Volume 3, Issue 6, 2025

Print ISSN:2959-9989

Online ISSN:2959-9997

WORLD JOURNAL OF EDUCATIONAL STUDIES

World Journal of Educational Studies

Volume 3, Issue 6, 2025

Published by Upubscience Publisher

World Journal of Educational Studies
Print ISSN: 2959-9989 Online ISSN: 2959-9997
Email: info@upubscience.com
Website: http://www.upubscience.com/

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World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3081

DEVELOPMENT AND VALIDATION OF THE COLLEGE STUDENTS' PURPOSE IN LIFE SCALE

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Abstract: With the advancement of the localization of research on the meaning of life, the precise measurement of college students' purpose in life has become a crucial entry point for analyzing the formation of youth value systems. Existing Western scales fail to accurately capture the integrated value characteristics of collective responsibility, social commitment, and individual development within the Chinese cultural context. In response, this study developed the College Students' Purpose in Life Scale based on a sample of 286 college students from a university in Guangzhou. Drawing on classical Western frameworks and integrating indigenous cultural features, items were generated through literature review, expert evaluation, and pilot testing. The final scale comprises four dimensions: collectivism, individualism, materialism, and hedonism. Exploratory factor analysis extracted four common factors, with a cumulative variance explanation of 61.8% and factor loadings ranging from 0.62 to 0.84. Confirmatory factor analysis indicated good model fit ($\chi^2/df = 2.31$, RMSEA = 0.057, CFI = 0.892, TLI = 0.871). Cronbach's α coefficients for the four dimensions ranged from 0.788 to 0.835, and all composite reliability values exceeded 0.82, meeting psychometric standards. The empirical results revealed that college students' purpose in life was predominantly "collectivism-oriented." The collectivism dimension had the highest mean score of 4.01 (3.60–4.21), while individualism 2.14 (1.87–2.39), materialism 2.01 (1.91–2.12), and hedonism 2.38 (2.05–2.64) all showed relatively low mean values. This scale enriches the repertoire of indigenous instruments for measuring college students' purpose in life and provides a standardized tool for research on youth value orientation and educational intervention.
Keywords: College students; Purpose in life; Scale development; Reliability and validity testing

1 INTRODUCTION

The As a central topic in psychology and education, purpose in life is regarded as a vital psychological resource that enables individuals to establish life meaning, form value orientations, and develop behavioral goals [1]. Empirical studies have shown that a well-defined life purpose not only enhances positive emotions and psychological well-being but also mitigates negative psychological states such as depression and anxiety among young people, while strengthening learning motivation and academic engagement [2,3]. However, most existing instruments measuring life meaning and life purpose were developed within Western cultural contexts, such as the Purpose in Life Test [4] and the Meaning in Life Questionnaire [5]. These instruments may encounter limitations in cross-cultural applicability. Among Chinese college students, the concept of life purpose is often interwoven with multiple value orientations, including collectivism, individualism, materialism, and hedonism [6,7]. Nevertheless, the development and systematic validation of scales that reflect these specific cultural and psychological characteristics remain insufficient.

In this context, the present study aims to develop a Purpose in Life Scale for Chinese College Students, examine its structural validity through exploratory factor analysis, and assess its reliability and validity. The ultimate goal is to provide a scientifically sound measurement tool that contributes to both empirical research on college students' life purpose and educational practices concerning value orientation and moral development.

2 LITERATURE REVIEW

Purpose in life is regarded as a core psychological resource through which individuals establish life meaning, achieve value goals, and attain self-integration [1]. A substantial body of empirical research has demonstrated that a clear sense of purpose can significantly enhance happiness, subjective well-being, and psychological health, while reducing negative emotions such as depression and anxiety [2]. During adolescence and early adulthood—particularly in the college stage—a sense of purpose is closely associated with academic motivation and social responsibility, and serves as a form of "identity capital" that enables individuals to respond positively to developmental challenges and social transformation [3,8]. However, studies conducted within Western cultural contexts tend to emphasize individual self-actualization and subjective happiness, whereas in Eastern collectivist cultures, life purpose is more often understood as a moral responsibility and value commitment that integrates the self and society [9].

