Activity Design and Effect Analysis of Integrating STEAM Education with High School Statistics and Probability Teaching

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ABSTRACT To address the tendency of high school statistics and probability teaching to emphasize calculation while neglecting critical thinking and real-world modeling, this study designs and implements a STEAM-based project learning activity. The project uses structural reliability of high-performance industrial textile fibers as an inquiry context, guiding students to analyze tensile strength variability and weave-density distributions as statistical data. Through project construction, interdisciplinary tool integration, data modeling, and multidimensional evaluation, students apply sampling, distribution analysis, regression modeling, and probability reasoning to practical engineering problems. A quasi-experimental design is used, with one experimental class adopting STEAM-integrated project-based learning and one control class adopting traditional lecture-based teaching. The results show that the post-test score of the experimental class reaches 85.67, significantly higher than the control class score of 79.43. All project-work evaluation items exceed 3.9 points, and the number of classroom discussions increases from 12.5 to 19.0. The findings indicate that STEAM-integrated teaching can improve students' data literacy, interdisciplinary application ability, and innovation awareness in statistics and probability learning.

INDEX TERMS steam education, statistics and probability, project-based learning, activity design, industrial textile fibers

I. INTRODUCTION

THE current high school "statistics and probability" teaching remains constrained by a traditional emphasis on rote calculation over conceptual depth, failing to address the complex stochastic modeling of high-performance industrial textile fiber strength. Consequently, teachers focus on abstract formula derivation rather than the practical application of probability in predicting the structural reliability of industrial textile weave patterns under mechanical stress. Although the students can skillfully calculate the mean and variance, they often encounter cognitive difficulties when applying statistical reasoning to explain random phenomena in real-world contexts, and can't help [1,2]. This is the deep-seated problem of traditional teaching in statistics and probability in cultivating students' ability to explain real world with data and problem solving ability across disciplines, and we need to import new teaching concepts and methods to break through.

Researchers have explored different perspectives on the reform of statistics and probability teaching. Tian reformed the probability theory and mathematical statistics course through case teaching and online-offline blended teaching to improve students' ability to solve practical problems [3]. DENTON compared relevant research with teacher training standards through a systematic review, pointing out that current research focuses more on the development of probability and statistics knowledge, while paying insufficient attention to teaching knowledge, practical experience, and reflective learning [4]. Callingham, taking the progress of empirical statistical reasoning learning as an example, proposed a curriculum development method that combines mathematical content knowledge with reasoning, understanding, and problem-solving abilities to support more targeted statistics and probability teaching [5]. Kennedy-Shaffer, through reviewing typical cases of the historical connection between statistics and eugenics, explored how to face this history in statistics teaching to strengthen methodological understanding and guide students to think about the ethical issues of data analysis[6]. Begolli et al. found that in seventh-grade probability learning, example-based exercises can effectively compensate for students' insufficient proportional reasoning ability, thereby promoting the understanding and development of probability knowledge[7]. In response to the problem that linguistics teaching is affected by multiple factors and its effects are difficult to evaluate, Li used an improved machine learning algorithm to construct an artificial intelligence teaching model to improve the efficiency and evaluation effect of linguistics teaching[8]. However, existing research mostly stays at the level of single-dimensional improvement, or emphasizes context but neglects the depth of thinking, or emphasizes technology but weakens the integration of subjects, and has not yet formed a systematic interdisciplinary teaching plan, making it difficult to truly achieve the comprehensive improvement of students' comprehensive abilities.

STEAM education emphasizes the organic integration of science, technology, engineering, art and mathematics, providing a new theoretical perspective for solving the above problems. Chen explored the integration of STEAM education concept and high school mathematical modeling teaching, pointing out that it can improve students' core abilities and promote basic education reform through interdisciplinary integration and practical inquiry[9]. Belbase et al. explored the current development status of STEAM education through literature review and analysis, and summarized its key themes and development issues from the aspects of teaching process and evaluation[10]. González-Martín et al. conducted a multi-case study on three primary schools, combined with interviews and classroom observation, to explore the key elements and educational value of music and mathematics integration in integrated STEAM teaching[11]. These explorations have initially verified the feasibility of the STEAM concept in mathematics teaching, but related studies are mostly concentrated in the compulsory education stage, and the systematic activity design and effect verification for the high school statistics and probability module are still insufficient.

