for exploration. Additional examples related to industrial applications include:

Electromagnetic cannon: a solenoid can be used to fire a small ball. A capacitor is used to energize the solenoid coil. Build a device with a capacitor charged to a maximum of 50 V. Investigate the relevant parameters and maximize the speed of the ball. (CUPT 2010)

Stirling engine: Make a Stirling engine, and research its performance. (BJUPEC 2014)

Such topics effectively demonstrate the integration of theory and practice, enabling students to better understand physics' role in industrial development.

Since only phenomenon descriptions are provided (without restrictive conditions or fixed parameters), students must employ open-ended thinking to conduct comprehensive investigations. To achieve this, they need to design and assemble their own experimental apparatus to explore how various factors—such as material properties, environmental conditions, initial states, and structural characteristics—influence experimental outcomes.

Moreover, students are often required to develop theoretical models beyond the scope of standard coursework to compare predictions with experimental results and analyze error sources. For instance, in the "Crazy Suitcase" topic (CUPT 2016), students must first propose a theoretical explanation for the wobbling mechanism based on mechanical principles, then design experiments to test how factors like luggage weight distribution, handle height, wheel material, and surface roughness affect wobble intensity. They also need to compare experimental data with theoretical simulations to identify potential errors (e.g., neglecting air resistance or simplifying center-of-mass calculations).

Typical topics and their underlying fundamental physics from CUPT and BJUPEC over the past decade are summarized in **Tables 1** and **2** (nature/daily life and industrial applications, respectively).

Table 1. Topics related to fundamental physics in nature and daily life

Topics	Fundamental
Water Spiral: If a stream of liquid is launched through a small hole, then under certain conditions it twists into a spiral. Explain this phenomenon and investigate the conditions under which the spiral will twist. (CUPT 2022)	Fluid dynamics, Instabilities
Refraction: Study the refractive properties of a substance and create a practical application device based on these properties. (BJUPEC 2022)	Refractive index, Snell's Law, Optical device
Rebounding Capsule: A spherical ball dropped onto a hard surface will never rebound to the release height, even if it has an initial spin. A capsule-shaped object (i.e. Tic Tac mint), on the other hand, may exceed the initial height. Investigate this phenomenon. (CUPT 2021)	Energy conservation, Elastic collision, Angular momentum
Random: Set up an experimental device to study random physical phenomena. (BJUPEC 2021)	Stochastic processes, Statistical regularity
Acoustic levitation: Small objects can levitate in acoustic standing waves. Investigate the phenomenon. To what extent can you manipulate the objects? (CUPT 2018)	Standing wave, Sound pressure, Potential energy
Granular Matter: Experimentally study the physical properties of granular materials (particles at the micrometer scale and above without quantum effects). (BJUPEC 2018)	Nonlinear phenomena, Friction, Volume fraction
Paper vice: Take two similar paperback books and interleave a few pages at a time. Push the books together. Hold the two books by their spines and try to pull them apart. Investigate the parameters that set the limits of being able to separate the books. (CUPT 2016)	Static friction, Self-locking phenomenon
Earth's Physical Parameters: Set up an experimental device to measure the physical parameters of Earth. (BJUPEC 2016)	Geomagnetic field, Gravitational acceleration
Thick lens: A bottle filled with a liquid can work as a lens. Arguably, such a bottle is dangerous if left on a table on a sunny day. Can one use such a 'lens' to scorch a surface? (CUPT 2015)	Focusing, Ignition point
Set up an experimental device to study the physical properties of water or an aqueous solution. (BJUPEC 2015)	Density, Conductivity, Viscosity coefficient

Table 2. Topics related to fundamental physics in industrial applications

Topics	Fundamental
Create a non-invasive device that determines the direction of fluid flow inside an opaque pipe. Optimize your device so that you can measure the smallest flow possible. (CUPT 2022)	Fluid dynamics, Non-invasive measurement
Thermal deformation: Study the thermal deformation properties of a substance and create a practical application device based on these properties. (BJUPEC 2021)	Thermal expansion, Thermo-mechanical deformation
Magnetism: Investigate the properties of a specific magnetic material and utilize it to develop a functional device for practical applications. (BJUPEC 2020)	Magnetic materials, Magnetization characteristics
Spatial Positioning: By utilizing physical principles and constructing self-built experimental setups to achieve the spatial positioning of objects. (BJUPEC 2019)	Spatial positioning principles, Time of flight
Construct a simple seismograph that amplifies a local disturbance by mechanical, optical, or electrical methods. Determine the typical response curve of your device and investigate the parameters of the damping constant. What is the maximum amplification that you can achieve? (CUPT 2018)	Disturbance, Damping, Amplification
Hair Hygrometer: A simple hygrometer can be built using human hair. Investigate its accuracy and response time as a function of relevant parameters (CUPT 2017)	Surface tension, Adsorption, Relative humidity
Design and make a vibration source, and then measure its characteristics (BJUPEC 2017)	Amplitude, Frequency, Period
Magnetic Train: button magnets are attached to both ends of a small cylindrical battery. When placed in a copper coil such that the magnets contact the coil, this "train" starts to move. Explain the phenomenon and investigate how relevant parameters affect the train's speed and power (CUPT 2016)	Solenoid, Magnetic field, Ampere force
Magnus Glider: glue the bottoms of two light cups together to make a glider. Wind an elastic band around the center and hold the free end that remains. While holding the glider, stretch the free end of the elastic band and then release the glider. Investigate its motion (CUPT 2015)	Bernoulli effect, Magnus effect, gyroscopic effect
Design and build an application device based on the principle of mutual inductance, study its mutual inductance characteristics, and device performance (BJUPEC 2015)	Mutual induction, Magnetic field, Energy conversion

3. Process of authentic learning

The authentic learning course is listed on BIT's Teaching Office website, with annual registration. In addition to this course, BIT offers other similar electives, such as robotics, optoelectronic devices, racing car design, and aeromodelling. During the registration period, an information session is organized to clarify the course objectives, content, research facilities, timelines, and assessment criteria. This session motivates students to enroll based on two key incentives: expanding their physics knowledge and enhancing innovative capacity, and gaining opportunities to participate in CUPT and BJUPEC competitions for awards.

