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Research on the Core Difficulties in High School Physics Electromagnetism and the Suitability of One-to-One Project-Based Instruction

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Abstract

High school physics electromagnetism is considered one of the difficult and essential parts of the entire physics curriculum because it contains abstract concepts, a large number of calculations, and difficult experiments. All three are problems of the traditional large-class lecture mode, the project-based teaching model and individualised learning, and they cannot meet the different cognitive levels of students and fail to achieve the dual goal of cultivating core competencies. Therefore, this paper will use constructivism, pragmatism and situated learning theory as its theoretical basis to systematically study the three problems of electromagnetism. Next, it will examine the soundness of the correspondence between one-to-one project-based teaching and the teaching of electromagnetism. Next, it puts forward some specific ways to achieve this in the three areas of project design, tiered guidance and diverse assessment; finally, it hopes to offer some practical teaching ideas for front-line teachers of electromagnetism. The above methods can help to address the problems in teaching and promote all-round development of students' basic physics abilities.

Keywords

High School Physics; Electromagnetism; One-to-One Instruction; Project-Based Learning; Instructional Alignment.

1. Introduction

Electromagnetism in high school physics is a typical part of classical physics and also features in the evaluation of the college entrance examination. At the same time, electromagnetism is also used in production, daily life and modern technology. At present, many parts of daily life and the electromagnetic control system for aerospace are based on the laws of electromagnetism. Therefore, the teaching of electromagnetism can be employed to achieve all the main physics competencies. Currently, there are many problems in the teaching of electromagnetism, such as the abstractness of physical concepts being difficult for students to grasp and significant differences in their learning. The above problems show that the current teaching model has some deficiencies; traditional large-class lectures cannot meet the different learning speeds of individual students, project-based teaching in large classes is often difficult to carry out properly due to free-riding behaviour from students, and one-on-one personalised instruction lacks contextual inquiry vehicles, so students are unable to build an all-encompassing knowledge system. Therefore, to solve the problems of traditional teaching of electromagnetism, a new integrated teaching model that can combine the advantages of different teaching methods needs to be built. It is the same one-to-one project-based instruction model constructed in this paper. The three main theoretical foundations of this teaching model are Constructivism, Pragmatism and Situational Learning. Constructivism is the theory that

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people learn by creating their own knowledge structures through interaction with the world based on previous experiences; therefore, personalised inquiry tasks need to be designed in teaching [1,2]. Pragmatism is about teaching problems that are close to life and helping students learn by solving these problems [3,4]. According to situated learning theory, the meaning of knowledge is contained in a particular situation and can only be understood there. Personalised advantage of one-to-one teaching is that teachers can create different learning situations based on students' various levels of understanding abstract ideas [5,6].

2. Review of Domestic and International Research

Research on project-based learning and one-to-one personalised instruction has begun abroad recently. At the University of Piura in Peru, a course in electromagnetism for engineering students has been given by way of real-life projects, such as the construction of a Faraday cage model and the design of renewable energy devices. Under the teacher's direction, the students formed groups to prepare Design Proposals and organised all sorts of tests and experiments to boost their application skills [4]. Keller's personalisation of learning was also employed to organise the steps in the learning of electromagnetism into 12 stages at the Federal University of Pará in Brazil. Based on the first diagnostic test, some students lacked knowledge and were then tutored one-on-one weekly. This can help the students better understand the basic knowledge and reduce their fear of learning [7].

Chinese studies on this subject can be divided into two general categories. Firstly, after an organised analysis of the main problems in electromagnetism, it has been found that there are four key issues: difficulty in grasping abstract concepts, lack of connections between mathematical tools and real life, weak analysis ability for complex processes, and insufficient experimental inquiry skills [8]. Second, Actual Applications of Project-based Learning in Chinese Schools. Dunhuang High School in Gansu Province carried out a strict comparison of project-based teaching with the self-inductive coil circuit experiment. Based on the above analysis, it was found that project-based learning classes had a higher proportion of high-scoring students and showed good overall academic progress compared with the old-style teaching mode [9].