Focusing on high school statistics and probability, this paper develops a STEAM-integrated project-based program that utilizes fiber performance testing and fabric structural analysis as real-world inquiry scenarios to resolve traditional teaching pain points through multidisciplinary tool integration and multi-dimensional evaluation. By applying statistical models to textile quality control and material durability data, the program establishes a complete inquiry process that bridges mathematical theory with the technical complexities of textile engineering. The main research innovation of this paper is: establish an operable STEAM integrated teaching activity framework, and verify the effectiveness of the integrated teaching activity in terms of knowledge mastery, interdisciplinary skills and classroom participation quasi-experimental research, and provide theoretical support and reference for the reform of high school statistics and probability teaching.

II. PROJECT CONTEXT CONSTRUCTION

The authenticity and difficulty of project contexts are the keys to the success of STEAM integrated teaching. From the very beginning of the design of activities, we took "from life, to problems" as the basic principle to build contexts. In practice, we took phenomena or current social issues that students could perceive in their daily lives as the source material and packaged them into driving problems with interdisciplinary inquiry value. Taking the "Urban Traffic Flow Prediction" project as an example, the teacher first showed students real traffic data in the city during the morning and evening rush hours, prompting students to think about "how to use statistical methods to predict the probability of congestion at different intersections." This problem is related to students' lives and can easily attract students to inquire about it.

Then, the teacher gradually broke down the problem: students needed to design sampling plans to collect traffic flow data, use probability models to analyze congestion situations, and then use engineering thinking to draw out the optimization flowchart, and finally present the predicted results with chart visualization. These abstract concepts of statistical sampling, normal distribution, regression analysis, etc. were naturally "dissolved" into the context of real problems. Students were not mechanically applying formulas to solve problems, but were actively constructing knowledge as they solved problems. Another typical example is "Optimization of Community Public Facilities". Students surveyed an old residential community near the school, collecting data on residents' needs for public facilities such as fitness equipment and garbage sorting stations through questionnaires and field visits. When analyzing data, students needed to consider factors such as population structure and spatial distribution, and use statistical inference methods to make suggestions for adding or adjusting the number of fitness equipment and garbage sorting stations, and finally present their analysis results with drawings of the optimized situation. This scenario not only includes key knowledge points of statistics and probability, but also involves sociological survey methods, thinking of spatial planning, and artistic expression, reflecting the interdisciplinary integration requirement advocated by STEAM education.

III. BUILDING AN INTERDISCIPLINARY TOOLKIT

After the background information of the project, this paper constructs the interdisciplinary toolkit step by step to help students apply the knowledge and skills from different fields in problem solving. The mathematical modeling tools are included in the toolkit. In the statistics and probability module, the students should understand the standard and selection criteria of sampling methods, organizing sample data method and thinking process of establishing probability models. For instance, in the project of "Traffic Flow Prediction", the teacher can ask the students to fit the traffic flow data with a normal distribution and explore the linear relationship between time and flow with regression analysis. The students are not limited to directly using the formula, but understand the applicable conditions and interpretative range of the model through repeated attempts. Technical tools provide support for data processing. Excel is the easiest data analysis platform for students to use. We teach students to use pivot tables to quickly summarize information, use functions to calculate descriptive statistics, and use charting tools to generate visualizations such as histograms and scatter plots. For groups with extra capacity, the teacher introduces Geometer's Sketchpad or online data analysis platforms, allowing students to try simple simulated sampling and dynamic demonstrations, enhancing their intuitive understanding of probability concepts.

Engineering thinking tools support students to make the inquiry process standardized. At the very beginning of the implementation of the project, the teacher guides the students to develop mind maps or flow charts to divide the research question into doable steps: define the objective—collect data—analyze/process data—draw conclusion—propose a solution. This apparently standardized flowchart prevents students from engaging in unsystematic or fragmented inquiry processes and assists them in building a structured, strategic research plan. Some of the groups also developed Gantt charts to rationally plan the time and tasks for the group members.

