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A Theoretical Framework for Interdisciplinary Instructional Design Targeting Statistical Reasoning

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Abstract

In the digital age, statistical reasoning (SR) is a core literacy for citizens navigating an information society. However, primary school statistics instruction has been striving to address the fragmented development of SR, disconnect between context and real life, and lack of wholeness in statistical activities. To bridge these gaps, this study proposes a novel interdisciplinary Project-Based Learning (PBL) framework grounded in Jones's four-dimensional SR model. Theoretically designed around the theme "Data-Driven Low-Carbon Action," the framework features a dual-path structure: "Longitudinal Competency Progression" (a sequenced progression through the four dimensions of Statistical Reasoning (SR), namely Describing Data Displays (D), Organizing and Reducing Data (O), Representing Data (R), and Analyzing and Interpreting Data (A)); combined with "Horizontal Disciplinary Collaboration" (integrating knowledge and practices from Mathematics, Science, Information Technology, and Chinese Language Arts). Driven by a genuine societal issue, this integrated structure aims to systematically address all dimensions of SR through a "Problem → Task → Product" spiral progression, enabling students to conceptually participate in the complete PPDAC cycle (Problem, Plan, Data, Analysis, Conclusion). This proposed framework offers a structured approach for fostering the synergistic development of students' scientific inquiry, digital innovation, language application, and SR, providing a theoretically grounded and replicable model for interdisciplinary thematic teaching design.

Keywords: Interdisciplinary Teaching; Statistical Reasoning(SR); Project-Based Learning (PBL); Primary Education

1. Introduction

With the advent of the era of big data, statistical reasoning (SR) has become an indispensable literacy for citizens to navigate in the complex information society. However, primary school instruction in statistics and probability continues to face significant challenges, including fragmented development of SR (He, 2013; Friedrich et al., 2024), disconnect between context and real life (He, 2013; Friedrich et al., 2024), and lack of wholeness in statistical activities (Pan et al., 2022; Friedrich et al., 2024). Against this backdrop, the Mathematics Curriculum Standards for Compulsory Education (2022 ed.). (hereinafter referred to as the New Curriculum Standards) explicitly mandates that "no less than 10% of class hours in each subject be allocated to interdisciplinary theme-based learning," emphasizing the integration of multidisciplinary knowledge to address real-world problems. This policy underscores an urgent need to explore interdisciplinary instruction as a viable pathway to tackle the aforementioned challenges in primary statistics education, with the goal of systematically fostering students' SR.

Positioning this study as conceptual design research, the paper focuses on developing a theoretically sound instructional framework prior to empirical validation. Its core objective is to respond to the persistent issues in primary SR instruction by examining how interdisciplinary teaching can function as an integrative mechanism—harnessing the convergence of multidisciplinary knowledge to solve complex real-world problems. Ultimately, this research aims to provide a replicable practical paradigm for interdisciplinary thematic learning under the New Curriculum Standards, with a specific focus on enhancing students' SR.

2. Literature Review

2.1. Statistical Reasoning

2.1.1. Jones' Four-Dimensional Framework

Jones et al.(2000) established a validated framework for evaluating SR in primary school students (Grades 1-5), grounded in Biggs & Collis'(1991) cognitive development model. Through clinical interviews with 20 students, they conceptualized SR through four hierarchical dimensions:

(1) Describing Data Displays (D)

This dimension focuses on students' ability to explicitly read and communicate information directly presented in raw data or various data representations (tables, charts, graphs). It encompasses:

D1: Interpreting Data Presentation: Identifying chart elements (title, axes, labels)

D2: Recognizing Different Representations of Same Data: Distinguishing diverse forms (charts, tables) for identical data

D3: Evaluating Different Representations of Same Data: Understanding characteristics of different chart types

(2) Organizing and Reducing Data (O)

This dimension focuses on students' ability to arrange, categorize, or consolidate data into summarized forms. This ability is essential for progressing to data analysis and interpretation, as organizing data (e.g., into groups) reveals patterns and trends, and facilitates comparisons between data sets through measures of center and spread. It includes:

O1: Grouping and Sorting Data: Classifying data by logical dimensions; sorting key indicators.

O2: Awareness of Data Reduction During Reorganization: Eliminating redundant information (e.g., irrelevant fields); extracting key data

O3: Describing Data Using Terms of Typicality/Distribution: Using terms like "maximum," "proportion," "distribution" to characterize data

(3) Representing Data (R)

This dimension focuses on students' ability to display data in graphical forms. It involves developing "graphical sense," which entails understanding the construction of graphs as tools for structuring data and, crucially, selecting the most effective graphical representation for a specific context. It consists of:

R1: Completing Partially Constructed Graphs: Filling in missing data on a graph based on a given data set.