Approximately 400 students apply for the authentic learning course each year. After an interview process, around 90 are admitted. These students form teams and dedicate their spare time and weekends to research: reviewing existing studies, learning relevant knowledge, designing experimental schemes, constructing setups, conducting repeated experiments, collecting large datasets, analyzing data and errors, developing theoretical models, and ultimately uncovering underlying physical principles. This work takes place in innovative practice laboratories or teaching laboratories. Students often purchase experimental materials (e.g., acrylic plates, electronic components, flowmeters, sensors) and may design/fabricate custom devices (e.g., water tanks, brackets, turntables, small wind tunnels). They also have access to advanced equipment from scientific research laboratories, such as high-speed cameras and microscopes. A typical project takes one semester to complete.

Student achievements are assessed through oral presentations and project demonstrations. Evaluation criteria include: clarity of physical principles, ingenuity/novelty of experimental methods, reasonableness of measurements and data analysis, consistency between experimental results and theoretical predictions, logical organization of presentation materials, and fluency of oral delivery. Detailed evaluation criteria are outlined in **Table 3**.

Table 3. Evaluation criteria

Score	Theory/ model (30%)	Relevant experiments (30%)	Theory- experiment comparison (10%)	Innovativeness/ own contribution (20%)	Presentation(10%)
0	**Almost none**	**Too few**	None/ almost none	None/ almost none	Poor
1	Some presented	Some elements included	Some attempt made	Some aspects fine	Partially adequate
2	Fair	Fair	Not well fitted	Fair	Not clear
3	Good	Well performed, sufficient data	Deviations qualitatively analyzed	Some interesting results	Clear statement, some errors
4	Quite detailed and correct	Good results, errors analyzed	Theory limits explained, conclusive	Considerable experimental/ theoretical effort	Clear, correct, PPT not very elegant
5	Detailed, complex, completely testable	Deep, comprehensive, with physical insight	Well fitted, deviations analyzed, conclusive	Considerable experimental and theoretical innovation	Clear, exquisite PPT, correct answers

When students encounter research difficulties, they can consult instructors for guidance and support at any time. The university covers costs for consumables and device fabrication. Additionally, we have drawn inspiration from the authentic learning program at the University of Technology Sydney, integrating some of their advanced pedagogical ideas into our teaching practices.

Through authentic learning—emphasizing solving real-world problems from a physical perspective—we aim to cultivate students' innovative capacity, innovation awareness, scientific research literacy, teamwork skills, and communication competence.

4. Training outcomes

By engaging with and completing authentic learning topics, students develop comprehensive academic competencies, including literature retrieval, physical model abstraction, theoretical derivation/calculation, research plan design, experimental setup construction, data acquisition/analysis, numerical simulation, law summarization, academic exchange, and research paper writing. In short, the program lays a solid foundation for cultivating top-tier innovative talents. Over the past decade, participating students have published more than 60 first-author papers and secured opportunities to pursue further research at world-class universities.

A student shared the following feedback in a post-course survey:

"Authentic learning taught us much knowledge and many skills beyond textbooks. First, when selecting a topic, we learned to search and review literature using databases such as CNKI, Wanfang, and Web of Science. We developed the ability to quickly assess whether a paper meets our needs by reading its abstract and conclusion. Literature review helped us understand research backgrounds, prospects, and methods, which guided our experimental design, procedure development, and result prediction.

Second, we mastered software tools such as MATLAB, Origin, Sketchpad, and LaTeX. Data processing software enabled us to solve problems that theoretical deduction alone cannot address—such as approximating solutions to transcendental equations or finding inverse functions—while making experimental results clearer and more visually intuitive.

Third, we designed and built experimental setups. This involved drafting mechanical components for manufacturing, sourcing materials from suppliers, and sometimes communicating directly with technicians and vendors to ensure materials met our requirements. We then conducted repeated experiments, analyzed data, identified error sources, and continuously improved experimental accuracy. This lengthy process required great patience and significantly enhanced our hands-on skills.

Finally, we synthesized our findings into research papers. Writing a paper is not simply stacking experimental results but constructing a logical narrative—from research purposes and background to theoretical derivation, experimental design, results, error analysis, and conclusions. Academic papers are highly logical: each sentence connects to those before and after, serving a specific purpose. We discussed the paper with our instructor sentence by sentence, made continuous revisions, and ultimately completed and submitted the draft.

Authentic learning provided valuable scientific research practice, enriching our experience, strengthening our abilities, and laying a foundation for future development."

In addition to academic skills, students' personal qualities are greatly enhanced—including curiosity for exploring the unknown, self-directed learning and management habits, teamwork spirit, communication/social skills, and resilience in the face of setbacks. These competencies and attributes form a solid foundation for their future careers, enabling them to become high-quality, innovative talents with great potential.

5. Conclusion

The implementation experience and outcomes of authentic learning demonstrate that this approach emphasizes the integration of theory and practice more effectively than traditional experimental teaching. In particular, authentic learning not only deepens students' understanding of physical principles and their applications but also proves highly effective in fostering innovative thinking and practical skills. Therefore, authentic learning represents a pedagogical model worthy of broader attention and implementation in university physics laboratory education.

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Disclosure statement

The authors declare no conflict of interest.

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