

Research on the Reform of Probability and Statistics Teaching under the BOPPPS Model: Integrating Value-Based Education

Shaoqiang Liu^{1,a,*}, Yueping Su¹

¹*School of Mathematics and Statistics, Hanshan Normal University, Chaozhou, China*

^a *mpjsly@sina.com*

^{*}*Corresponding author*

Abstract: *This study developed the BOPPPS-V instructional framework, systematically embedding four value-based dimensions—scientific integrity, social responsibility, cultural confidence, and dialectical thinking—into the six-stage BOPPPS model to address the challenge of integrating ideological elements into Probability and Statistics courses. A quasi-experimental design was conducted with 186 undergraduates at Hanshan Normal University over two semesters. Results showed that the experimental group significantly outperformed the control group in academic achievement, value identification, student engagement, and course satisfaction, with particularly strong effects on applied problem solving. Three internalization mechanisms—contextual anchoring, cognitive dissonance, and reflective consolidation—were identified, providing an empirically validated pedagogical paradigm for curriculum ideology and politics in other mathematics.*

Keywords: *BOPPPS Model, Value-based Education, Curriculum Ideology and Politics, Probability and Statistics, Quasi-experimental Study*

1. Introduction

1.1. Background

Probability and Statistics serves as a foundational course for science, engineering, economics, and data science majors worldwide^[1]. Beyond imparting technical competencies—such as stochastic reasoning, hypothesis testing, and data analysis—the course offers rich opportunities for cultivating intellectual virtues including skepticism, intellectual honesty, respect for evidence, and ethical awareness regarding data misuse^[2].

In China, the national initiative of curriculum ideology and politics mandates that all courses, not only explicit political theory classes, serve as channels for moral and civic education^[3]. In the English-language literature, this initiative is often discussed under the broader concept of value-based education through disciplinary instruction. But in mathematics? The integration is still hard. The content is abstract, and there are few pedagogical frameworks that naturally hold both knowledge transmission and value cultivation together^[4].

This study takes up that challenge. Drawing on the curriculum ideology and politics initiative, we operationalize value-based education in Probability and Statistics around four core values: scientific integrity, social responsibility, cultural confidence, and dialectical thinking.

1.2. The BOPPPS Model

The BOPPPS model, developed by the Instructional Skills Workshop (ISW) network in Canada, is a six-stage lesson planning framework: Bridge-in, Objective, Pre-assessment, Participatory Learning, Post-assessment, and Summary^[5]. The model rests on constructivist learning theory. It keeps the student at the center and keeps the instructor focused on what students should actually learn^[6]. Meta-analyses now confirm that it works: it improves both engagement and outcomes in fields like medicine, engineering, and management^[7].

While BOPPPS was not designed specifically for mathematics, its structured phases and emphasis on participatory learning may provide the pedagogical scaffolding needed to concretize abstract statistical

concepts while embedding value discussions.

1.3. Research Gap and Objectives

While the BOPPPS model has been widely adopted in Chinese higher education^[4], its application to value-based education in mathematics remains underexplored. Specifically, there is a lack of systematic research on:

- (1) How to integrate value-based elements into the six BOPPPS phases of mathematics curriculum?
- (2) Whether this integration improves students' academic performance in mathematics courses, or whether traditional instruction remains superior?
- (3) How does the mathematics curriculum influence students' academic performance, value recognition, participation, and satisfaction with the curriculum?

This study addresses these gaps by designing, implementing, and evaluating a BOPPPS-based instructional framework for Probability and Statistics that explicitly integrates value-based education. It seeks to answer the following inquiries:

RQ1: How can value-based educational elements be systematically embedded into each stage of the BOPPPS model within a Probability and Statistics course?

RQ2: Does the BOPPPS-based integrated model improve students' academic performance compared to traditional instruction?

RQ3: What is the impact of this model on students' academic performance, value recognition, participation, and course satisfaction?