R2: Representing Different Organizations of the Same Data set: Converting data between charts, tables, text; selecting optimal representation

(4) Analyzing and Interpreting Data (A)

This dimension constitutes the core of statistical reasoning. It focuses on students' ability to recognize patterns and trends within data and to make inferences and predictions based on data. It encompasses:

A1: Identifying What the Display Does Not Reveal: Recognizing data limitations (sample, time frame); reflecting on conclusion reliability

A2: Comparing and Combining Data (Reading Between Data): Comparing associations between different datasets

A3: Inferring and Predicting from Data (Reading Beyond Data): Predicting trends based on data

2.1.2. Hierarchical Levels of Statistical Reasoning

The four-dimensional structure of SR aligns with Biggs & Collis'(1991) SOLO (Structure of the Observed Learning Outcome) taxonomy, forming a developmental continuum from low to high cognitive complexity. Jones et al. (2000) defined these levels as follows:

Level 1 (Idiosyncratic): Students focus on irrelevant information and rely heavily on subjective judgment when describing, representing, or analyzing data.

Level 2 (Transitional): Students begin using quantitative reasoning but typically focus on only one aspect of the data. Their representation and analysis remain incomplete and narrow.

Level 3 (Quantitative): Students consistently use informal quantitative reasoning and start to consider multiple aspects of the data exploration task. They tend to provide multiple responses when representing and analyzing data.

Level 4 (Analytical): Students demonstrate analytical and quantitative reasoning. They can provide multiple, logically coherent perspectives and interpretations within the data context.

2.1.3. Alignment with Curriculum Standards

The conceptualization of SR outlined above is consistent with contemporary educational goals. New Curriculum Standards emphasizes "data awareness" as a core competency, aiming to cultivate students' ability to address real-life problems by thinking through data, extracting useful information, and making reasonable inferences. The Standards designate "Statistics and Probability" as one of four key learning domains, encompassing themes such as "data classification," "data collection, organization, and expression," and "possibility of random phenomena"—all of which align closely with the four dimensions of SR defined by Jones et al.This alignment is further supported by international research. Gao (2020) noted that Jones et al.'s SR model is consistent with most international primary statistics education goals, highlighting its universal applicability.

Synthesizing the New Curriculum Standards with existing research, this study defines SR as the capacity students demonstrate in solving statistical problems to: Describing Data Displays (D), Organizing and Reducing Data (O), Representing Data (R), and Analyzing and Interpreting Data (A).

2.2. Problems in Primary SR Instruction

2.2.1. Fragmented Development of SR

The proportion of statistics and probability content in the primary school mathematics curriculum is limited, and its weight in standardized assessment is relatively low, which leads some teachers to underestimate its teaching significance (He, 2013). In traditional classrooms, instruction often mechanically focuses on reading data from charts or memorizing average formulas, and few activities are designed to cultivate SR (Friedrich et al., 2024).

2.2.2. Disconnect Between Context and Real Life

Authentic data and contexts are central to developing statistical literacy(Friedrich et al., 2024). However, there is a disconnection in primary school statistics teaching. Many teachers rely entirely on the scenarios provided in textbooks and lack the ability to transform knowledge into problem situations(He, 2013), which hinders students' understanding of the complexity and variability of real-world data.

2.2.3. Lack of Wholeness in Statistical Activities

Teachers often lack awareness of the need for complete statistical practice, frequently omitting the problem formulation stage (Pan et al., 2022). This prevents students from establishing the logical 'problem-data-decision' chain. Friedrich et al., (2024) pointed out in a systematic review that most activities are still confined to a single data processing step (e.g., graphing or calculation), making it difficult for students to understand the essence of statistics.Students often passively follow the teacher's instructions in repetitive tasks, lacking in-depth participation in the background of the problems, which stifles their interest and autonomy.

2.3. Interdisciplinary Learning

Wagner (2014) proposed that interdisciplinary thinking is "the key skill of the 21st century" and defined its essence as "the cognitive ability to identify the connections among multiple disciplines in complex problems". In STEM education, interdisciplinary studies are clearly defined as "the utilization of comprehensive knowledge and skills in science, technology, engineering and mathematics to solve real-world problems and support students' academic, professional and social success" (Halawa et al., 2024). Focusing on school settings, Xia (2022) further defined Interdisciplinary Project-Based Learning (Interdisciplinary PBL), emphasizing that students, to solve a complex and authentic driving question, need to engage in creative knowledge integration, ultimately forming integrated understanding and products that transcend single disciplines, rather than mere juxtaposition of subject knowledge. Guo and Yuan (2023) categorized interdisciplinary thematic learning along two dimensions: knowledge status and disciplinary relationships. Regarding knowledge status, it can be "applying knowledge to solve complex problems" or "learning knowledge through interdisciplinary themes." Regarding disciplinary relationships, it can be either "Single Discipline-Led" or "Multiple Disciplines-Led."

Synthesizing these perspectives, this study defines interdisciplinary learning as: An interdisciplinary thematic learning process anchored in a genuine and complex real-world problem, employing a "Single Discipline-Led" model, which guides students to apply and integrate multi-disciplinary knowledge, methods, and skill to solve the core problem.

2.4. Interdisciplinary Teaching Facilitates SR Development

Traditional primary statistics instruction faces core problems—fragmented competency development, lack of authentic contexts, and incomplete activities—in cultivating SR. This study argues that Interdisciplinary Teaching, particularly through Interdisciplinary PBL, provides an effective pathway to address these issues and systematically foster SR.

