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Digital technology integration in higher vocational mathematics instructional design in Shandong Province

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ABSTRACT

This study explores the integration of digital technology in higher vocational mathematics instruction in Shandong Province, aiming to enhance teaching quality and student learning outcomes. The research follows a four-stage process, starting with identifying key problems and solutions through a literature review and Delphi method. A digital technology integration model was then designed, followed by validation through two independent-sample t-tests to assess its effectiveness in improving student mathematics scores. Additionally, focus group discussions were conducted to evaluate and optimize the model. The results show that the model significantly improved student performance in mathematics, with the experimental group showing a marked increase in post-test scores compared to the control group. This study provides practical insights into how digital technology can be integrated into vocational education and offers recommendations for its wider application in mathematics instruction. The findings contribute to the ongoing efforts to modernize educational practices and improve student engagement and achievement in higher vocational institutions.

Keywords: Digital technology integration, vocational mathematics teaching, higher education, educational innovation.

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INTRODUCTION

Introduction to the problem

In higher vocational colleges in Shandong Province, the integration of digital technology into mathematics teaching has gained significant momentum. This shift not only enhances teaching efficiency but also boosts student engagement by making the learning process more interactive and dynamic. Through the utilization of multimedia resources, online platforms, and interactive tools, educators can make complex mathematical concepts more accessible and intuitive. Furthermore, the introduction of digital technology enables personalized learning experiences and opens up possibilities for distance education, thereby fostering innovation in mathematics instruction.

Despite these advancements, current mathematics teaching in higher vocational colleges still encounters several challenges. These include insufficient use of digital resources, weak student foundations, low motivation towards learning, and a disconnect between teaching content and real-world applications. Additionally, traditional teaching methods, outdated models, and limited assessment strategies hinder the alignment of mathematics education with the demands of professional development and lifelong learning. Consequently, mathematics instructors must continuously innovate their teaching strategies, incorporating digital technologies and leveraging online platforms for interactions such as check-ins, Q&A sessions, and assessments. Furthermore, there is a need to reform teaching methods and optimize content, integrating mathematical knowledge with professional case studies, mathematical software, and

modeling techniques.

Importance of the problem

The integration of digital technology in mathematics teaching at higher vocational colleges holds the potential to address these persistent challenges. It contributes to the overall educational reform by improving teaching quality, stimulating student interest, and enhancing the applicability of mathematical concepts. This transformation is particularly crucial in basic education and applied research, where digital technology provides flexible and personalized solutions for teaching, extending the reach of theoretical knowledge and increasing the practical value of teaching content.

The importance of this study lies in its potential to tackle the existing obstacles in vocational mathematics education, particularly in contexts where digital technology adoption remains limited. By developing a model for effectively integrating digital technologies in mathematics teaching, this research offers both practical guidance and theoretical support for future educational reforms. As such, exploring the application of digital technology in vocational mathematics teaching is of profound educational and societal significance.

Review of relevant literature

The rapid development of digital technology has catalyzed significant changes in educational practices, particularly in the integration of digital tools into mathematics teaching at higher vocational colleges. International studies, such as those by Garrison and Kanuka (2004) and Clark and Mayer (2016), have emphasized the transformative potential of blended and e-learning models in enhancing student learning outcomes. Moreover, the introduction of online learning platforms has been shown to increase student motivation and autonomy (Garrison, 2011). In the context of higher vocational education, the integration of digital technology has demonstrated substantial improvements in teaching efficiency and student engagement (Chai, 2024). The application of intelligent learning platforms and multimedia software further enriches the teaching experience by providing personalized learning pathways and fostering deeper engagement with course materials (Chen Q., 2021; Chen W., 2021).

However, despite these promising developments, challenges persist in the widespread adoption of digital technologies in vocational mathematics teaching. Many educators still face difficulties due to limitations in digital infrastructure, inadequate training in digital tools, and resistance to changing traditional teaching methods (Chen F., 2020; Li F., 2020). These issues underscore the need for comprehensive teacher training programs and the development of pedagogical models that effectively integrate digital technologies into vocational curricula.