Although many studies have been conducted around the world on the teaching of electromagnetism, there are two main deficiencies in the current research: First, one-to-one instruction and project-based learning have been studied separately and have not been integrated; Second, although the existing teaching methods address individual problems, a systematic solution to several core difficulties has not been put forward. Therefore, this paper will take both paths and design corresponding instructional paths.

3. Core Difficulties in High School Physics Electromagnetism

3.1. Conceptual Comprehension Challenges

The main reason for the difficulty in conceptual understanding is that it cannot be applied to the abstract knowledge of electromagnetism. Fields are special kinds of matter that cannot be directly sensed by the five senses. Therefore, students often learn based on the ideal model of electric field lines and magnetic field lines, which may be prone to cognitive bias [10]. Furthermore, there are many interconnected logical relations among electromagnetic concepts. The definition of magnetic flux is directly based on the vector nature of magnetic flux density, and in the analysis of electromagnetic induction, changes in magnetic flux must be assessed. Therefore, there may be some problems with the ideas. In addition, the formulas for the ratio of electric field strength (1) and electric potential (2) are very similar, but they are actually

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different types of physical quantities. Therefore, there will be a serious lack of understanding [11].

$$E=\frac{F}{q} \tag{1}$$

$$\phi=\frac{E_p}{q} \tag{2}$$

3.2. Challenges in Mathematical-Physical Integration

The combination of mathematics and physics is a characteristic of high school electromagnetism that should be known to students, and it is also one of the difficulties in learning this subject. Algebraic operations are used to compute physical quantities, and knowledge of functions and graphs can be applied to analyze dynamic problems to extract physical meaning from the slope, intercept and area of graphs [12]. Geometric knowledge has found very beautiful applications in the problems of circular motion of charged particles. Vector composition and decomposition are needed to analyse Ampere's force and the Lorentz force; at the same time, the concept of infinitesimal is also included in the definition of induced electromotive force and the calculation of work done by variable forces. Therefore, the ideas of functional equations, integration of numbers and shapes, and geometry have become important means of addressing problems in electromagnetism. Comprehensive dual-rod model problems are good examples of the above concepts [13].

3.3. Experimental Operational Challenges

The four general types of problems in electromagnetism experiments are: not knowing the rules, choosing a method, collecting and analysing data, etc. In the resistivity measurement experiment, one needs to decide whether to connect the ammeter inside or outside the unknown resistor independently according to the features of the unknown resistor and the internal resistance of the ammeter. Based on this, we need to derive how the ammeter's internal resistance will affect the measurement circuit. The three methods for measuring the electromotive force and internal resistance of a power source are the volt-ampere method, the ampere-resistance method and the volt-resistance method; they have different theoretical bases, application scopes and error origins. Therefore, in order to process the data, graphical analysis must be employed [14]. The difficulty of the electromagnetic induction experiment is that there are very few obvious phenomena that can be seen. The induced current is very small, so students need to carefully control the experimental parameters and repeat the experiment many times to derive Lenz's Law reasonably and rigorously. Many students can carry out the steps in practice but cannot form a basic connection between pointer deflection and magnetic flux change [15].

4. Analysis of the Suitability of One-to-One Project-Based Instruction for Electromagnetism Instruction

4.1. Personalized Guidance for Precise Overcoming of Knowledge Difficulties

Individualised Direction in one-to-one project-based teaching can solve the problem that students are learning electromagnetism in an imprecise manner. Teachers can use concept differentiation questions, mathematical application problems and knowledge interviews to find the precise conceptual problems. Based on the results of cognitive diagnosis, personalised learning paths will be designed for the students. When there are problems in the understanding

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of concepts, concrete simulations and comparative analysis of concepts are used. Tiered progressive tasks will be prepared for students with difficulties in mathematical integration according to their foundation in mathematics. Students are led to draw diagrams to discover the physical meaning, practice vector operations, and thus intuitively feel the idea of infinitesimals [16].

