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Research on Teaching Practice and Strategies of Probability and Statistics Thinking in Middle Schools Empowered by Modern Educational Technology

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Abstract: With the implementation of General Senior High School Mathematics Curriculum Standards (2017 Edition, Revised in 2020), probability and statistics, as important carriers of the core mathematical competencies "mathematical modeling" and "data analysis," have increasingly highlighted their educational value. By summarizing the historical evolution of probability and statistics thinking and combining with teaching practice cases, this study explores its unique role in cultivating students' core mathematical competencies. The research proposes a project-based teaching strategy relying on real scenarios and empowered by technology. Through cases, it demonstrates how to use modern educational technology to realize the whole-process exploration of data collection, model construction, and conclusion verification, so as to promote the transformation of middle school probability and statistics teaching from knowledge imparting to competency development, and provide a practical reference for curriculum reform.

Keywords: Probability and statistics; Core competencies; Modern educational technology; Project-based learning; Teaching strategies

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1. Introduction

In the era of big data and artificial intelligence, probability and statistics thinking has become an essential basic competency for students. Compulsory Education Mathematics Curriculum Standards (2022 Edition) [1] clearly states: "Students should be guided to experience the whole process of data collection, organization, and analysis, and understand the differences between statistical thinking and deterministic thinking." As a mathematical discipline that studies the quantitative laws of random phenomena in the objective world, probability and statistics are of great significance in the information society with increasing uncertainty. At the middle school stage, the design of probability and statistics teaching content not only affects students' cognition of the random world, but also lays a foundation for their subsequent mathematics learning. Based on the training objectives of subject core competencies [2], this paper systematically examines the educational value of probability and statistics [3], traces the origin and development of its thinking, and combines practical cases to analyze the implementation path and application significance of this field in middle school mathematics teaching.

2. Historical evolution and educational insights of probability and statistics thinking

2.1. From gambling problems to scientific methodology

Probability and statistics originated from gambling games popular among European nobles in the 17th century, such as dice-throwing. These games provided practical problems and initial research models for probability theory. For instance, the Italian mathematician Girolamo Cardano began studying gambling-related issues like dice-throwing as early as the 16th century. In the 17th century, the "Chevalier de Méré's Problem" proposed by the French nobleman Chevalier de Méré explored the probability differences of specific points appearing in consecutive dice throws. Meanwhile, the "problem of points" put forward by Luca Pacioli sparked a correspondence and research discussion between Blaise Pascal and Pierre de Fermat in 1654. Through personal experiments and mathematical analysis, they systematically solved the probability calculation problems in gambling for the first time, laying the foundation of probability theory. In 1657, Christiaan Huygens published On the Calculations in Games of Dice, which further introduced core concepts such as mathematical expectation, marking probability theory as an independent mathematical branch. Subsequently, Jacob Bernoulli proved the Law of Large Numbers, elevating probability theory from a tool for solving gambling problems to a scientific method for studying the regularity of random phenomena. Pierre-Simon Laplace introduced mathematical analysis methods through the Analytical Theory of Probability, promoting the evolution of probability theory into a modern science. This evolutionary process from specific problems to abstract theories shows that mathematical knowledge arises from the needs of real scenarios. In teaching, emphasis should be placed on guiding students to understand the practical background and application value of mathematical concepts through real-world problems, thereby cultivating their ability to model and solve problems [4,5].

2.2. From deterministic thinking to cognition of uncertainty

The emergence of probability and statistics has completely transformed the traditional deterministic thinking mode of mathematics. Early probability theory, represented by the work of Pascal and Fermat, applied mathematics to the analysis of random phenomena for the first time by quantifying uncertainty in gambling. Bernoulli's Law of Large Numbers revealed the stability law in a large number of random events. The normal distribution and error theory proposed by Abraham de Moivre and Carl Friedrich Gauss further extended the cognition of uncertainty to fields such as physics (e.g., observation errors) and social sciences (e.g., population statistics). Adolphe Quetelet introduced probability theory into statistics and founded social physics. He emphasized that random phenomena also follow mathematical laws, breaking the limitations of deterministic thinking. At the beginning of the 20th century, Andrey Kolmogorov established the axiomatic system Foundations of the Theory of Probability, which based probability theory on measure theory. This not only made it a rigorous mathematical branch but also promoted the development of mathematical statistics. This cognitive transformation from determinism to uncertainty holds revolutionary significance for middle school mathematics education. It not only broadens students' mathematical horizons but also, more importantly, cultivates their dialectical and critical thinking abilities. By learning probability and statistics, students can understand the randomness and regularity in the world, thereby maintaining rationality in data analysis and decision-making and avoiding cognitive biases.