2.4.1. Constructs a Systemic Competency Framework, Addressing Disjointed Competency Development

SR development involves a coherent cognitive process spanning four dimensions: Describing Data Displays (D), Organizing and Reducing Data (O), Representing Data (R), and Analyzing and Interpreting Data (A) (Jones et al., 2000) However, traditional classrooms often divide statistical knowledge into isolated skills such as chart reading or formula calculation, hindering students' grasp of the holistic logic of SR.

This division stems from the neglect of the need to integrate the cognitive, behavioral and affective dimensions in the development of statistical literacy (Friedrich et al., 2024). Watson et al.(2003) suggested mathematics can be integrated with other subjects to provide social contexts for statistical learning and foster decision-making skills. Interdisciplinary teaching, by utilizing real problems to integrate statistics with practices from science and technology, has the potential to form a coherent competency development path that addresses such fragmentation.

2.4.2. Leverages Authentic Societal Issues, Realizing Data Value Transformation

Real data and background are the core of the development of statistical literacy (Friedrich et al., 2024). However, teachers often rely solely on textbook data, neglecting the motivating power of real problems (Liu, 2020). This gap necessitates context reconstruction. Interdisciplinary teaching, oriented towards socio-economic realities (Gibbons, 1994) bridges the classroom-reality divide through its contextualized knowledge production mode. The research by Vahey et al.'s (2012) further indicates that addressing genuine interdisciplinary issues such as "water resource usage" or "climate change" can significantly enhance students' key data interpretation skills and their willingness to apply what they have learned to life.

2.4.3. Covers the Complete Statistical Inquiry Cycle, Preventing Activity Discontinuity

Traditional instruction often limits statistical activities to single steps (e.g., graphing), resulting in passive execution and a lack of experience with the entire process. When embedded in authentic measurement contexts, the proportion of students completing the full cycle (design-collect-represent-interpret) increases significantly: 58% of the students could independently plot and interpret the data distribution, and 39% of the students could compare the distribution in different scenarios (English & Watson, 2015). Combining this with Xia 's (2022) progressive interdisciplinary prototype—emphasizing decomposing sub-problems according to problem-solving logic to form a complete inquiry chain with "dynamic disciplinary synergy and progressive competency development" —avoids fragmentation. Such an approach ensures that statistical activities are not isolated but part of a continuous, purposeful inquiry process.

In summary, interdisciplinary teaching offers tripartite support for developing Statistical Reasoning (SR) through its systemic framework design, authentic problem contexts, and complete inquiry cycles. However, current practices have yet to systematically integrate Jones' cognitive dimensions (D-O-R-A) with disciplinary collaboration mechanisms. The dual-dimensional framework ('Longitudinal Competency Progression + Horizontal Disciplinary Collaboration') proposed in this study responds to this limitation, seeking to enable synergistic development across SR's four dimensions via a structured pathway.

3. "Data-Driven Low-Carbon Action" Project Design

3.1. Project Overview

Project Title: Data-Driven Low-Carbon Action

Driving Question: How can we use data to persuade community residents to participate in low-carbon action?

Core Competency Goals: Develop SR; enhance low-carbon awareness and agency.

Core Product Chain: Greenhouse Effect Lab Report (Math/Science) → Household Carbon

Footprint Analysis Report (Math/Science) → AI Creative Low-Carbon Poster (Math/IT) → Letter to Community Residents (Math/Chinese).

3.2. Interdisciplinary Integration Framework

The project established a two-dimensional "Longitudinal Competency Progression + Horizontal Disciplinary Collaboration" framework (Figure 1). Longitudinally, it uses the D-O-R-A model (Describing Data Displays → Organizing and Reducing Data → Representing Data → Analyzing and Interpreting Data) as the SR development path. Horizontally, it establishes a Mathematics-led disciplinary network: Mathematics provides core statistical knowledge/methods; Science provides anchoring contexts (e.g., greenhouse experiment) and principle support (e.g., carbon neutrality); Information Technology (IT) enables tool application (e.g., AI poster design); Chinese Language Arts drives product output and persuasive logic (e.g., letter argumentation). Disciplines dynamically align with lesson competency goals, forming a progressive product chain ("Lab Report → Carbon Footprint Report → AI Poster → Advocacy Letter") serving the driving question: "Persuading the community with data."

