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Evaluating Dual Project-Based Learning Approaches in Vocational Education: Evidence from a Parallel-Class Experiment in a Data Analysis Course

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Abstract: To improve the practical teaching effect of the data analysis course, this study innovatively adopted a three-group parallel class experiment to explore the differences in the impact of personal project-based, team project-based, and traditional teaching. This study used the "Data Analysis Foundation" course at a vocational college as a scenario, implemented teaching interventions on three classes with similar foundations, and evaluated the results through project outcome scoring, practical exam scores, and final exam scores. By comparing project results, practical skills, and theoretical assessments, we found that project-based teaching can significantly improve students' practical abilities. However, the two modes have different strengths: team projects are better for developing the ability to solve complex problems, while individual projects are better for mastering basic skills. Theoretical knowledge is not affected by the teaching mode. The study shows that project-based teaching is an effective way to strengthen data analysis skills. Among the two modes, the individual mode is better for training basic skills, while the team mode is better for solving complex problems. It is recommended that the course reform design be flexible in selecting the dual mode path according to the training goals.

Keywords: Higher Vocational Education; Teaching Reform; Practice Teaching; Project-Based Learning

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1.Introduction

As big data technology becomes more deeply embedded in various industries, the ability to analyze data has gradually become one of the core professional qualities of high vocational school business and trade talent. As a key course in developing this ability, the importance of the "Data Analysis Fundamentals" course is increasingly apparent. Through research, it was found that the teaching model of this course is currently widely adopted as "theory teaching+distributed experiment," but the limitations of this teaching model are gradually becoming apparent as the times change[1]. The main limitations are as follows:

Skills training is inadequate. Students passively complete fragmented exercises and lack training in the complete data analysis process (problem definition, data processing, model building, and decision output), which leads to their inability to handle real business data[2].

(2) Students' interest is not stimulated by abstract theories and isolated practices, which leads to low classroom participation and weak high-level analytical skills[3].

(3)The evaluation criteria are limited. Currently, the evaluation of this course is mainly reflected in the final written exam, which ignores the quantitative assessment of practical skills such as data cleaning, modeling, and visualization[4].

In response to the aforementioned issues, project-based learning (PBL) has gradually been introduced into the reform of data analysis courses in recent years[5][11][12]. This model drives students through full-process practical experiences via real-world scenario tasks, aligning with the vocational education principle of "learning by doing"[5][8][9]. Previous studies indicate that research on the teaching effectiveness of PBL has predominantly focused on qualitative, single-course investigations. While some researchers have begun attempting quantitative analyses, these studies remain limited in scope. They primarily examine issues identified during the implementation of PBL within a specific course and propose improvements, without establishing consistent methodological approaches[10]. Crucially, there is a lack of evaluation methods specifically designed to assess the actual teaching outcomes.

Moreover, the current implementation of this course reform faces two major blind spots[13]. First, the choice of teaching model remains ambiguous, as there is a lack of empirical evidence to determine whether individual independent practice or team collaboration projects within the course are more effective, leading to a certain degree of arbitrariness in instructional design[6]. Second, the validation of outcomes remains rudimentary. Current practice evaluations are largely confined to qualitative summaries of individual classes or comparisons between a single class's current status and its past performance. These studies lack quantitative comparisons with contemporaneous control groups, making it difficult to isolate the influence of confounding factors[7].

Due to the scarcity of quantitative analysis methods and research in previous studies, coupled with the lack of a systematic research methodology[1][14], there has been a shortage of unified approaches and quantitative methods for evaluating the effectiveness of project-based teaching. Taking the required course "Data Analysis" in vocational colleges' commerce-related majors such as E-commerce and Supply Chain Operations as an example, this paper proposes constructing a multidimensional quantitative evaluation framework integrating project outcome scoring (process-oriented), practical assessment (skills-based), and theoretical testing (cognitive-based) indicators. This approach breaks through the limitations of traditional single-assessment methods by employing mature statistical comparison techniques to provide quantifiable evaluation methods. It evaluates the pilot effectiveness of the project-based teaching model within this course. Furthermore, drawing from the case study and analysis process, this paper attempts to propose a universal approach and quantitative analytical method for evaluating the teaching effectiveness of this model.