3. Practical values of probability and statistics in senior high school mathematics education

3.1. A key carrier for cultivating core mathematical competencies

3.1.1. Data analysis competency

Through real-life cases such as the "birthday paradox" and "lottery winning probability," students are guided to understand the theorem of frequency stability and master basic methods of data processing. In teaching, teachers can design lottery simulation experiments. Students conduct experiments themselves, record data, and observe the phenomenon that frequency gradually stabilizes as the number of experiments increases—this helps them intuitively understand the essence of the Law of Large Numbers. This real-scenario-based teaching method not only enables students to better master skills like creating frequency distribution tables and drawing frequency distribution histograms, but also cultivates their ability to extract information and identify patterns from data.

3.1.2. Mathematical modeling competency

Projects such as "optimization of product sampling inspection plans" and "setting of traffic signal timing" are designed to let students experience the process of constructing probability models from practical problems [5]. Through project-based learning, students form groups to collect data collaboratively, establish binomial distribution or normal distribution models, calculate expectations and variances, and finally propose optimization plans. This teaching model transforms abstract concepts (e.g., classical probability models, random variable distributions) into operable practical problems, fostering students' ability to abstract real-world problems into mathematical ones and solve them [4].

3.1.3. The educational function of mathematical culture

Classic paradoxes in the history of probability (e.g., Bertrand's paradox) are used to integrate the education of scientific spirit and rational thinking [6]. When explaining the definition of probability, teachers can reconstruct the concept's formation process—from the classical definition to the statistical definition, and then to the axiomatic definition. This helps students understand the logical formation of mathematical knowledge rather than mechanically memorizing conclusions. By analyzing common cognitive misunderstandings such as the "gambler's fallacy," students' critical thinking and habits of rational decision-making are cultivated. This enables them to recognize the uncertainty of the world while mastering scientific analytical tools.

3.2. A strategic choice for adapting to talent cultivation in the new era

3.2.1. An inevitable requirement for responding to the information society

Against the social background of "data-driven decision-making," the ability to think in terms of probability and statistics has become a core component of information literacy [7]. From risk assessment in financial investment to epidemiological research in the medical field, from sampling design in market research to data preprocessing in machine learning, all rely on probability and statistics knowledge. Senior high school mathematics education exposes students to practical application scenarios through case teaching, equipping them with basic abilities to handle the massive amounts of data in the information age [8].

3.2.2. An important bridge connecting to higher education

Studies have shown that students who master the basic ideas of probability and statistics demonstrate stronger adaptability in university science and engineering studies. As a compulsory course for most undergraduate majors, probability and statistics complements the deterministic mathematics taught in middle schools. It cultivates students' ability to think randomly and conduct statistical inference [9,10]. Through practical training in senior high school, students not only adapt in advance to the research-oriented learning mode of universities, but also lay a methodological foundation for future in-depth research in fields such as economics and psychology.

3.3. Teaching practice strategies and innovative paths

To realize the practical value of probability and statistics education, diversified teaching strategies are required. In scenario creation, teachers can introduce real cases such as insurance claim probability and drug effectiveness testing, helping students understand the key role of probability and statistics in risk management and scientific decision-making. In terms of technology integration, tools like Python and R are used for data simulation and visual display to make abstract concepts concrete—for example, verifying the Central Limit Theorem through computer simulations of coin-tossing experiments. In evaluation reform, a diversified evaluation system is established, which not only focuses on students' mastery of basic knowledge but also values the cultivation of their practical abilities and innovative thinking.

4. Construction of teaching strategies based on core competencies

4.1. Project-based learning in real scenarios

In traditional probability and statistics teaching, students often struggle to connect abstract mathematical concepts with the real world, leading to low learning interest and insufficient application ability [11]. To break through this dilemma, project-based learning in real scenarios has become an important approach to cultivating students' core competencies [6]. This teaching strategy emphasizes placing students in problem scenarios with practical significance. Through a complete project practice process, it comprehensively improves students' data analysis ability, mathematical modeling ability, and innovative awareness [4,5,12]. A typical case design is the "Campus Waste Classification Effect Evaluation" project. This project theme is closely related to students' daily lives, easily stimulating their interest in exploration, while covering rich application points of probability and statistics knowledge and skills. The project implementation is divided into three main stages.

4.1.1. Data collection stage

Students work in groups, each responsible for counting the daily average amount of different types of waste (e.g., recyclables, kitchen waste, residual waste). This process requires continuous tracking and recording for 2 to 3 weeks, using designed forms to log daily data. Through this link, students not only learn scientific data collection methods but also develop a patient and meticulous work attitude and understand the importance of collecting original and authentic data.