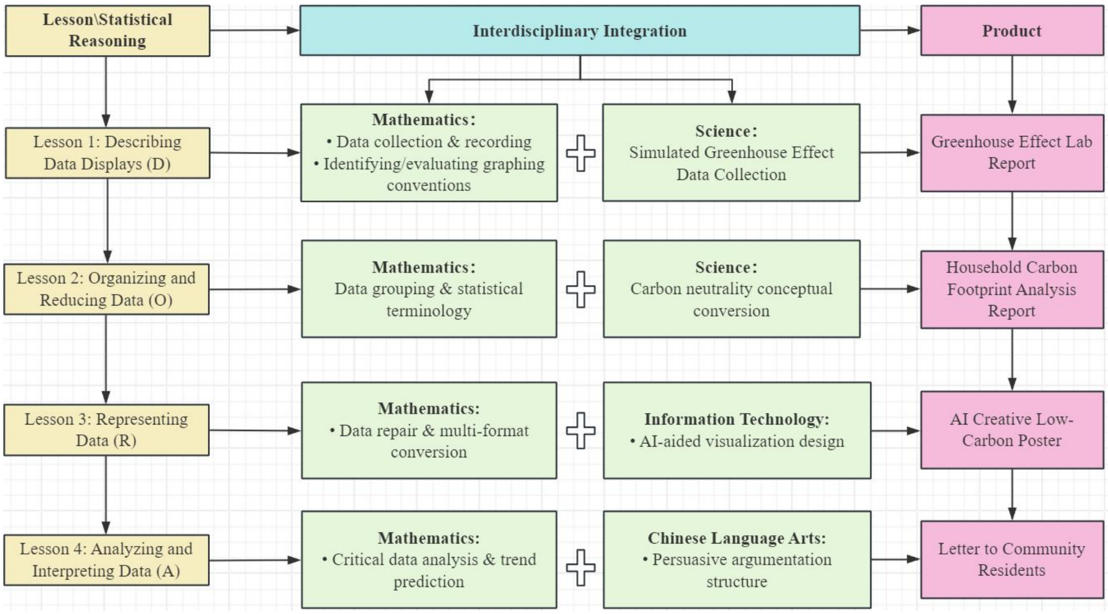

Figure 1. Interdisciplinary Integration Framework

3.3. Project Activity Flow

Centered on the driving question "How can we use data to persuade community residents to participate in low-carbon action?", the project designs four interdisciplinary lessons targeting the four SR dimensions (D, O, R, A), achieving a transformation from "Scientific Experiment Data → Household Lifestyle Data → Community Action Data." The specific flow is shown in Figure 2.

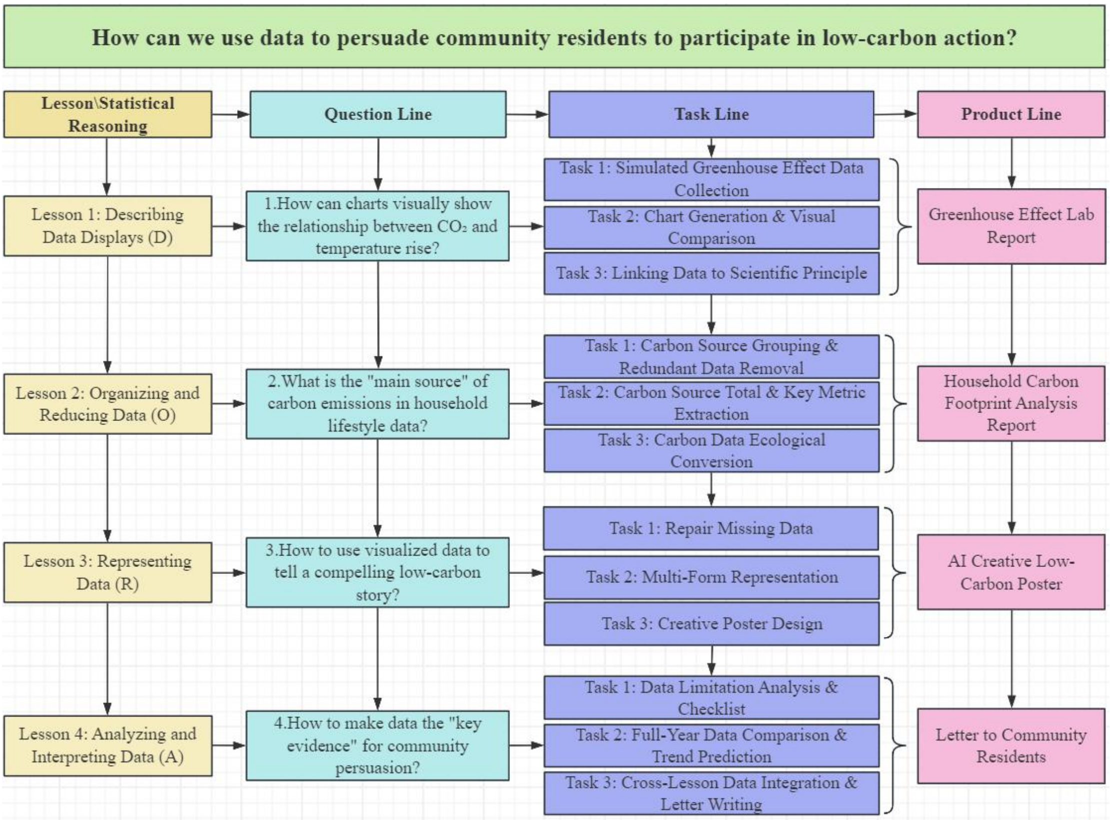

Figure 2. Project Activity Flow

3.4. Lesson Process Design

Lesson 1: Describing Data Displays (D)

Sub-question: How can charts visually show the relationship between CO_2 and temperature rise?

Product: Greenhouse Effect Lab Report

Task 1: Simulated Greenhouse Effect Data Collection

(1) Conduct sealed bag + dual thermometer experiment. Record internal/external temperature (°C) every minute (5 min).

(2) Calculate temperature difference. Record in Temperature Change Log, labeling units (°C).