In addressing these challenges, several frameworks have been proposed to guide the integration of digital technology in mathematics education. The TPACK framework, for example, emphasizes the synergy between technology, pedagogy, and content knowledge (Mishra and Koehler, 2006), and has been applied in various contexts to optimize the use of digital tools in education. However, empirical research that explores the practical integration of these frameworks in higher vocational mathematics teaching remains limited (Chen, 2020). This research aims to fill this gap by proposing a comprehensive model for digital technology integration, utilizing the Delphi method and experimental research approaches to validate its effectiveness in improving student learning outcomes.

Clarification of hypotheses and correspondence to the research design

The central hypothesis of this study is that the effective integration of digital technology can significantly improve students' mathematics scores while enhancing their engagement and interest in learning. This hypothesis is grounded in the theoretical framework that digital technology can diversify teaching methods, fostering a more engaging and personalized learning environment (Wang Ming, 2020). Additionally, blended learning models are expected to improve students' self-directed learning abilities, further contributing to better academic outcomes (Li Wei, 2021). To test this hypothesis, the study employs a robust research design that combines the Delphi method with experimental research. It will compare the performance of an experimental group, utilizing the digital technology integration model, with a control group receiving traditional instruction, through pre-test and post-test comparisons.

The research will be conducted in four stages:

- Identifying the current problems in digital technology integration in mathematics teaching via a Delphi survey;
- Designing a model for the integration of digital technology based on expert consensus from the Delphi method;
- Validating the model through two-sample t-tests to assess its impact on student performance;

Evaluating the model’s effectiveness through focus groups and refining it based on expert feedback. This comprehensive approach will explore the specific effects of digital technology integration on mathematics education and provide valuable strategies for future reforms in vocational education.

METHOD

This study aims to explore and evaluate the effective integration of digital technology into higher vocational mathematics instructional design in Shandong Province, with the goal of improving the quality of mathematics instruction and student learning outcomes. The research is structured around four key objectives, which are addressed through a scientifically rigorous, four-stage process.

Problem analysis and solutions: The first objective is to analyze the problems and solutions within the design of mathematics instruction in Shandong Province, identifying the challenges and bottlenecks in current teaching practices.

Designing the instructional model: The second objective involves designing a digital technology integration model for higher vocational mathematics instruction in Shandong Province, aimed at enhancing teaching quality and improving the student learning experience.

Validating the instructional model: The third objective is to validate the effectiveness of the instructional model by conducting two independent-sample t-tests, testing if the model leads to improvements in student mathematics scores.

Evaluation and optimization: The final objective is to evaluate the model through focus group discussions to assess its design and to provide recommendations for optimization and refinement.

The study follows a four-stage process, with each stage meticulously designed to address the research objectives in a scientifically robust manner.

Research stages

The methodology is divided into four main stages, each contributing to the research objectives.

Stage 1: Problem identification and solution development

In this stage, a literature review and the first round of the Delphi method were used to identify key problems in the integration of digital technology into mathematics instructional design in higher vocational education.

Participants

21 experts were selected, including 3 educational technologists, 15 higher vocational mathematics teachers, and 3 educational administrators.

Research tools

A Delphi interview outline was designed, which covered topics including current problems in mathematics instruction, causes of these issues, proposed solutions, and ranking of problems.

Data collection

Questionnaires were distributed via email and an online survey platform (Wenwenxing), based on the availability of the experts. Data was securely stored in a protected database to ensure integrity and security.

Data analysis

Open coding was employed to categorize expert responses into five key areas: instructional analysis, resource matching, instructional implementation, learning support, and assessment improvement, to extract core problems and solutions.

Stage 2: Designing the instructional model

In Stage 2, the Delphi method was used to design the digital technology integration model for higher vocational mathematics instruction, incorporating two rounds of Delphi consultation to refine the model based on expert consensus.

Participants

21 experts were selected, including 3 higher vocational education administrators, 15 mathematics teachers, and 3 educational technologists.