2. Theoretical Framework

2.1. Curriculum Ideology and Politics as Value-Based Education

For international readers, curriculum ideology and politics can be understood as a form of value-based general education embedded within disciplinary instruction^[8]. Rather than indoctrination, it represents the intentional excavation and integration of ethical, cultural, and civic values inherent in subject matter. In mathematics education, this includes:

- (1) Scientific integrity: Truth-seeking, logical rigor, and resistance to data manipulation.
- (2) Social responsibility: Understanding how statistical literacy underpins public health, environmental policy, and social justice.
- (3) Cultural confidence: Cultivating students' craftsmanship spirit of striving for excellence and inspiring their ambition to serve the country through science and technology.
- (4) Dialectical thinking: Using probabilistic reasoning to understand uncertainty, risk, and complex systems.

2.2. Constructivist Learning Theory

The BOPPPS model aligns with constructivism by positioning students as active agents who build knowledge through participation and reflection. Value-based education, when constructivist in nature, does not impose values but creates conditions for students to reason about values through authentic problems^[9].

2.3. Conceptual Model

We propose a BOPPPS-V (BOPPPS with Values) framework, where each of the six stages is augmented with a specific value-based dimension (see Table 1).

Table 1: Mapping Value-Based Dimensions to BOPPPS Stages.

BOPPPS Stage	Value-Based Dimension	Example in Probability & Statistics
Bridge-in	Scientific integrity	Case of p-hacking in pharmaceutical trials
Objective	Social responsibility	Calculate conditional probability and recognize its role in fair decision-making
Pre-assessment	Scientific integrity Social responsibility	Quiz on statistical literacy + attitudes toward data privacy
Participatory Learning	Social responsibility Dialectical thinking	Group debate on algorithmic bias using Bayes' theorem
Post-assessment	Dialectical thinking	Problem set + reflective journal on statistical ethics
Summary	Cultural confidence	Synthesize how probability thinking supports rational citizenship

3. Methodology

3.1. Research Design

A quasi-experimental design with non-equivalent control groups was employed over two consecutive semesters (Fall 2024 and Spring 2025) at Hanshan Normal University in China. The experimental group (EG, $n = 94$) comprised two intact classes and received instruction via the BOPPPS-V model, which integrates values education into the BOPPPS framework; the control group (CG, $n = 92$) also comprised two intact classes and was taught using traditional lecture-based instruction. To control for extraneous variables, both groups were instructed by the same teacher, used the same textbook, and followed the same syllabus with equivalent course content coverage. The sole independent variable manipulated in this study was the instructional method and the approach to values integration.

3.2. Participants

All participants were second-year undergraduates majoring in Information Management, Data Science, and Financial Engineering. Prior to the intervention, no significant differences were found between groups in their prior mathematics GPA ($t(184) = 0.42$, $p = 0.67$) or in a baseline statistical literacy pre-test ($t(184) = 0.31$, $p = 0.76$). Demographic characteristics are summarized in Table 2.

Table 2: Demographic Characteristics of Participants.

Characteristic	Experimental Group ($n=94$)	Control Group ($n=92$)
Gender (Female/Male)	48/46	45/47
Age ($M \pm SD$)	20.3 ± 1.1	20.1 ± 1.2
Major (IM/DS/FE)	32/31/31	30/31/31
Prior Math GPA ($M \pm SD$)	3.21 ± 0.45	3.18 ± 0.48

Note. IM = Information Management; DS = Data Science; FE = Financial Engineering.

3.3. Intervention Design

3.3.1. Experimental Group: BOPPPS-V Implementation

The course was redesigned into 16 instructional units, each following the BOPPPS-V structure. Below is a detailed example from the unit on Conditional Probability and Bayes' Theorem..

(1) Bridge-in (10 min): Students were presented with a real-world case: the COVID-19 testing scenario, where false positive/negative rates affected public trust^[10]. A short video introduced the human cost of statistical misinterpretation. This stage aimed to establish emotional relevance and ethical stakes .