(3) Competency Goal: Master basic data collection and recording skills (D1 Prep).

Task 2: Chart Generation & Visual Comparison

(1) Observe bar chart and line chart corresponding to log (X-axis: Time/min; Y-axis: Temperature/°C). Compare internal/external temperature trends.

(2) Group discussion & recording:

a. How do bar and line charts present data differently?

b. Which chart more intuitively warns about CO_2 concentration and climate crisis linkage? Why?

Competency Goal: Interpret chart elements (D1); Recognize presentation features of different charts (D2); Evaluate chart effectiveness (D3).

Task 3: Linking Data to Scientific Principle

Explain "Why does the sealed bag heat up more?" using data, linking to CO_2 greenhouse effect principle.

Competency Goal: Derive scientific conclusions from data phenomena (D1 Deep Interpretation).

Lesson 2: Organizing and Reducing Data (O)

Sub-question: What is the "main source" of carbon emissions in household lifestyle data?

Product: Household Carbon Footprint Analysis Report

Task 1: Carbon Source Grouping & Redundant Data Removal

(1) Classify household weekly carbon emission data (containing redundant fields like "usage period," "device ID") into: Appliances / Transport / Gas / Waste / Other.

(2) Mark irrelevant columns for deletion (e.g., "device ID"), justifying removal (e.g., "unrelated to source type").

Competency Goal: Group data by logical dimensions (O1); Identify invalid information (O2).

Task 2: Carbon Source Total & Key Metric Extraction

(1) Calculate weekly totals for 5 source types. Record in simplified table ("Source Type," "Carbon Emission").

(2) Describe data distribution using statistical terms:

a. Which source has the highest emissions? What proportion?

b. What is the average daily household carbon emission?

Competency Goal: Use terms like "maximum," "proportion" to describe distribution (O3).

Task 3: Carbon Data Ecological Conversion

(1) Annual Emission Estimate: Annual Emission (kg) = Weekly Total × 52.

(2) Carbon Neutrality Concept: Briefly explain: Achieving net-zero carbon emissions via reduction and carbon absorption (e.g., afforestation). Emphasize "reduction is core, absorption is supplementary."

(3) Afforestation Offset Estimate: Trees Needed = Annual Household Emission (kg) ÷ Average Annual Carbon Sequestration per Tree (kg/tree). (Note: Teacher provides sequestration data; focus is on understanding the offset concept).

Competency Goal: Establish quantitative link between data and real-world ecology.

Lesson 3: Representing Data (R)

Sub-question: How to use visualized data to tell a compelling low-carbon story?

Product: AI Creative Low-Carbon Poster

Task 1: Repair Missing Data

Complete missing data on a bar chart of weekly average AC carbon emissions for a household.

Competency Goal: Understand impact of data completeness on charts (R1).

Task 2: Multi-Form Representation

(1) Convert repaired bar chart into: (a) Statistical table (daily emissions); (b) Line chart (trend arrows). Compare forms: Which best shows "AC carbon emission trend"? Why?

(2) Competency Goal: Master multiple representations of same data (R2).

Task 3: Creative Poster Design

(1) Extract core data insights (e.g., "Weekend peak," "Summer trend"). Combine with "Smart AC Use" concept. Input into AI tool to generate poster.

(2) Poster must include:

a. ≥1 statistical chart (bar/line).

b. Low-carbon message

c. Color elements (e.g., green theme for eco-friendliness).

Competency Goal: Use visualization to convey data narrative (R2 Application).

Lesson 4: Analyzing and Interpreting Data (A)

Sub-question: How to make data the "key evidence" for community persuasion?

Product: Letter to Community Residents

Task 1: Data Limitation Analysis & Checklist

(1) Discuss limitations of previous lesson's “Single-Week AC Carbon Emission Line Chart”:

Time: Covers seasonal (winter/summer) differences?

Sample: Can single household represent whole community?

(2) Complete Data Blind Spot Checklist: Record ≥2 limitations and their impact on conclusions.

Competency Goal: Critically analyze data boundaries (A1).

Task 2: Full-Year Data Comparison & Trend Prediction

(1) Analyze household's 12-month AC carbon emission line chart:

Peak Month: ______, Reason ______ (e.g., "8h daily use in heat").

Secondary Peak: ______, Reason ______ (e.g., "heating + AC").

(2) Calculate annual total. Assume 2 % annual growth, predict next year's total.

Competency Goal: Compare/combine multi-source data (A2); Infer trends from data (A3).

Task 3: Cross-Lesson Data Integration & Letter Writing

(1) Select ≥2 data types from previous lessons (e.g., Lesson 1 temp diff, Lesson 3 weekend peak).

(2) Write letter using Letter Framework:

a. Science Intro: Cite Lesson 1 experiment on CO_2-emissions link.

b. Data Warning: Use Lesson 2 "Appliances = 58% emissions" & Lesson 4 "Summer peak XXkg" to argue problem severity.

c. Action Proposal: Based on Lesson 3 "Raise thermostat 1°C saves 19kg/month," propose collective community reduction goal.

Competency Goal: Build persuasive logic with data chain (A2, A3); Apply formal letter format (Chinese integration).