2.Teaching Practice Research Design

2.1 Research Subjects and Grouping

To scientifically compare the effectiveness of different teaching models, this study selected three parallel classes (Class 1, Class 2, and Class 3) enrolled in the same grade's "Fundamentals of Data Analysis" course at our institution. Students across all three classes possessed comparable foundational proficiency (no significant differences in entrance math scores or prerequisite course grades), and class assignments were determined by random student ID number sequencing. Consequently, student learning profiles were nearly identical with no discernible variations. Specific grouping arrangements are as follows:

Class A employs individual project-based instruction, where students independently complete three practical projects such as backend data cleansing, user behavior visualization, and seasonal sales forecasting. Class B employed team-project-based instruction, where groups of 3-4 students collaboratively completed an integrated project (e.g., annual operational analysis of an e-commerce platform), covering the entire process from data collection to decision-making recommendations. Class C served as the control group, continuing the traditional lecture-plus-laboratory model. After explaining key concepts, the instructor guided students through practical exercises organized by chapter.

The key control points of the study are that all three classes are taught by the same instructor, using identical textbooks, core knowledge points, and theoretical course content. Only the practical components differ in design.

2.2 Teaching Implementation Process

First, theoretical instruction is standardized. The weekly theory sessions (2 academic hours) for all three classes are conducted simultaneously, with core knowledge points explained uniformly to ensure consistent and unbiased knowledge delivery.

Regarding differentiated practical training design, drawing from existing scholarly research and adapting to our specific context, three practical session models were developed: Class A students engage in "independent analyst"-style practice, completing one project every three weeks with one-on-one instructor feedback on individual analysis outcomes; Class B students simulate corporate data analysis teams, requiring group planning, collaboration, mid-term proposal presentations, and final integrated report submissions; Class C adopts a conventional lab format where students progressively replicate instructor demonstrations, sequentially completing skill training scattered across textbook chapters.

To ensure fairness, instructors, program directors, and external teaching consultants evaluated project difficulty. Class B's integrated project was confirmed to match the combined complexity of Class A's three individual projects, establishing this experimental design as equitable.

2.3 Effectiveness Evaluation System

The teaching effectiveness will be assessed across the following three dimensions:

Table 2.1 Teaching Effectiveness Evaluation Form

Evaluation Dimension	Evaluation Method	Evaluation Timing
Project Practical Skills	Score outcomes using the Project Scoring Sheet (Maximum 100 points)	Week 15
Core Operational Skills	Independent analysis of real data within a 2-hour time limit (on-site scoring)	Week 16
Theoretical Knowledge Mastery	Final closed-book examination (covering over 90% of knowledge points)	Final Unified Examination

The design of the project grading rubric is comprehensively structured based on the competency objectives outlined in the course standards. It assesses mastery of various skills, including whether data cleaning procedures are standardized, whether analytical methods are properly applied, and whether report logic is clear and reasonable. Additionally, since Class B's practical component is designed as teamwork, the final grade consists of a group total score and an individual contribution score. The individual contribution score is determined through peer evaluation within the group, with the two components weighted at the 7:3 ratio.

2.4 Data Analysis Methods

To validate differences in practical teaching effectiveness, this study adopted a quantitative comparative paradigm with the following procedures. First, preliminary observations were conducted, descriptive statistics were applied to the average scores of the three student groups. Second, Levene's test was used to verify homogeneity of variance during the prerequisite analysis phase. In the critical testing phase, one-way ANOVA was applied to examine mean differences across the three groups for each of the three indicators, determining whether significant overall differences existed among the groups. If significant results were found, post-hoc testing proceeded; the Tukey HSD test was employed for pairwise comparisons among the three groups. Finally, conclusions were drawn and relevant recommendations provided.

3.Data Collection and Organization

To ensure the authenticity and reliability of research data, this study systematically collected and processed teaching data from three classes of the "Fundamentals of Data Analysis" course between March and July. The entire process was implemented in accordance with enterprise data analysis procedures, following these specific steps:

3.1 Data Sources

Data sources comprise comprehensive records of the teaching process. Regarding project outcome archives:

(1)Class A (individual project-based learning) collected 45 valid reports—three independently completed project reports per student.

(2)Class B (team project-based learning) gathered comprehensive project documentation from five groups and 15 peer contribution evaluation forms within each group.

(3) Class C (traditional teaching) did not involve project grading; chapter-based practical assignments were retained as

process records.

For competency assessment data, practical evaluations comprised timed skill tests administered uniformly to all three classes during Week 16. Theoretical assessments utilized the Academic Affairs Office's standardized final examination papers.

Regarding quality control measures: Project grading implemented double-blind, back-to-back evaluations, with program directors and instructors scoring independently. A three-party review was initiated if score discrepancies exceeded 5 points. Practical assessments featured proctored environments, with exam computer labs blocking external networks and recording screens throughout for evidence preservation.