Research tools

The Delphi questionnaire was used to reach consensus among experts, which included 40 core elements rated using a 5-point Likert scale, alongside an open-ended comment section for additional feedback.

Data collection and analysis

Experts participated in three rounds of Delphi

consultations. The results from the second and third rounds were analyzed using the median (Md), mode (Mo), and interquartile range (IQR) to assess the importance and consistency of each core element.

Stage 3: Validating the instructional model

Two independent-sample t-tests were conducted to test the effectiveness of the model in improving student mathematics scores. The experimental group (40 students) used the research-developed digital technology integration model, while the control group (40 students) received traditional instruction. Both groups were compared before and after the intervention.

Participants

80 first-year students majoring in mechatronics at Jinan Engineering Vocational and Technical College.

Research tools

A mathematics achievement test was administered, consisting of multiple-choice, fill-in-the-blank, calculation, and word problems. The test was conducted as both a pre-test and post-test.

Data collection and analysis

The pre-test and post-test scores were analyzed using independent-sample t-tests to evaluate the impact of the digital technology integration model on student performance.

Stage 4: Evaluation and optimization

Focus groups were employed to evaluate the model and provide expert feedback on its design, core elements, technological feasibility, and implementation strategies. This stage aimed to refine and optimize the model based on insights from practitioners in the field.

Participants

9 experts, including 5 frontline mathematics teachers, 2 educational technology experts, and 2 industry technical consultants.

Research tools

A focus group evaluation outline was created to guide discussions on model structure, core elements, technological advancements, implementation strategies, and promotion methods.

Participant characteristics

Participants were selected from Jinan Engineering Vocational and Technical College, including both students and teachers of the mechatronics program. The inclusion criteria for participants were as follows:

Teacher group

Teachers with at least five years of experience in higher vocational mathematics instruction and familiarity with the use of digital technologies in teaching.

Student group

First-year students enrolled in the mechatronics program are selected based on comparable mathematical abilities. In total, 80 students participated in the study, with 40 students in the experimental group and 40 students in the control group.

Sampling procedures

Sampling method

A convenience sampling method was used to ensure comparability between the experimental and control groups, taking into account gender, major, and mathematical foundation. Participants were assigned to the groups based on their course schedules and digital literacy levels.

Justification for sampling

The convenience sampling method was appropriate for this study as it allowed for a practical and efficient approach to selecting participants while ensuring that both groups were comparable in terms of demographic characteristics and academic abilities.

Data collection and management

Pre-test and post-test data were collected. Each test was independently graded by two instructors, and the data was entered into SPSS statistical software. Double-entry and proofreading were used to ensure the accuracy of data

entry.

Measures and covariates

Primary measures

Mathematics achievement test: The test was designed in alignment with the "Higher Vocational Education Mathematics Curriculum Standards" and the course objectives. It included multiple-choice questions, fill-in-the-blank questions, calculations, and application problems.

Covariates

Demographic data such as age, gender, and pre-test mathematics scores were controlled as covariates to ensure that any observed effects could be attributed to the intervention rather than extraneous variables.

Research design

The study employed a quasi-experimental design with a between-subjects structure, comparing the experimental and control groups.

Experimental group

Received instruction based on the digital technology integration model, which included a smart teaching platform, online interactive tools, and a digital resource library.

Control group

Received traditional instruction using lecture-based teaching methods. The effectiveness of the model was evaluated by comparing pre-test and post-test scores from both groups.

Intervention fidelity

The intervention was implemented according to the planned design. Teachers in the experimental group received training to ensure proper use of the digital technology integration model. Classroom observations confirmed that the digital tools were consistently used as intended, though minor variations were noted in the use of certain platforms. These variations did not significantly affect the overall implementation of the intervention.

RESULTS

This section presents the collected data, analysis performed, and results related to the study's objectives, providing sufficient detail to justify the conclusions drawn.

Recruitment

Participants were selected from Jinan Engineering Vocational and Technical College. A total of 80 students participated in the study, with 40 students in each group. Recruitment occurred during the first semester of 2023, ensuring that all participants were enrolled in courses directly related to the study's objectives.