3.5. Product Showcase & Assessment

During the showcase, groups sequentially present their interconnected products guided by "Data-Driven Low-Carbon Action": (1) Present Greenhouse Effect Lab Report via visualizer, explaining CO_2-temperature relationship using charts. (2) Explain process of organizing/reducing household carbon data using the Carbon Footprint Analysis Report; Present source totals and analysis (max, proportion) via statistical table; Explain carbon neutrality and afforestation calculation. (3) Showcase AI Low-Carbon Poster, explaining chart choice, message, and color design intent. (4) Read the Letter to Community Residents.

An interactive Q&A follows, where other groups/teachers pose questions. Presenting groups respond, clarifying challenges and highlights. Finally, using the assessment rubric (see Appendix A) students conduct self-assessment, peer assessment (within group), and teacher assessment based on SR, Interdisciplinary Literacy, and Collaboration, comprehensively evaluating group performance and learning outcomes, guiding deep reflection to enhance SR and interdisciplinary literacy.

4. Discussion

4.1. Innovations and Theoretical Contributions

This study addresses three core issues in primary statistics teaching—fragmented competency development, lack of authentic contexts, and incomplete activities—by constructing a dual-dimensional framework ("Longitudinal Competency Progression + Horizontal Disciplinary Collaboration"). This framework embeds Jones' (2000) four-dimensional SR model into the interdisciplinary PBL structure. Distinct from traditional single-subject designs, this Mathematics-led framework dynamically integrates Science (experimental context), IT (tool empowerment), and Chinese Language Arts(argumentation/expression), enabling systematic SR development within authentic problem-solving. This responds to Friedrich et al.'s (2024) call for interdisciplinary data literacy cultivation and conceptually aligns with the effectiveness of Xia 's (2022) "progressive interdisciplinary prototype" in statistics education.

Most importantly, this project transforms abstract statistical concepts into concrete cognitive experiences through the social science topic of "Data-Driven Low-Carbon Action." For instance, in the "Household Carbon Footprint Analysis" task, students' quantitative operations (calculating emissions, trees for offset) not only build mastery of terms like "distribution" and "proportion" (O3) but also deepen understanding of data's value as a tool for environmental decision-making (A2, A3). This is consistent with the assertion of Watson et al.'s (2003) that combining statistical data with real-world problems (such as climate change) can cultivate critical data interpretation skills.

4.2. Practical Implications for SR Development

This research provides a replicable and practical model for the teaching reform in the field of statistics at the primary school stage.

By designing the interdisciplinary project "Data-Driven Low-Carbon Action", it demonstrates how the integration of multidisciplinary knowledge can enhance SR. This model can be widely applied to other domains, supporting the cultivation of talent with interdisciplinary literacy and innovative capacity.

Furthermore, the study emphasizes the significance of real data and real-world contexts in statistics teaching. By guiding students to collect, analyze, and interpret real data, it helps them establish connections between data and the real world, enhancing data application and problem-solving skills.

4.3. Construction of a Support System for Teachers' Interdisciplinary Competency

The successful implementation of Interdisciplinary Project-Based Learning (such as the "Data-Driven Low-Carbon Action" project) imposes extremely high requirements on teachers' interdisciplinary literacy. This not only includes teachers' profound content knowledge in their own discipline (e.g., Mathematics) but also requires sufficient understanding of collaborative disciplines (Science, Information Technology, Chinese Language Arts) to effectively integrate their concepts, methods, and practices. To address this critical challenge, it is necessary to provide teachers with a systematic and practical support system. To enhance the practical feasibility of the framework and empower teachers, the following support strategies are proposed:

4.3.1. Hierarchical Training System

Stage 1: Foundation and Philosophy

Introduce the theoretical basis for cultivating interdisciplinary statistical reasoning, the D-O-R-A model, principles of Project-Based Learning, and disciplinary integration models (e.g., the Mathematics-led model).

Stage 2: Collaborative Design and Planning

Provide tools and processes for teachers of different disciplines to collaboratively design project units, including identifying driving questions, mapping the statistical reasoning development pathway to activities, clarifying the specific contributions and integration points of each discipline, planning assessment schemes, and allocating resources.

Stage 3: Implementation and Guidance

Focus on classroom management strategies for interdisciplinary projects, guiding students in interdisciplinary inquiry, integrating technologies (e.g., AI tools for visualization), assessing interdisciplinary outcomes, and facilitating effective group collaboration.

4.3.2. Typical Case Studies and Lesson Repository

Organize and develop detailed cases of successfully implemented interdisciplinary statistical reasoning projects, particularly those framed by the D-O-R-A development pathway. The "Data-Driven Low-Carbon Action" project itself should be documented as a core case. These cases should include: detailed lesson plans highlighting integration points and key focuses of statistical reasoning dimensions for each lesson; samples of students' works and final outputs; teachers' reflections on challenges encountered and corresponding solutions; video or textual records of key classroom interactions. Exposure to such concrete cases can provide teachers with valuable examples for adaptation.