3.2 Data Cleaning

To address common issues in the raw data, this study implemented a three-step cleaning process according to statistical protocols. Seven project reports were revised to resolve scoring discrepancies. The final valid sample characteristics are summarized as follows:

Table 3.1 Valid Sample Characteristics

Class	Project Score Sample	Practical Score Sample	Theory Score Sample
Class A	15students	15students	15students
Class B	15students	15students	15students
Class C	15students	15students	15students

3.3 Data Conversion: Standardized Evaluation Scale

Due to variations in the weighting of scores across different classes' practical projects, a standardized evaluation scale must be established prior to data analysis. This primarily involves converting individual contributions within Class B's team project scores. It was predetermined that team project scores comprise 70% group base points and 30% individual contribution coefficients. Thus, Class B's scoring formula is: Final Individual Score=(Group Score*0.7)+(Group Score*0.3)* Contribution Coefficient.

Following the data collection and organization phase, this study yielded three sets of analyzable data, which can be used to address the core question of how different practical teaching models impact student competencies.

4.Data Analysis

4.1 Descriptive Statistics

The study primarily employed a group comparison approach to examine whether students' performance across various metrics improved after adopting the project-based teaching model. To preliminarily assess the impact of different teaching models on student competencies, descriptive statistics were first applied to the three classes' performance across three dimensions: project implementation ability, core operational skills, and theoretical knowledge mastery. The analysis focused on examining the mean levels of each group's scores, providing an intuitive display and comparison of the differences in mean values among the three groups. Statistical indicators included the mean, standard deviation, and score range, with results presented in Table 4.1.

Table 4.1 Descriptive Statistics for Students' Three Performance Measures

Class	Measure	Mean	Standard Deviation	Range
Class A	Project Score	84.95	4.35	78.4-94
Class A	Practical Score	82.76	5.54	73.1-91.6
Class A	Theory Score	78.45	7.47	65.0-89.9
Class B	Project Score	90.01	4.17	82.9-96.7
Class B	Practical Score	80.54	6.35	68.7-90.9
Class B	Theory Score	77.09	6.92	65.9-88.7

Class	Measure	Mean	Standard Deviation	Range
Class C	Project Score	74.42	6.10	64.2-84.6
Class C	Practical Score	70.32	6.78	58.0-82.5
Class C	Theory Score	76.36	5.78	66.9-85.2

As shown in Table 4.1, in terms of project implementation skills, both Class A (individual projects) and Class B (team projects) achieved higher average scores than Class C (traditional teaching), with Class B recording the highest average score. Regarding core operational skills, Class A scored slightly higher than Class B, and both significantly outperformed Class C. However, in theoretical knowledge mastery, the average scores across the three classes showed minimal variation.

4.2 Prerequisite Tests

Descriptive statistics can only illustrate the magnitude relationships within a dataset and cannot conclusively demonstrate that differences in the means of different groups are statistically significant. To assess whether the differences in the means of the three groups are statistically significant, we will proceed to conduct a more detailed comparative analysis and investigation of the group means using the ANOVA method and Tukey HSD test. First, ANOVA will be employed to analyze mean differences. However, prior to analysis, we must verify whether the collected data satisfy the fundamental assumptions of normality and homogeneity of variance. After conducting Shapiro–Wilk tests on the residuals of each data group, the results show P-values greater than 0.05. This indicates that all three data groups substantially conform to the assumption of normal distribution, passing the normality test. Following Levene's test for homogeneity of variances, the P-values for both project scores and practical scores exceeded 0.05, confirming that variance homogeneity was satisfied. Theoretical scores also met the variance homogeneity requirement. Consequently, all three indicator datasets in this study are suitable for mean difference testing using one-way ANOVA.

4.3 One-Way Analysis of Variance

To determine whether statistically significant differences exist among the mean values of the three data sets, the study employed the commonly used statistical comparison method ANOVA to conduct a one-way analysis of variance. After performing the ANOVA analysis on the three data sets using the AOV function in R software, the results are presented in Table 4.2.

Table 4.2 ANOVA Analysis Results

Indicator	F-value	Degrees of Freedom	P-value	Conclusion
Project Score	67.74	(2,42)	<0.001	Significant differences exist among the three groups
Practical Score	8.84	(2,42)	<0.001	Significant differences exist among the three groups
Theoretical Score	0.42	(2,42)	0.75	No significant differences exist among the three groups

The analysis results from the ANOVA method indicate that in project practical ability (project score), the analysis shows F-value=67.74 and P-value<0.001, thus demonstrating extremely significant differences between teaching models. For core operational skills (practical skills score), the analysis yielded an F-value of 8.84 and a P-value<0.001, indicating significant differences. However, for theoretical knowledge mastery (theory score), the analysis showed an F-value of 0.42 and a P-value of 0.75, indicating no significant differences. Based on the comprehensive ANOVA analysis results, the project-based teaching model significantly impacts students' project practice abilities and core operational skills, but has no discernible effect on theoretical performance.