4.2. Project-Based Learning Effectively Enhances Experimental Skills

Project-based learning can help solve the problems that have arisen in electromagnetism experiments due to the reality of life. Problems-based learning gives students a reason to learn the rules of experiments. Set goals to teach students how to measure the electromotive force of a power source and select a suitable metal for the transmission wire independently. Students have been actively involved in the design and construction of the system, and thus obtained some basic operation experience through practical operation. The phenomenon of electromagnetic induction is a typical case. On the other hand, when learning by yourself, students can create their own experimental plans, carry out the experiments themselves, construct data recording tables, process the data through graph representation, systematically analyse the sources of error, propose corresponding improvement measures based on the analysis, and draw conclusions to the experimental phenomena of electromagnetic induction with a stronger sense and depth [17].

5. Implementation Strategies for One-to-One Project-Based Instruction in Electromagnetism Teaching

5.1. Difficulty-Oriented Project Design

The difficulty-oriented Design of the project should be in line with the logic of the knowledge points and students' cognitive patterns, and a clear graded project path needs to be provided. A typical design problem is a basic multimeter; therefore, we first derive the formula for a shunt resistor based on the characteristics of a sensitive ammeter, and then we can construct a parallel circuit. A high-level task is that students should be able to design a measuring circuit independently, add a power supply and a sliding resistor, and systematically address the problem of scale calibration. The goal at the level of task is to combine the functions of individual components reasonably to create a multimeter, verify its accuracy first, and then conduct an orderly error analysis. Tasks at different levels have different demands for parameter calculation, circuit construction, debugging and optimisation, as well as result verification and the corresponding way to solve the problem [18].

5.2. One-to-One Tiered Instruction Strategy

Tiered instruction should take into account the different levels of students' knowledge foundations, thinking ability and inquiry. A general diagnostic test on the concepts of electromagnetism will be conducted to divide the students into groups of foundational, advanced and extended students [19]. Foundation-level students are to strengthen their basic knowledge in the fundamental course of electric field lines and simple circuits through teaching and demonstration. Intermediate-level students will be guided and inspired to conduct all kinds of projects on applying the Lorentz force. Advanced students need to develop higher-order thinking abilities in the teaching. To give students a place to study independently, new application area projects for new electromagnetic induction have been set up.

5.3. Competency-Oriented Diverse Assessment

Competency-based multi-dimensional assessment aims to improve the basic physics competencies of students in the four areas of knowledge, skills, character development and project work. The knowledge mastery dimension determines how thoroughly a person has

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understood the basic ideas and rules; the skill development dimension tests whether one can conduct experiments, solve problems, etc.; the competency cultivation dimension is essentially a subset of physics knowledge and scientific thinking; and the project practice dimension utilises assessment tasks to promote the development of projects and evaluates learning results based on project outputs. A joint mechanism will be established for teachers to conduct self-assessment and peer evaluation of students. Teachers carry out formative assessments in class; students reflect on and present the results of self-study with their peers. Formative assessment is about behaviour in this case; Summative assessment is about the results. Differentiated assessment standards will be applied to different levels of proficiency, and the results of the assessment will be used to adjust teaching plans and adjust the students' classes dynamically [20].

6. Establishing a One-to-One Project-Based Instruction Methodology System

According to the three main problems in electromagnetism, this paper takes project design based on difficulty, one-to-one tiered instruction and competency-based diversified assessment. Finally, it has formed a one-to-one project-based teaching model. As shown in Figure 1, the start of this system is learning diagnostics; that is, through concept clarification, mathematical/physical tests and basic practical exercises, one can determine the current knowledge level and skill deficiencies of students to set the basis for the following teaching. Then it will proceed to the staged project implementation stage, and students will be distributed among the foundation, advanced and extension groups according to the diagnosis results. Tailor the difficulty of the electromagnetism inquiry project according to students' cognitive levels and conduct the project. Change the strength and direction of guidance flexibly to provide students with timely and specific assistance in their project-based learning and help them learn this way. The fourth is the stage of multi-dimensional evaluation and feedback. In terms of formative and summative assessment, at this time, we will focus on observing how actively the students are engaged in the project and how they are learning through practical questions and exploration. Finally, based on the results of the assessment, teaching methods will be revised and improvements will be made.