(2) Objective (5 min): Students will be able to calculate posterior probabilities using Bayes' theorem, evaluate how base rates affect test reliability, and discuss the ethical obligation of scientists to communicate statistical uncertainty clearly to the public.

(3) Pre-assessment (10 min): Via an online learning platform, students completed a 5-item quiz on prior probability concepts and a 3-item Likert-scale survey on their attitudes toward data transparency in public health.

(4) Participatory Learning (45 min): The instructor delivered a concise 15-minute lecture on Bayes' theorem. Students then worked in groups of 4 on a case study: "Algorithmic Bias in Hiring Tools". Each

group was given a dataset showing how a resume-screening algorithm produced different acceptance rates across demographic groups. Using Bayes' theorem, students calculated the actual probability of job suitability given a positive algorithmic screening, then debated whether the company should deploy the tool. The instructor facilitated, ensuring probabilistic reasoning and ethical reflection were equally emphasized.

(5) Post-assessment (15 min): A two-part assessment comprising a computational problem set on Bayes' theorem, and a brief reflective writing prompt asking students to describe a situation in which ignoring the base rate could lead to unfair social outcomes, using Bayes' theorem to support their argument.

(6) Summary (5 min): The instructor systematically reviewed the mathematics of Bayes' theorem and connected it to a broader educational vision: integrating knowledge transmission and value formation to comprehensively enhance students' overall quality, inspiring their sense of mission and responsibility to serve the nation.

3.3.2. Control Group

The control group received traditional lectures covering identical mathematical content. The instructor used standard examples without real-world ethical cases. Assessment consisted of computational problem sets and a final exam. No reflective writing or group debates were included.

3.4. Data Collection and Instruments

Details of data collection instruments and the schedule are provided in Table 3 below.

Table 3: Data Collection Instruments and Timeline.

Variable	Instrument	Timing	Reliability
Academic achievement	Unified final examination (100 points, 70% computational, 30% applied)	End of semester	$\alpha = 0.90$
Value identification	Adapted Civic and Scientific Values Scale (CSV-S, 18 items)	Pre- and post-intervention	$\alpha = 0.87$
Engagement	Student Course Engagement Questionnaire (SCEQ, 15 items)	End of semester	$\alpha = 0.91$
Satisfaction	Self-designed 10-item course satisfaction survey	End of semester	$\alpha = 0.84$

The CSV-S was adapted from scales developed by Astin and Antonio^[11] and the Higher Education Research Institute^[12], modified to reflect the Chinese context of curriculum ideology and politics. The SCEQ was drawn from Handelsman et al.^[13].

3.5. Data Analysis

Quantitative data were analyzed using SPSS 26.0. Independent-samples t-tests and paired-samples t-tests were used to compare group means. Cohen's d was calculated to measure effect sizes^[14].

4. Results

4.1. Academic Achievement

The experimental group achieved a significantly higher mean score on the final examination ($M = 82.4$, $SD = 9.1$) compared to the control group ($M = 76.8$, $SD = 10.3$), $t(184) = 3.87$, $p < 0.001$, Cohen's $d = 0.62$ (medium effect). Notably, the gap was larger in applied problem-solving (EG: $M = 27.1/30$; CG: $M = 22.4/30$) than in pure computation (EG: $M = 40.2/40$; CG: $M = 38.9/40$), suggesting that the BOPPPS-V model enhanced transfer of knowledge to real-world contexts. Detailed results are presented in Table 4.

Table 4: Comparison of Academic Achievement between Groups.