4.3.3. Construction of an Interdisciplinary Teaching and Research Community

It is recommended that schools establish fixed teams consisting of teachers from Mathematics, Science, Information Technology, Chinese Language Arts, and other disciplines, equipped with curriculum coordinators or subject experts to provide professional guidance, thereby forming a supportive community characterized by "teacher collaboration + expert leadership." This community should focus on authentic interdisciplinary themes (e.g., "Data-Driven Low-Carbon Action"), clarify the core contributions and integration nodes of each discipline in tasks through regular joint lesson preparation (e.g., data analysis in Mathematics, principle support in Science, expression logic in Chinese Language Arts), and avoid the mere superimposition of disciplinary knowledge. It should also conduct cross-classroom observations and mutual evaluations to refine strategies for disciplinary integration.

4.4. Future Research Directions

Future research should first focus on empirical verification of the proposed framework. As a conceptual design, the effectiveness of the framework in cultivating students' statistical reasoning (SR) requires systematic empirical testing. Subsequent studies could adopt mixed research methods, such as pre-post tests to measure changes in students' SR competencies (using the assessment rubric in Appendix A), classroom observations to record implementation processes, and interviews with students and teachers to collect data on learning outcomes and practical implementation barriers. Such empirical evidence will help refine the framework and enhance its practical applicability.

Deepening Teacher Professional Development Support: As highlighted in Section 4.3., teacher interdisciplinary literacy remains a critical challenge and a key area for future research.

Exploring Broader Applications: Future research should further explore the potential of interdisciplinary teaching in other subject areas. Designing and implementing more innovative and practical projects, integrating knowledge and methods from different disciplines, is of great significance for cultivating compound talents.

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Appendix A: Project Assessment Rubric

Primary Dimension	**Secondary Dimension**	**Key Elements**	**Scoring Standard**
Statistical Reasoning	Describing data displays (D)	D1: Interpret elements of experimental data charts/graphs (e.g., title, axes, labels).	1: Fails to identify any chart elements 2: Identifies isolated elements without data relevance 3: Identifies partial core elements (e.g., title/values) with incomplete descriptions 4: Can fully identify and explain all chart elements (title, horizontal/vertical axes, values)
		D2: Recognizing Different Representations of Same Data	1: Unable to distinguish chart types or provides irrational justifications 2: Distinguishes types based on superficial features (e.g., "look different") 3: Correctly identifies types but lacks analytical justification 4: Correctly distinguish chart types and interpret them by combining with the data in the charts.
		D3:Evaluating Different Representations of Same Data	1: Irrelevant reasons based solely on subjective preferences (e.g., "Bright colors") 2: Evaluation based on non-data factors (e.g., "Line charts are faster to draw") 3: Points out a single advantage (e.g., "Line charts can show changes") 4: Conducts multi-dimensional evaluation (e.g., "Bar charts are suitable for comparing instantaneous values"; "Line charts are suitable for showing CO_2-induced temperature rise trends"; "The slope angle shows the acceleration of temperature rise")
	Organizing and reducing data (O)	O1: Group household carbon emission data by source type.	1: No grouping or irrelevant grouping criteria 2: Chaotic grouping (e.g., classifying air conditioners separately) 3: Correctly completes single-dimensional grouping (e.g., all electrical appliances are classified as "home appliances" without further subdivision) 4: Groups carbon emission sources by multiple dimensions (e.g., "Classifies air conditioners as electrical appliances and gasoline-powered vehicles as transportation") and explains the

			grouping logic
		O2: Identify and remove redundant information from the data table.	1: Does not delete any information or deletes data randomly 2: Can delete some redundant information but retains a small amount of irrelevant fields 3: Can delete major redundant information and briefly explain the reason (e.g., "Unrelated to carbon emissions") 4: Can comprehensively identify redundant fields (e.g., "device ID", "usage period") and explain the reason for deletion and its relevance to data
		O3: Use statistical terms like "maximum" and "proportion" to describe the distribution characteristics of carbon emissions.	1: Unable to use statistical terms to describe data. 2: Can use non-precise terms such as "most" and "half" to describe distribution 3: Can accurately point out the source of the maximum value (e.g., "Air conditioners have the highest emissions") and calculate simple proportions 4: Can calculate proportions based on data (e.g., "Transportation emissions account for 35%") and explain their significance for low-carbon actions
	Representing data (R)	R1: Understand and complete missing data in charts/graphs.	1: Fills in randomly or leaves blank 2: Completes the conversion but omits key information such as trend arrows 3: All data is reasonable but no method is explained 4: Accurately completes based on data patterns and explains the method
		R2: Convert air conditioner (AC) carbon emission data between representations (e.g., bar chart, statistical table, line chart).	1: Unable to convert or with incorrect formats 2: Converts formats but omits key information such as trend arrows 3: Correctly completes chart/table conversion but with brief reasons 4: Correctly completes chart/table conversion and explains advantages (e.g., "Line charts can highlight the changing trend of air conditioner carbon emissions")
	Analyzing and interpreting	A1: Critically analyze the limitations of a	1: Fails to identify limitations 2: Can simply mention incomplete data but does not explain the impact