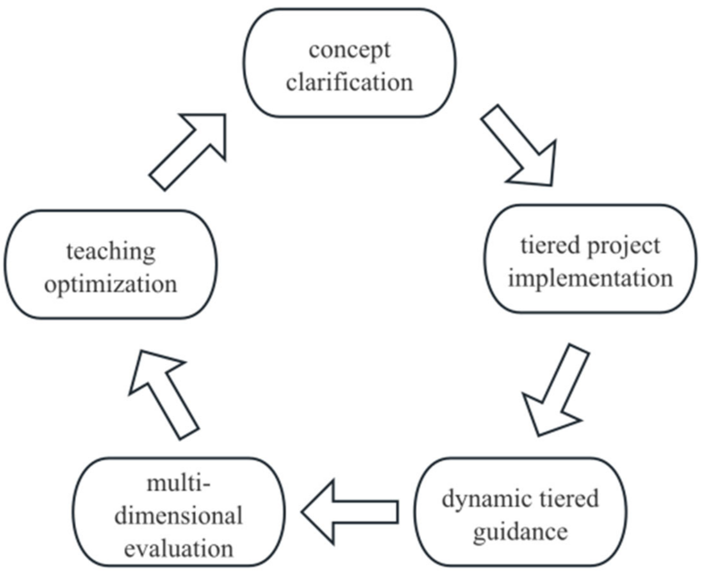

Figure 1. Implementation System of One-to-One Project-Based Instruction.

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The main type of projects in the one-to-one project-based instruction method is tiered projects. The knowledge units of basic electromagnetism can be divided into three consecutive project activities, namely electric fields, magnetic fields and electromagnetic induction, and a general project can be based on this knowledge. As shown in Table 1, the designed three-tier progressive projects are becoming more difficult and strictly comply with the rules of cognitive development; they are moving from "basic understanding" to "integrated application", and at the foundation level, concrete experiments are carried out to overcome cognitive barriers in abstract concepts and help students learn the fundamental laws of electricity and magnetism. The number of upper-level courses has increased the demand for the integration of mathematics and physics. Take the task of electrical meter modification as an example to have students integrate theoretical calculations and circuit design to train their ability to apply abstract rules to practical problems. Extension-level projects are motivated by real problems, and students need to apply knowledge from all modules to carry out innovative designs; thus, they have shifted from learning knowledge to using knowledge. A good point of the divided structure is that it can better meet the different needs at different stages of students' thinking development and learning, and students with weak foundations can create a solid knowledge scaffold through foundational-level projects to boost their confidence in learning. At the same time, academically capable students are also given some good problems for the high-level projects to address. At the same time, although each module project is relatively independent, they also have natural connections and will form an organic link in the development of knowledge and skills. Therefore, by completing all the projects, the electromagnetic knowledge network students have formed is comprehensive and organised; it is not a collection of isolated concepts.

Table 1. Examples of Difficult Design Projects.

Project Levels	Foundation Level	Advanced Level	Extension Level
Core Knowledge	Electrostatic Field	Constant Current	Electromagnetic Induction
Drive Project	Constructing a Simple Electroscope to Visually Demonstrate Electrostatic Induction	Modify a sensitive ammeter into a simple ammeter or voltmeter	Design a Simple Electromagnetic Induction Alarm for Precise Detection of Magnetic Field Changes
Learning Objectives	Master the principle of electrostatic induction Understand the material nature of electric fields	Master the principles of electrical meter modification Enhance mathematical and physical calculation skills	Integrate the application of electromagnetic induction principles Enhance innovative design and practical problem-solving skills
Adapting to Challenges	Conceptual Understanding (Field Properties)	Conceptual Understanding (Circuit Selection) Mathematical Integration (Formula Application)	Conceptual Understanding (Lenz's Law) Mathematical Integration (Dynamic Analysis) Experimental Operation (Integrated Design)

One-to-One Tiered Instruction: Utilise the strengths of personalised teaching to vary the form of instruction. At the beginning of teaching, diagnostic tools are employed to determine

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students' ability levels. At the start of the class, only one-to-one instruction will be used to teach basic operations. Advanced-level students are given one-on-one group guidance, and attention is paid to the main problems in their learning; at the same time, help with difficult calculations will be provided promptly. Extension-level students will be taught individually again, explore on their own, experiment and improve, and so on. Therefore, this direction will be in line with the students' current stage of development.