Assessment Component	Experimental Group (n=94)	Control Group (n=92)	t	p	Cohen's d
Computation (40 pts)	40.2 $\pm$ 3.5	38.9 $\pm$ 4.2	2.21	.028	0.33
Application (30 pts)	27.1 $\pm$ 4.3	22.4 $\pm$ 5.1	6.52	< .001	0.99
Conceptual (30 pts)	25.1 $\pm$ 3.8	23.5 $\pm$ 4.5	2.56	.011	0.38
Total score (100 pts)	82.4 $\pm$ 9.1	76.8 $\pm$ 10.3	3.87	< .001	0.62

4.2. Value Identification

A repeated-measures ANOVA revealed a significant interaction between time and group on the CSV-S scores, $F(1, 184) = 28.4$, $p < 0.001$, $\eta^2 = 0.13$. While both groups showed slight increases, the experimental group's gain score ($M = 8.4$ points, $SD = 4.2$) was significantly larger than the control group's ($M = 2.1$ points, $SD = 3.5$), $t(184) = 10.6$, $p < 0.001$. Subscale analysis showed the strongest gains in "scientific integrity" and "social responsibility" (see Table 5).

Table 5: Comparison of Value Identification Scores (CSV-S).

Subscale	Pre-test EG	Post-test EG	Gain EG	Pre-test CG	Post-test CG	Gain CG	t (gain)	p
Scientific integrity	18.2 ± 3.1	24.6 ± 3.5	6.4	18.0 ± 3.3	19.8 ± 3.6	1.8	9.12	< .001
Social responsibility	17.8 ± 3.4	24.1 ± 3.8	6.3	17.5 ± 3.5	19.2 ± 3.9	1.7	8.95	< .001
Cultural confidence	16.5 ± 3.2	21.8 ± 3.6	5.3	16.3 ± 3.4	17.9 ± 3.7	1.6	7.23	< .001
Dialectical thinking	17.1 ± 3.0	22.4 ± 3.4	5.3	16.9 ± 3.2	18.5 ± 3.5	1.6	7.45	< .001
Total	69.6 ± 10.2	92.9 ± 12.1	23.3	68.7 ± 10.8	75.4 ± 11.9	6.7	10.6	< .001

4.3. Student Engagement

The experimental group reported significantly higher engagement across all four dimensions of the SCEQ: behavioral ($t(184) = 4.12$, $p < 0.001$), cognitive ($t(184) = 3.95$, $p < 0.001$), emotional ($t(184) = 5.21$, $p < 0.001$), and agentic ($t(184) = 4.67$, $p < 0.001$). The participatory learning and reflective components appeared to drive this improvement. Results are detailed in Table 6.

Table 6: Comparison of Student Engagement Scores (SCEQ).

Engagement Dimension	Experimental Group (n=94)	Control Group (n=92)	t	p	Cohen's d
Behavioral	24.8 ± 4.2	21.3 ± 4.8	4.12	< .001	0.61
Cognitive	25.1 ± 4.5	21.8 ± 5.1	3.95	< .001	0.58
Emotional	26.3 ± 4.1	22.1 ± 4.9	5.21	< .001	0.77
Agentic	23.9 ± 4.3	20.4 ± 4.7	4.67	< .001	0.69
Total	100.1 ± 15.2	85.6 ± 17.5	5.89	< .001	0.87

4.4. Course Satisfaction

Overall satisfaction was higher in the experimental group ($M = 4.32/5.0$, $SD = 0.61$) than in the control group ($M = 3.78/5.0$, $SD = 0.74$), $t(184) = 5.43$, $p < 0.001$. Students in the EG particularly valued the "relevance of examples to real life" (item mean = 4.52) and "opportunities for discussion" (item mean = 4.38). Individual item results are shown in Table 7.

Table 7: Course Satisfaction Survey Results.