4.1.2. Model construction stage

After obtaining the original data, students are guided to establish a probability model for waste distribution. They need to apply the learned probability distribution knowledge (such as binomial distribution, Poisson distribution) and try to use different probability models to describe the generation rules of various types of waste. During this process, teachers can guide students to discuss the characteristics and applicable conditions of different probability models. For example, why might the generation of certain types of waste conform to the Poisson distribution rather than the normal distribution? This link deepens students' understanding and application ability of probability models.

4.1.3. Decision-making and suggestion stage

Students need to apply statistical methods, such as maximum likelihood estimation, to analyze problems in the existing garbage bin configuration and put forward optimization suggestions. For instance, by calculating the maximum likelihood estimation value of waste generation in different areas, they determine the optimal configuration ratio and placement position of various garbage bins. Finally, each group needs to write an evaluation report and put forward specific suggestions to the school management department, completing the entire process from data analysis to practical application.

4.2. Inquiry-based teaching integrated with technology

With the in-depth integration of information technology in the education field, probability and statistics teaching is undergoing profound changes. Technical tools not only make abstract statistical concepts and probability principles more intuitive and visible, but also provide students with a platform for independent inquiry, greatly enriching the learning experience and teaching effect. The following are three implementation paths of inquiry-based teaching integrated with technology.

4.2.1. Dynamic visual presentation

Using mathematical software such as GeoGebra [13] to simulate classic probability experiments (e.g., coin flipping, dice rolling) can intuitively demonstrate abstract concepts like the Law of Large Numbers and the Central Limit Theorem. For example, when explaining the relationship between frequency and probability, students can set up a large number of virtual experiments and observe in real time how the frequency of the coin landing heads gradually stabilizes at the probability value of 0.5 as the number of experiments increases. This dynamic visual teaching method is more vivid and effective than traditional theoretical explanations, helping students establish an intuitive understanding of probability convergence. Teachers can also guide students to design different experiments (e.g., using an uneven coin) and observe changes in the probability distribution, thereby deepening their understanding of the concept of probability.

4.2.2. Interactive inquiry platform

With the help of Python programming to implement the Monte Carlo algorithm, students can explore the probability distribution rules of complex problems. For example, when solving the classic probability problem of the "birthday paradox," students can write programs to simulate the probability of birthday matches under different group sizes. This method of using computer simulation instead of mathematical derivation helps students solve problems that are mathematically complex but computationally feasible. Furthermore, students can use Python's data analysis libraries (e.g., NumPy, Pandas) to process and analyze actual data, experience the complete statistical process from data collection to analytical inference, and cultivate computational thinking and data analysis ability [14].

4.2.3. Thinking visualization tools

Using mind mapping tools to sort out the probability concept system helps students establish a connection network between knowledge points. Many concepts in probability and statistics are closely related, but these connections are often overlooked in traditional teaching. Through mind maps, students can intuitively see the logical relationships between these concepts and form a systematic knowledge structure. Inquiry-based teaching integrated with technology not only changes the teaching method of probability and statistics but also redefines the roles of teachers and students. Teachers transform from knowledge imparters to learning guides and resource providers, while students transform from passive recipients to active inquirers [15]. This transformation conforms to the requirements of the new era's educational philosophy and is more conducive to cultivating the core competencies and abilities that students need to adapt to future society.

5. Conclusion and outlook

Currently, senior high school probability and statistics teaching still faces many challenges. These challenges are mainly reflected in the tendencies of "prioritizing calculation over thinking" and "prioritizing exam preparation over application," as well as the thinking stereotypes formed by students due to long-term exposure to deterministic mathematics training. To address these dilemmas, teaching reform needs to focus on three key dimensions: First, focus on actively resolving cognitive conflicts. By designing counterintuitive cases, guide students to face the huge gap between empirical judgments and statistical results. This can effectively correct their cognitive biases and help them understand the inherent laws of random phenomena. Second, build a progressive thinking gradient. Carefully design progressive problem chains to help students make the leap from mechanically applying formulas to understanding the essence of probability models. Third, reconstruct the teaching evaluation system. Change the practice of simply pursuing correct answers; instead, adopt a performance evaluation scale that focuses on the entire process of data analysis. Integrate the assessment of abilities in data collection, organization, analysis, and interpretation throughout the process.

As an important part of senior high school mathematics, the educational value of probability and statistics lies not only in knowledge imparting, but more importantly in enabling students to develop the ability and literacy to view the world from a random perspective and solve problems with data-driven evidence. By creating real scenarios, infiltrating mathematical culture, and empowering with technical tools, a new "competency-oriented, practice-based" teaching paradigm can be constructed. These practical strategies can not only strengthen the application orientation of knowledge, but also cultivate students' interdisciplinary literacy and lifelong learning ability, responding to the core requirement of talent cultivation in the new era—"equipping with innovative spirit and practical ability."

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