Artistic expression tools are applied in presenting the results. We encourage the students to use the help of infographics, hand-drawn posters or even animated PPT to present their research findings. For the project of Waste Sorting Optimization, one group used bubble maps to show the amount of waste collected at different collection points and made a vivid comparison of the differences between the areas; another group developed a set of cartoon style posters and converted the data analysis conclusions into a set of easily understandable initiatives for the residents of the community.

IV. IMPLEMENTATION OF THE RESEARCH PROCESS

This paper divides the project implementation into five overlapping stages, each with a well-defined task and corresponding methodological support. Stage 1: Identify problems and design solutions. After clarifying the project theme, each group needs to further transform the general contextual problem into a specific research question. For example, for the theme of "optimization of community public facilities," some groups clarified "whether there are differences in the frequency of using fitness equipment by residents of different age groups," while other groups clarified "the relationship between the distance to garbage disposal points and residents' willingness to dispose of garbage." The teacher guided the students to discuss what kind of data needed to be collected, what sampling method should be adopted and what is the size of sample, and to draw the research flowchart. The focus of this stage is to train students to have problems awareness and planning ability and to avoid blind spots in later implementation.

Stage 2: Collect data and organize. Students implemented field investigation according to the design plan and acquired primary data based on questionnaires, observation, interview, etc. Back to the school, each group needed to clean and code the raw data, discard invalid questionnaires, standardize the data format, and enter the results into the Excel spreadsheet. While the data entry and cleaning process is inherently meticulous and repetitive, it serves as a critical pedagogical phase for fostering professional rigor and ensuring data integrity. Some groups found that the sample was not representative enough during data collection. The teacher prompted them to reflect on the deficiencies in the sampling plan and implemented supplementary investigation when possible.

The third stage is model building and analysis. After mastering the preliminary data, students need to use their knowledge of statistics and probability to uncover the patterns behind the data. Teachers provide differentiated guidance based on each group's research questions: some groups are suitable for using frequency distribution tables to describe the central trend of the data, some need to draw scatter plots and try to fit a regression line, and others can introduce probability models for prediction. Students repeatedly experience the cycle of "guessing—verifying—adjusting" in this stage; statistical concepts are no longer just definitions in textbooks, but analytical tools in their hands.

The fourth stage is result interpretation and solution formulation. Students make preliminary conclusions according to the results of data analysis and convert them into concrete solutions that can be implemented. For instance, in the "Traffic Flow Prediction" project, one group proposed "to extend the timing of traffic lights in the morning rush hour from 7:30 to 8:00" according to the regression model; in the "Garbage Sorting Optimization" project, one group proposed to increase the number of garbage bins in areas with high concentrations of elderly people according to the garbage disposal frequency. Students should not only be able to calculate, but also be able to explain what the data means, and what limitations the conclusions have in terms of their scope.

The fifth stage is exchange, presentation, reflection, and summary. Each group presents its research results to the whole class using PPT, posters, or short plays, and answers questions from teachers and students. After the presentation, each group must submit a written reflection report, summarizing the difficulties encountered during the project, the solutions, and personal gains. The teacher organizes the whole class to comment on outstanding works, while guiding everyone to think about "how to improve if we did it again." This stage is both an evaluation of the project results and a process of transforming individual experience into collective wisdom.

V. RESULTS PRESENTATION AND EVALUATION

A project defense meeting is held at the end of each project cycle. Each group has ten minutes to present and five minutes to answer questions. The presentation format is determined by the group itself. Some groups create PowerPoint presentations, some create posters to illustrate their research findings, and others create short skits to recreate the research process. This diverse presentation format itself reflects artistic literacy. Students need to clearly convey their research questions, data sources, analytical methods, main conclusions, and suggestions for improvement within a limited time, which places high demands on logical expression and on-the-spot adaptability. There are three parts in evaluation. Teacher evaluation takes into account for the professional evaluation on basis of statistical method selection, data analysis process and derivation of conclusion. Peer evaluation is after each group presentation, we ask each group to score for presenting group according to the standard evaluation form. Such arrangement motivate students to listen attentively to other group's presentation and also learn from others' work. Student self-evaluation requires each student submit their personal reflection report on their individual work and learning in project, analysis for their deficiency and future plan.