4.4 Post-hoc Comparisons

To further determine whether significant differences exist between the average scores of the experimental group classes using the project-based teaching model and those of the control group classes, pairwise comparisons among the three classes will be conducted. For this purpose, the Tukey HSD test from statistical methods was selected to perform pairwise comparisons between the experimental group data and the control group. This study employed the TukeyHSD function in R software to perform TukeyHSD tests on the three sets of data, enabling pairwise comparisons. The results are presented in Table 4.3.

Table 4.3 Tukey HSD Test Results

Indicator	Group Comparison	Mean Difference	95%CI	P-value	Conclusion
Project Score	A-B	-5.07	[-8.71,-1.43]	0.004	B is significantly higher than A
Project Score	A-C	11.91	[8.27,15.54]	<0.001	A is significantly higher than C
Project Score	B-C	16.97	[13.34,20.61]	<0.001	B is significantly higher than C
Practical Score	A-B	-0.42	[-6.16,5.32]	0.983	No significant difference
Practical Score	A-C	8.80	[3.06,14.54]	0.002	A is significantly higher than C
Practical Score	B-C	8.38	[2.65,14.12]	0.003	B is significantly higher than C
Theoretical Score	A-B	0.78	[-4.99,6.55]	0.94	No significant difference
Theoretical Score	A-C	-1.01	[-6.78,4.76]	0.91	No significant difference
Theoretical Score	B-C	-1.79	[-7.56,3.98]	0.73	No significant difference

By examining the results of the Tukey HSD test, it is evident that the confidence intervals for the differences in average scores across different teaching models do not include the value 0. Based on the p-values: - For the project component, Class B (team project) achieved the highest score and significantly outperformed Class A (individual project) and Class C (traditional teaching). Class A also significantly outperformed Class C. - For the practical skills component, both Class A and Class B significantly outperformed Class C, but the difference between Class A and Class B was not significant. - For the theoretical knowledge component, no significant differences were found among the three groups.

5.Analysis Results

5.1 Project Practical Ability

According to the results of single-factor analysis of variance, significant differences were found in project-based practical skills among the three student groups. Further Tukey HSD post-hoc comparisons revealed that Class B (team project-based) achieved the highest scores, significantly outperforming Class A (individual project-based) and Class C (traditional instruction). Class A also significantly outperformed Class C.

These findings indicate that the project-based teaching model significantly enhances students' project-based practical skills, with team projects demonstrating optimal performance in comprehensive and complex tasks.

5.2 Core Operational Skills

Regarding core operational skills, significant differences were also observed across the three groups. Tukey's HSD post-hoc test revealed that both Class A (individual project-based) and Class B (team project-based) achieved significantly higher scores than Class C (traditional teaching), while no significant difference existed between Class A and Class B.

This indicates that both individual and team project-based approaches significantly enhance students' practical skills, while traditional teaching demonstrates clear shortcomings in cultivating operational competencies.

5.3 Mastery of Theoretical Knowledge

Regarding theoretical performance, no significant differences were observed among the three groups of students. Post-hoc Tukey HSD tests also failed to reveal any significant differences between groups.

This result indicates that students' mastery of theoretical knowledge primarily relies on standardized classroom instruction and textbooks. Differences in teaching models do not significantly impact students' theoretical performance.

5.4 Summary of Findings

In summary, this study yielded the following key results:

1.project-based teaching significantly outperformed traditional teaching methods, effectively enhancing students' practical skills regardless of whether individual or team-based approaches were employed.

2.The team-based approach demonstrated clear advantages in comprehensive projects, with the team collaboration practice class achieving the highest practical scores. This indicates that teamwork is more conducive to solving complex problems and fostering the development of students' comprehensive abilities.

3.The individual model aids in foundational skill training, with independent operation classes achieving comparable practical scores to teamwork classes. This demonstrates that completing projects independently better hones students' mastery of basic skills.

4.Theoretical performance remains unaffected by teaching models, as no significant differences exist among the three groups' theoretical scores. This indicates that standardized theoretical courses are the primary determinant of theoretical knowledge acquisition.