	data (A)	single data source.	3: Can point out one key limitation (e.g., "Data only covers 1 week") 4: Can, in combination with research purposes (e.g., community promotion), point out the sample limitations of the data (e.g., "Data from only 1 household") and time limitations (e.g., "Does not include winter")
		A2: Compare and combine data across charts/graphs.	1: Unable to identify "Peak Month" or "Secondary Peak", or confuses data (e.g., misjudges the lowest month as the highest month), with reasons unrelated to data (e.g., "Guessed randomly") 2: Can correctly identify either "Peak Month" or "Secondary Peak" but describes reasons without referring to data 3: Can accurately identify both "Peak Month" and "Secondary Peak" and describes reasons with reference to data 4: Can accurately identify both "Peak Month" and "Secondary Peak" and describes reasons based on data patterns
		A3: Make simple trend predictions for carbon emissions based on existing data.	1: Unable to make any predictions 2: Can simply guess the trend (e.g., "It will keep increasing") 3: Can accurately calculate annual total emissions (e.g., the sum of 12-month data is 1200kg) and correctly predict the total for next year with a 2% growth ($1200 \times 1.02 = 1224$kg) but does not explain the prediction basis (e.g., fails to state "The 2% growth is based on the assumption that household electricity usage habits are stable") 4: Can accurately calculate annual total emissions, correctly predict the total for next year with a 2% growth, and explain the prediction logic (e.g., "Household electricity usage habits have been stable in the past 3 years, so a 2% growth is assumed; if energy-saving measures are promoted, the growth may drop to 0.5%"), reflecting consideration of data limitations
Interdisciplinary Literacy	Scientific Inquiry Practice	1. Derive scientific conclusions (greenhouse	1: Only repeats experimental steps without mentioning data and principles 2: Can describe experimental phenomena (e.g., "The temperature inside the bag is higher") but

		effect principle) from experimental data phenomena.	fails to link to principles 3: Can link data to the greenhouse effect and explain "More CO_2 → Higher temperature" 4: Can comprehensively explain the heat preservation effect of CO_2 based on temperature difference data (e.g., "3℃ higher inside the sealed bag")
		2. Understand the concept of carbon neutrality and correctly calculate the number of trees needed to offset annual household carbon emissions.	1: Unable to complete calculations or does not understand the meaning of formulas 2: Has minor calculation errors but understands the offset concept 3: Can correctly calculate results and briefly explain the meaning of carbon neutrality 4: Can accurately calculate annual emissions and the number of trees needed, and explain the logic that "Emission reduction takes priority over offset"
	Digital Innovation	1.Poster Completeness: Clearly tells a low-carbon story by integrating at least one statistical chart, text message, and visual image elements.	1: Missing elements (e.g., no charts) with vague information 2: Contains 1 element with complete information but lacking relevance 3: Contains 2 elements with close correlation between charts and text 4: Contains 3 or more elements (e.g., line chart + slogan + icon) with coherent logic (e.g., "Trend chart → Problem → Action")
		2.Creative Expression: Uses color/layout and other visual elements to enhance the persuasive power of the data.	1: Chaotic colors with obscured data 2: Single color with basically reasonable layout 3: Colors conform to the theme, layout is clear, and data is placed reasonably 4: Uses green tones to symbolize environmental protection, with layout highlighting core data (e.g., enlarging peak values) to enhance visual impact
	Language Application	1. Richness of data sources: Integrates data from at least	1: Does not use any data 2: Integrates data from 1-2 lessons but with complete irrelevance (e.g., using "experimental date" from Lesson 1 to discuss "carbon

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		two project lessons.	emission issues") 3: Integrates data from 2 lessons and clearly distinguishes data types 4: Integrates data from 3-4 lessons (e.g., experiment + household + community), marks sources (e.g., "Table 1-1 experimental data"), and proposes suggestions with a data chain
		2. The community letter follows standard formal letter format.	1: Chaotic format (e.g., confusing salutation and body text) 2: Complete format but missing key parts (e.g., no signature) 3: Basically complete format 4: Includes salutation, body text (data argumentation), signature, and date, with standard format and appropriate tone
Collaborative Practice	Teamwork	1. Clear division of labor within the group with reasonable task allocation.	1: No division of labor or chaotic division of labor 2: Has division of labor but some members have vague tasks 3: Reasonable division of labor with clear tasks for each member 4: Fixed roles (e.g., recorder, analyst) with tasks matching abilities
		2. Mutual help and communication among group members to jointly solve problems encountered during the project.	1: Only completes personal tasks without participating in collaboration 2: Can participate in discussions but with few contributions 3: Can cooperate to solve problems and provide 1-2 effective suggestions 4: Takes the initiative to help peers and solves 3+ problems through discussions
	Project Output	Completed all project tasks on time and produced high-quality deliverables.	1: Unfinished with many errors 2: Basically completes tasks with a small number of issues needing revision 3: Completes all tasks on time with error-free outcomes 4: Completes all tasks in advance with outcomes exceeding expectations

Scoring Levels: 1 point: Idiosyncratic; 2 points: Transitional; 3 points: Quantitative; 4 points: Analytical.

Author Contributions:

Conceptualization, **Yutong Wang**; methodology, **Yutong Wang;** writing—original draft preparation, **Yutong Wang**; writing—review and editing, **Qi Shen**; supervision, **Qi Shen**. All authors have read and agreed to the published version of the manuscript.

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