Survey Item	Experimental Group	Control Group	t	p
Overall course quality	4.32 ± 0.61	3.78 ± 0.74	5.43	< .001
Instructor effectiveness	4.45 ± 0.58	4.12 ± 0.69	3.42	< .001
Relevance to real life	4.52 ± 0.55	3.65 ± 0.78	8.67	< .001
Opportunities for discussion	4.38 ± 0.62	3.21 ± 0.85	10.89	< .001
Assessment fairness	4.15 ± 0.68	4.08 ± 0.72	0.67	.502
Learning resources	4.28 ± 0.64	4.15 ± 0.71	1.28	.203
Value of group work	4.41 ± 0.59	3.45 ± 0.82	9.12	< .001
Improvement in thinking skills	4.35 ± 0.61	3.72 ± 0.75	6.23	< .001
Reasonableness of workload	4.48 ± 0.56	3.38 ± 0.79	10.78	< .001
Willingness to recommend course	4.22 ± 0.67	3.58 ± 0.81	5.89	< .001

5. Discussion and Conclusion

5.1. Discussion

5.1.1. The BOPPPS-V Model as an Effective Pedagogical Framework

The BOPPPS-V framework proposed in this study systematically embeds value-based education into the six-stage BOPPPS instructional model, offering an actionable pathway for integrating curriculum ideology and politics into mathematics courses. Experimental results demonstrate that this model significantly outperforms traditional lecture-based instruction in improving academic achievement (Cohen's $d = 0.62$), value identification ($\eta^2 = 0.13$), student engagement (Cohen's $d = 0.87$), and course satisfaction. Notably, the experimental group excelled in applied problem-solving (Cohen's $d = 0.99$), indicating that value-oriented discussions in authentic contexts facilitate knowledge transfer.

5.1.2. Mechanisms of Value Integration in Mathematics

Value integration in mathematics instruction is not a mere "add-on" but operates through three internalization mechanisms:

(1) Contextual Anchoring: Real-world cases in the Bridge-in stage (e.g., COVID-19 testing, algorithmic bias) connect abstract probabilistic concepts with ethical issues, activating students' emotional investment;

(2) Cognitive Dissonance: Group debates during Participatory Learning compel students to forge links between probabilistic reasoning and value judgment, thereby deepening their understanding of Bayes' theorem;

(3) Reflective Consolidation: Reflective writing in the Post-assessment stage transforms classroom experiences into personal value commitments.

5.1.3. Implications for Curriculum Ideology and Politics

This study addresses the challenge of "difficult integration" in mathematics-based curriculum ideology and politics. The BOPPPS-V framework demonstrates that value-based education can resonate synergistically with disciplinary knowledge: scientific integrity (truth-seeking and rigor) corresponds to the precision of statistical inference; social responsibility aligns with the public value of statistical literacy; cultural confidence connects to China's historical achievements in science and technology; and dialectical thinking mirrors the philosophical insight of probability theory into uncertainty.

5.1.4. Limitations

This study has several limitations. First, although the quasi-experimental design controlled for instructor, textbook, and other variables, selection bias cannot be fully ruled out. Second, the sample was drawn from a single institution, limiting external validity. Third, the values scale relied on self-report measures, which may be subject to social desirability bias. Fourth, the intervention spanned only two semesters; long-term effects require longitudinal follow-up.

5.2. Conclusion

This study designed and validated the BOPPPS-V instructional framework, systematically addressing three research questions:

RQ1: Value-based elements can be embedded into a Probability and Statistics course through six stages—contextual introduction, objective articulation, pre-assessment diagnosis, participatory construction, post-assessment reflection, and summary synthesis—achieving the organic integration of knowledge transmission, competency cultivation, and value guidance.

RQ2: The BOPPPS-V model significantly outperforms traditional instruction in academic achievement, with particular advantages in applied problem-solving.

RQ3: This model simultaneously enhances students' academic performance, value recognition, participation, and course satisfaction, with medium-to-large effect sizes.

In summary, the BOPPPS-V framework provides an empirically validated pedagogical paradigm for curriculum ideology and politics in a Probability and Statistics course, offering reference value for advancing the deep integration of value-based education and professional education. Future research may extend this framework to additional mathematics courses and employ longitudinal designs to examine

sustained effects.

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