Evaluation dimension 1: Mathematical correctness. The correctness of selection and application of statistical method and standardization of data analysis process; Technological innovation. Whether there are flexibly apply the technical tool and consciously use new method in analysis process of data; Engineering logic. Whether the research plan is systematically feasible and clear. Whether the solving problem path is clear and reasonable; artistic expression. The effect of view and creative expression of result and whether the audience can quickly acquire the key information. The scoring points of each item in four dimensions are set according to the above basis to ensure the objectivity and operability of evaluation. Based on four dimension, we establish the multivariate evaluation index system as shown in table 1 to evaluate students' project results.

VI. ANALYSIS OF THE PRACTICAL EFFECTIVENESS OF INTEGRATED TEACHING ACTIVITIES

A. EXPERIMENTAL SETUP

This study used quasi-experimental design, and randomly selected two parallel classes from the second year of senior high school as the research subjects. There were no statistically significant differences between the two classes in the pre-test mathematics score, gender ratio and statistics and probability score ($p>0.05$). The experimental class (48 students) was randomly selected to receive the STEAM integrated teaching, and the control class (47 students) received traditional lecture teaching. The duration of the experiment was 18 weeks. The experimental class focused on the teaching content of sampling method, estimating population from sample and variable correlation. This study was approved by the Ethics Committee of Cangzhou Normal University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

This study used teaching methods as the independent variable, and the dependent variables were knowledge attainment, interdisciplinary application ability to solve problems and classroom participation. After completing the pre-test, the experimental class conducted project activities, such as "Optimization of campus waste classification" and "Prediction of traffic congestion period", and the control class continued the previous teaching. In the post-test, the unified knowledge test was conducted, and the learning achievement of experimental class was collected by collecting the score of class project work. Classroom observation and learning attitude questionnaires were also conducted in both classes. The quantitative data were analyzed by SPSS for descriptive statistics and t-tests. The qualitative data were extracted by thematic analysis.

B. COMPARATIVE TEST OF TEACHING MODEL AND STEAM INTEGRATED TEACHING

In order to study the effectiveness of STEAM integrated teaching in high school statistics and probability module teaching, this study chooses the second year of two parallel classes in the classes as the experimental class (48 students) and the control class (47 students), respectively. The experimental class uses project-based STEAM integrated teaching in real life as the experimental class, and the control class uses traditional lecture mode. The teaching content, speed and class hour of two classes are consistent. Standardized test is used before and after the teaching to test the degree of students' knowledge mastery, so as to compare the effectiveness of the two teaching modes.

In Table 2, the average score of the experimental class in the post-test was 85.67, significantly higher than the 79.43 of the control class ($t=4.826$, $p<0.01$). In terms of score improvement, the experimental class showed a gain of 13.32 points, more than double the 6.42-point increase observed in the control class. While the control class improvement is attributed to the standard progression of the national curriculum and conventional classroom exercises, the significantly higher gain in the experimental group ($t=4.826$, $p<0.01$) underscores the added value of the STEAM intervention. These data indicate that interdisciplinary project-based learning is more conducive to deepening students' understanding and application of statistical concepts than traditional pedagogical methods alone. It should be noted that although the traditional teaching method used in the control class has certain advantages in knowledge transmission efficiency, STEAM-integrated teaching, driven by real-world problems, shifts students from passive acceptance to active construction, thus achieving a more solid learning outcome.