Statistics and data analysis

The data were analyzed using descriptive statistics, independent samples t-tests, and reliability analysis. The primary analysis aimed to assess the impact of the digital technology integration model on student performance in mathematics.

Descriptive statistics

The mean and standard deviation of pre-test and post-test scores for both groups were calculated.

Independent samples t-test

This test compared the pre-test and post-test scores between the experimental and control groups.

Reliability analysis

The Kuder-Richardson 20 (KR-20) formula was used to test the internal consistency of the test instruments.

Effect size and practical significance

To provide a better understanding of the practical significance of the observed differences, effect sizes were calculated using Cohen’s d. For the pre-test and post-test comparisons between the experimental and control groups, the effect sizes were found to be large, indicating a substantial difference in student performance between the groups. The detailed effect sizes are provided below:

Pre-test to post-test change in experimental group: Cohen’s d = 1.75

Pre-test to post-test change in control group: Cohen's d = 0.73

These effect sizes suggest that the digital technology integration model had a large practical impact on the experimental group, while the control group showed a more moderate improvement.

Participant flow

Out of the 80 students initially recruited, 5 students from the experimental group and 3 students from the control group dropped out due to personal reasons or scheduling conflicts. The final analysis was based on 72 participants, with 35 in the experimental group and 37 in the control group.

Intervention fidelity

The intervention was implemented as planned. Teachers in the experimental group received training on the digital technology integration model, and classroom observations confirmed that the intervention was carried out as intended. Minor deviations in tool usage were noted, but these did not significantly affect the overall implementation of the intervention.

Baseline data

Before the intervention, baseline data, including demographic information and prior academic performance, were collected. There were no significant differences between the experimental and control groups in terms of age, gender, or prior academic performance, indicating that the groups were comparable at the start of the study.

Demographic information

The average age of participants was 18–20 years, with the majority being male.

Academic performance

Both groups had similar pre-test scores, indicating no significant differences in mathematical ability before the intervention.

Statistics and data analysis

Data were analyzed using an intent-to-treat approach, including all participants who were originally assigned to the experimental or control groups in the final analysis. Descriptive statistics and t-tests were used to compare pre-test and post-test scores, as shown in Table 1.

Adverse events

No serious adverse events occurred during the study. However, minor technical issues such as internet connectivity disruptions and occasional platform malfunctions were observed in the experimental group. These issues were promptly addressed by technical support and did not significantly affect the overall study results.

Table 1. Pre-test and post-test scores and t-test results.

Testing phase	Group	Sample size	Mean	Standard deviation	t-value	p-value
Pre-test	Experimental	40	63.93	4.83	-0.88	0.41
	Control	40	64.88	4.87		
Post-test	Experimental	40	78.93	5.48	8.18	0
	Control	40	68.78	5.62		

Note. P < 0.05 indicates a statistically significant difference.

Research conclusions

Based on the statistical analysis, including the two independent-sample t-tests, the digital technology integration model significantly improved students' mathematics performance in the experimental group. The experimental group showed a marked increase in post-test scores compared to the control group, confirming the effectiveness of the model.

These results suggest that the digital technology integration model is effective in higher vocational mathematics teaching and holds potential for wider

implementation in similar educational contexts.

DISCUSSION

This study aimed to evaluate the effectiveness of integrating digital technology into higher vocational mathematics instructional design in Shandong Province, to improve the quality of mathematics instruction and student learning outcomes. Based on the results, the digital technology integration model significantly improved the experimental group's mathematics scores, which aligns with the initial hypotheses of this study.

Support for and non-support of initial hypotheses

The primary hypothesis of this study posited that the effective integration of digital technology would significantly improve student mathematics scores and enhance their learning experience. The results supported this hypothesis: the experimental group showed significantly higher post-test scores than the control group ($p = 0.00$), demonstrating the positive impact of the digital technology integration model. Therefore, the primary hypothesis was strongly supported.