There are two kinds of formative and summative forms of competency-based differentiated assessment. As shown in Table 2, through scoring criteria and weight allocation, the basic idea of this system is no longer about knowledge memorisation. The four dimensions have different weights, and now it is about cultivating capabilities rather than testing knowledge to assess all-around ability and core competence. In addition, different scoring standards will be applied to students at various levels. Thus, it can be determined precisely which students lack certain knowledge and at the same time stimulate the innovation of high-achieving students; this is an example of personalised teaching. Many evaluators work together in a collaborative way to conduct the assessment of teachers, students, etc. Therefore, it will be less subjective and biased by a single party's view, so it will produce more objective and comprehensive results. A quantified multi-dimensional evaluation system has established a path for the improvement of students and provided some data that can be used by teachers to adjust their teaching level and optimise their teaching methods in time.

Table 2. Quantitative Table of Competency-Based Diverse Assessment.

Evaluation Dimension	Knowledge Mastery	Competence Development	Literacy Cultivation	Project Practice
Evaluation Subjects	Teacher + Self-assessment	Teacher + Peer Assessment	Teacher + Self-assessment + Peer Assessment	Teacher + Peer Assessment
Basic Level Criteria(0–100)	≥80: Accurate concept memorization; Derivation of basic formulas	≥80: Standard experimental operation; Correct data calculation	≥80: Complete guided inquiry; Truthfully record experimental phenomena	≥80: Complete basic tasks; Complete project deliverables
Advanced Level Criteria(0–100)	≥80: Comprehensive knowledge application; Flexible formula utilization	≥80: Design experimental schemes; Conduct mathematical-physical analysis	≥80: Conduct independent inquiry; Reflect on inquiry issues in a timely manner	≥80: Complete tasks efficiently; High-quality project outcomes
Extended Level Criteria(0–100)	≥80: In-depth knowledge comprehension; Flexible problem-solving	≥80: Innovatively design experiments; Solve complex practical problems	≥80: Conduct innovative inquiry; Adhere to a factual and realistic attitude	≥80: Complete tasks ahead of schedule; Innovative project outcomes
Weight	20%	30%	30%	20%

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7. Conclusion

One-to-one project-based teaching can make full use of accurate learning diagnosis to provide personalised instruction for students and help them better grasp abstract concepts and solve the problem of a weak link between theory and practice. To solve the old problem of the gap between theory and practice in a real way, students need to engage in actual projects and learn by conducting their own experiments. In addition, there are tiered, three-level progressive projects and different assessment criteria that can meet the development requirements of students at various stages of cognition. It will help build an organized system of electromagnetic knowledge and promote students' improvement in higher-order thinking abilities in terms of experimental operation and problem-solving. Finally, it can achieve the goal of fostering core physics literacy. The above-mentioned teaching model will also provide some materials in this paper, such as typical project design and various quantitative assessment tables. Its own implementation system is a good way to innovate the model of subject teaching. It should be noted that this study has not yet been widely used in teaching across various levels and student circumstances. There are also other reasons that need to be considered in the design of the projects and their implementation, such as teaching facilities and class schedules. Therefore, in the future, research should be conducted in both directions cautiously: First, the scope of application will be expanded to incorporate big data technology for the optimisation of learning diagnosis and dynamic stratification mechanisms, and more electromagnetic project cases suitable for all kinds of teaching scenarios need to be developed. Second, in depth study the actual effects of this teaching mode on the long-term development of students' physics thinking and modify the quantitative indicators in the teaching evaluation system. Thus, one-to-one project-based instruction will be able to take root and flourish in physics and other subjects of science teaching.

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