6.Related Discussions

6.1 The Significant Enhancement of Practical Skills Through Project-based Instruction

The findings of this study indicate that project-based instruction significantly outperforms the traditional "chapter-by-chapter lecture + practice" model, regardless of whether implemented individually or in teams. This conclusion aligns with most existing research, which demonstrates that learning driven by authentic tasks can markedly improve students' professional skills and overall competence. In this study, project-based learning not only guided students through the complete data analysis process (problem definition-data cleaning and processing-data analysis-result interpretation) but also enabled them to continuously practice within contextualized tasks. This approach cultivated their problem-oriented thinking and enhanced their ability to logically structure and analyze issues.

6.2 Differentiated Advantages of Individual and Team Modes

The findings reveal that team project classes significantly outperformed individual project classes in project scores, indicating that collaborative practice exercises are more conducive to solving complex problems. This aligns with the "collaborative learning theory" in management and education studies. Collaborative learning theory posits that through division of labor and cooperation, students can share cognitive resources within groups, compensate for individual shortcomings, and thereby achieve better overall performance.

Additionally, individual project classes demonstrated comparable practical skills to team project classes, indicating that the individual model is more suitable for foundational skill training and fundamental competency reinforcement. These findings suggest that the individual model excels in skill development, while the team model excels in integrating capabilities. This complementary dual-model approach offers valuable insights for related course design.

6.3 Stability of Theoretical Performance

Regarding theoretical performance, no significant differences were observed among the three groups, indicating that mastery of theoretical knowledge primarily relies on standardized classroom instruction and textbook content. This finding aligns with conclusions from comparative studies, suggesting that teaching organization methods have limited impact on theoretical learning, while students' theoretical performance is more dependent on the overall curriculum framework and unified assessment standards. This conclusion also prompts us to maintain consistency in theoretical instruction during the current curriculum reform process, while pursuing differentiated innovation through practical components.

6.4 Teaching Implications

The findings of this study offer the following insights for curriculum reform and instructional design:

(1)Project-based course implementation should become the core model for higher vocational data analysis courses. It significantly enhances students' practical and applied skills, addressing the shortcomings of traditional teaching in skill development.

(2)The dual-mode complementary approach of individual and team projects warrants promotion. The individual mode suits the introductory stage, helping students master fundamental operational skills, while the team mode is appropriate for the advanced stage, training students in solving complex problems and enhancing team collaboration abilities.

(3)A tiered course design aligns with students' cognitive progression. This curriculum reform may adopt a blended tiered approach-such as “individual projects in the early phase, team projects in the later phase” or “foundational individual projects, advanced team projects”-to achieve a spiral advancement in students’ practical abilities.

(4)Theoretical instruction should maintain consistency. The current unified teaching approach-standardized textbooks, uniform lectures, and consistent assessments-should be sustained to ensure systematic mastery of theoretical knowledge. This should be complemented by innovations in practical components to foster students’ comprehensive skill development.

6.5 Comparison and Extension of Previous Research

Compared to the more frequently explored “multiple-teacher-per-course” model in recent years, this study, while focusing on a different teaching model, employs the same quantitative evaluation approach of “parallel-class comparison+ANOVA+Tukey HSD.” This demonstrates that both teacher-combination and project-based models can utilize identical statistical methods to assess teaching effectiveness and establish replicable research paradigms. The innovation of this study lies in its detailed comparison of individual versus team-based project-driven approaches, providing more granular empirical evidence for instructional design in such courses.

7.Conclusions and Recommendations

7.1 Research Findings

This study concludes that project-based teaching significantly outperforms traditional models in enhancing students’ practical skills. Both individual and team-based project approaches markedly improve students’ hands-on capabilities. Additionally, each mode exhibits distinct advantages: team-based learning excels in developing comprehensive competencies, while individual projects prove superior for mastering foundational skills. Furthermore, theoretical performance remains unaffected by teaching mode, as differences in theoretical scores are insignificant. This indicates that theoretical learning primarily relies on standardized instructional components.

7.2 Teaching Recommendations

Project-based teaching can be promoted as the core model for higher vocational data analysis courses. When implementing curriculum reform using this model, instructors may flexibly adopt either the individual project mode or team project mode based on corresponding talent development objectives, or employ a tiered combination approach. Additionally, consistency in theoretical instruction must be maintained to ensure the stability of students’ knowledge frameworks. A multidimensional evaluation system integrating theoretical performance, practical skills, and project outcomes should be established to comprehensively assess student learning.

7.3 Research Limitations and Future Directions

While this study demonstrated that project-based teaching significantly enhances students’ practical skills, certain limitations remain. These primarily include a restricted sample size and the need to broaden evaluation dimensions. Future research could expand the sample and incorporate psychological dimensions such as learning motivation and self-efficacy to conduct interdisciplinary and cross-major studies. Additionally, the long-term effectiveness of this model should be examined by integrating data from students’ graduation internships and workplace performance.

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Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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