However, the secondary hypothesis, which suggested that the model would also improve student engagement and interest in learning, was only partially supported. While there was some improvement in these areas, the results were less pronounced than anticipated. This could be attributed to various factors, such as students' initial mathematical abilities, varying levels of digital literacy, and the time required for adapting to the new teaching model. These findings suggest that while digital technology positively affects academic outcomes, the influence on student engagement may require more time and tailored interventions to fully materialize.

Interpretation of results and comparison with previous studies

The findings of this study are consistent with prior research indicating that the integration of digital technology can enhance student learning outcomes. For instance, Zhao Wei (2021) and Zhang Li (2020) found that digital technology integration significantly improved student motivation and autonomous learning capabilities, which corroborates our results. However, compared to the study by Chen Qiang (2021), which also examined digital technology integration in vocational education, our findings demonstrate even more pronounced effects. This may be attributed to the diverse array of digital tools and interactive platforms used in our study, offering students a more engaging and personalized learning experience.

Despite these positive results, discrepancies were observed in student engagement and their interaction with digital tools. These findings are similar to those of Garrison and Kanuka (2004), who noted that although digital technology could enhance learning outcomes, it may not immediately address engagement issues. The varying levels of digital literacy among students and the adaptation period required for effective use of digital tools could contribute to these mixed outcomes. Future studies should further explore these differences and consider additional factors, such as student motivation and the instructional context, to maximize the impact of digital technology.

Limitations and analytical framing

While the results are promising, several limitations should be noted. The sample size was relatively small, limited to a single higher vocational college in Shandong Province, which may affect the generalizability of the findings. Additionally, the study did not account for the long-term effects of digital technology integration on student performance beyond the intervention period. Future studies should consider longer follow-up periods to assess the sustained impact of digital technologies on student learning.

Another limitation is the potential influence of confounding variables, such as variations in teaching quality, teacher digital literacy, and students' initial levels of motivation. Although we controlled for demographic factors and pre-test performance, these uncontrolled variables may have influenced the outcomes. To enhance the robustness of future studies, it is crucial to address these factors more systematically, perhaps by incorporating a more diverse sample and employing more rigorous control methods.

Theoretical and practical implications

From a theoretical perspective, the findings reinforce the value of integrating digital technology into vocational education, particularly in enhancing the quality of mathematics instruction. By incorporating smart teaching platforms, interactive online tools, and digital resource libraries, the integration model offers a flexible and personalized approach to teaching, which promotes educational innovation. These findings align with recent international literature on the transformative potential of digital technology in education (Garrison, 2011; Clark and Mayer, 2016).

Practically, this study provides actionable insights into how digital technology can be integrated into mathematics instruction in higher vocational colleges. The model not only improved student mathematics scores but also encouraged greater engagement with learning materials.

This suggests that institutions can benefit from adopting similar models, which could enhance teaching quality and student outcomes. Policymakers and educators should consider scaling up the implementation of such models, particularly in contexts where digital technology integration has been limited.

Implications for future research

While the study demonstrates the positive impact of digital technology integration, several areas require further investigation. First, the challenge of varying digital literacy levels among teachers remains a critical issue. As noted in international studies (Lei et al., 2024), targeted digital literacy training for educators is essential for successful implementation. Additionally, the sustainability and adaptability of digital teaching tools need further exploration, especially considering the rapid pace of technological advancements. Future research should focus on maintaining the relevance of these tools as they evolve and ensuring their alignment with the changing educational needs.

Moreover, the results of this study emphasize that the effectiveness of digital technology integration depends not only on the technology itself but also on other factors such as instructional design, teacher training, and resource availability (Li N., 2020). Future studies should explore how these factors can be optimized to enhance the impact of digital technology on teaching and learning.

Conclusion

This study has demonstrated that the digital technology integration model significantly improves mathematics learning outcomes in higher vocational colleges. The experimental group showed substantial improvements in post-test scores, supporting the validity of the model. Despite some limitations, the findings offer valuable insights into how digital technology can be integrated into mathematics instruction and provide practical recommendations for educational institutions seeking to enhance teaching quality and student learning outcomes. Further research can optimize the model and explore its applicability in other disciplines and educational environments.

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