C. INTERDISCIPLINARY INNOVATION ABILITY ASSESSMENT EXPERIMENT

To investigate the effectiveness of STEAM integrated teaching in cultivating students' interdisciplinary innovation ability, this study designed a project task of 'Campus Waste Data Collection and Intelligent Recycling Scheme Design' for 48 students (namely 8 groups) in an experimental class. To establish a comparative baseline, students in the control

TABLE 1. Multivariate Evaluation Index System

Evaluation Dimension	Observation Points	Evaluators	Weight	Reference
Applied Mathematical Reasoning	Whether statistical methods are appropriately applied to solve real-world complexities and interpret data trends	Teacher	25%	
Technological Innovation	Whether technical tools are flexibly used and whether there are innovative attempts	Teacher, Peer Assessment	25%	
Engineering Logic	Whether the research plan is systematic and feasible, and whether the problem-solving path is clear	Teacher, Peer Assessment	30%	
Artistic Expression	Whether the presentation is intuitive and aesthetically pleasing, and whether the expression is compelling	Peer Assessment, Self-Assessment	20%	

TABLE 2. Comparison of Test Scores Between the Two Classes

Group	N	Pretest Mean (Full Score 100)	Pretest SD	Posttest Mean (Full Score 100)	Posttest SD	Gain Score
Experimental Class	48	72.35	6.24	85.67	5.82	13.32
Control Class	47	73.01	6.57	79.43	6.91	6.42

class (47 students) were assigned a traditional case-study analysis on the same topic; however, their performance was limited to mathematical calculations without the interdisciplinary components of engineering and art. Consequently, the experimental class scores represent a verified advancement over the baseline of traditional problem-solving by incorporating multi-dimensional innovation that was absent in the control group.

As shown in Figure 1, STEAM integrated teaching effectively promoted the comprehensive development of students' interdisciplinary innovation ability. The average scores across all dimensions were above 3.9 out of 5. Mathematical accuracy showed the best performance (M=4.25, SD=0.35), indicating that project-based learning is highly effective in consolidating foundational knowledge. Artistic expression (M=4.06, SD=0.44) and technological innovation (M=4.00, SD=0.44) scored moderately, reflecting students' creativity in data visualization and tool application. Engineering logic scored the lowest (M=3.91, SD=0.34), suggesting that while the 'Interdisciplinary Toolkit' provided procedural flowcharts, students struggled to internalize the iterative nature of engineering optimization under real-world constraints. This indicates that future iterations of the toolkit must transition from providing static templates to fostering dynamic, constraint-based decision-making to better support engineering literacy. Overall, STEAM project activities provide an effective pathway for cultivating interdisciplinary literacy.

D. ANALYSIS OF STUDENT LEARNING BEHAVIOR AND PARTICIPATION

To investigate the effects of STEAM integrated teaching on students' classroom learning behavior, this study adopted classroom observation to observe students in an experimental class (48 students) and a control class (47 students) systematically. Although the full pedagogical experiment spanned 18 weeks to cover the entire curriculum, the behavioral observation focused on a critical 6-week window during the intensive project implementation phase, where interdisciplinary tool use and group collaboration were most prominent. The observation form developed by the researchers was named as "Classroom Learning Behavior Observation Record Form", and the behaviors of four dimensions: active questioning, group discussion participation, attention maintenance, and resource tool use were recorded for the experimental class and the control class each for 5 minutes. The data were recorded by two trained observers simultaneously and the inter-observer reliability was 0.85 or above.

As shown in Figure 2, the classroom participation of students in the experimental class was significantly higher than that in the control class. During the six-week observation period, the frequency of group discussions in the experimental class steadily increased from 12.5 times in week 1 to 19.0 times in week 6, while the control class remained fluctuating between 8.5 and 9.8 times. Regarding resource tool use, the experimental class increased from 8.2 times to 16.2 times, while the control class remained stable at 3.2 to 4.0 times. In the control group, 'tool use' was strictly defined as the basic application of scientific calculators and reference to printed statistical tables during the independent practice portion of the lecture. Unlike the experimental group, these tools were used for rote computation rather than exploratory data analysis or digital modeling. By week 6, the experimental class had 1.9 times more discussion frequency and 4.4 times more tool usage frequency than the control class. This indicates that STEAM-integrated teaching effectively stimulates students' enthusiasm for classroom participation, and its positive impact on learning behavior accumulates as the project progresses.

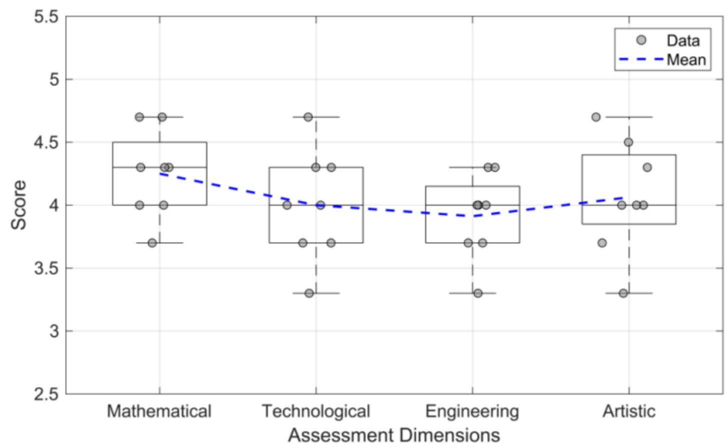

FIGURE 1. Box Plot of Score Distribution for Each Dimension of STEAM Project Works

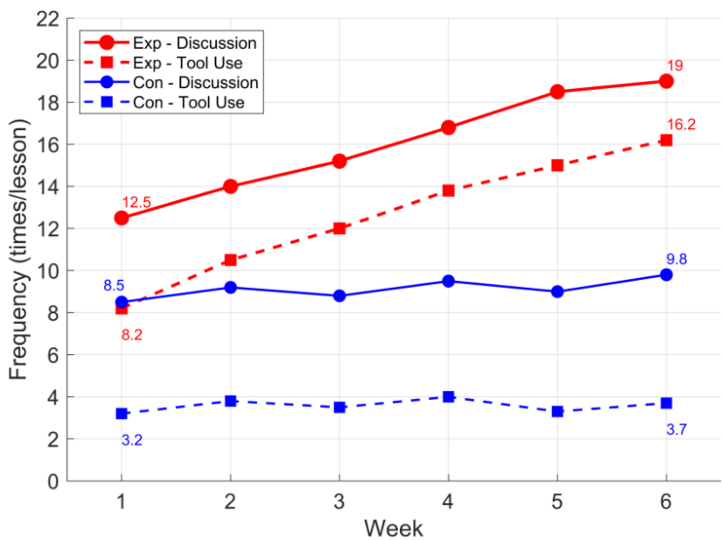

FIGURE 2. Trends in Key Learning Behaviors of the Two Classes over 6 Weeks

VII. CONCLUSION

To address the overemphasis on calculation over critical thinking in high school statistics, this paper designs a STEAM-integrated project-based program that utilizes fiber strength variability and textile weave consistency as authentic datasets for inquiry. By embedding statistical analysis within the technical evaluation of textile material performance, the program fosters high-order reasoning through a complete multidisciplinary exploration of industrial data. According to the results of the experiments, this strategy has brought positive outcomes in three aspects, namely, the knowledge acquisition, the ability development, and the classroom participation. The post-test scores on the experimental class were also much higher than on the control class; project projects registered a higher score on mathematical accuracy and technological innovation than 3.9 points; and the extent of student classroom discussion and usage of tools continued to rise as the teaching went on. This work confirms the efficiency of teaching that incorporates STEAM into enhancing data awareness and other interdisciplinary abilities of students. This research was not able to cover all classes in one school because of the research period and the size of the sample thus only selected two classes in one school participated in the experiment and trailed them through one semester. The conclusions should be further verified by generalization. Future studies should utilize larger sample sizes and extended follow-up periods to evaluate how STEAM-driven inquiry into textile engineering parameters and fiber degradation cycles affects the longitudinal development of students across different academic levels. This approach will allow for a more nuanced understanding of how analyzing the physical properties of textile polymers serves as a catalyst for cognitive growth and statistical proficiency.

AUTHOR CONTRIBUTIONS

Conceptualization –Jing Zhang and Yongyan Fan; methodology – Jing Zhang and Yongyan Fan; investigation – Jing Zhang and Yongyan Fan; writing-original draft preparation – Jing Zhang and Yongyan Fan. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

HUMAN RESEARCH SUBJECTS

This study was approved by the Ethics Committee of Cangzhou Normal University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

ACKNOWLEDGEMENTS

Not applicable.

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