At the measurement level, two representative instruments are the Purpose in Life Test (PIL) developed by Crumbaugh and Maholick and the Meaning in Life Questionnaire (MLQ) developed by Steger et al. [4,5]. The former, grounded in existential psychology, assesses individuals' overall perception of life meaning and goals, while the latter distinguishes between two dimensions—"presence of meaning" and "search for meaning"—and demonstrates strong cross-cultural reliability and validity. In recent years, researchers have revised and longitudinally validated these scales in local contexts. For instance, Luo et al. confirmed the temporal stability and longitudinal measurement invariance of the MLQ among Chinese college students, providing methodological support for the present study [7]. Moreover, the works of Podsakoff and Hu & Bentler established internationally recognized standards for controlling common method bias and evaluating model fit in scale development [10,11], forming the methodological foundation for the subsequent statistical analyses and validity testing in this research.

Meanwhile, studies situated in the cultural context of China have revealed that college students' sense of purpose embodies a complex value tension: it encompasses collectivist responsibility and social contribution while also reflecting personal achievement, material pursuit, and hedonic orientation [12]. Drawing on Schwartz's value theory and the cross-cultural validation of the PVQ-RR [13], scholars have identified a four-dimensional structure—collectivist, individualist, materialist, and hedonist orientations—that characterizes the interplay between social responsibility and self-realization among Chinese college students [14,15]. These findings suggest that the cultural construction of life purpose in contemporary youth has evolved from a singular spiritual pursuit toward a multidimensional integration of social and personal values.

Therefore, it is necessary to develop a measurement instrument that combines international comparability with cultural adaptability, in order to capture the structural characteristics and psychological mechanisms of life purpose among Chinese college students. Against this background, the present study integrates the theoretical foundations of the PIL and MLQ, incorporates the cultural features and value orientations of Chinese college students, and develops and validates the College Students' Purpose in Life Scale.

3 RESEARCH METHOD

3.1 Participants

A convenience sampling method was adopted to distribute an online questionnaire at a university in Beijing. A total of 286 valid responses were collected, including 198 male participants (69.2%) and 88 female participants (30.8%). All respondents were full-time college students, among whom 211 were undergraduates (73.8%) and 75 were postgraduates (26.2%).

3.2 Scale Development

Based on a systematic review of relevant literature, the present study drew upon the Purpose in Life Test developed by Crumbaugh and Maholick and the Meaning in Life Questionnaire developed by Steger et al. [4,5]. It also referred to studies conducted by Chinese scholars such as Zhang and Wang on the applicability of meaning-in-life scales among Chinese college students [16,17]. Considering the value orientations characteristic of Chinese college students, life purpose was conceptualized as encompassing four dimensions: collectivism, individualism, materialism, and hedonism. Initial items were generated according to these four dimensions and were semantically refined to align with the everyday linguistic context of college students. Three experts in psychology and five graduate students were subsequently invited to evaluate and revise the wording and dimensional allocation of the items. After expert review and pilot testing, the final version of the College Students' Purpose in Life Scale consisted of 17 items—six measuring collectivism, four measuring individualism, three measuring materialism, and four measuring hedonism. The scale employed a five-point Likert scoring format (1 = strongly disagree, 5 = strongly agree), with higher scores indicating a stronger orientation toward the corresponding dimension. Following pilot revisions, the finalized questionnaire was confirmed for formal administration.

3.3 Data Processing

Data analysis was conducted using SPSS 27.0 for descriptive statistics, item analysis, and exploratory factor analysis (EFA). The critical ratio (CR) method and the corrected item–total correlation (CITC) were employed to evaluate item discrimination and internal consistency [18]. Before conducting the EFA, the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of sphericity were performed to assess the suitability of the data for factor analysis. Subsequently, principal component analysis with varimax orthogonal rotation was used to extract factors with eigenvalues greater than 1, and items with factor loadings below 0.50 or substantial cross-loadings were removed to determine the final factor structure [19,20].

On this basis, confirmatory factor analysis (CFA) was carried out using AMOS 27.0, and composite reliability (CR) and average variance extracted (AVE) were calculated to evaluate the convergent and discriminant validity of the scale [12]. Model fit was assessed in accordance with the standards proposed by Kline and the latest structural equation modeling (SEM) reporting guidelines [21,22], with the following cutoff criteria: $\chi^2/df < 3$, RMSEA < 0.08, CFI > 0.90, and TLI > 0.90.Reliability was examined through Cronbach's α coefficient, split-half reliability, and test–retest reliability, where α values greater than 0.70 were considered indicative of satisfactory internal consistency [23,24].

4 RESULTS

4.1 Descriptive Analysis

Descriptive statistics were conducted for each dimension of the College Students' Purpose in Life Scale. As shown in Table 1, within the collectivism dimension, mean scores for all items ranged from 3.60 to 4.21, with standard deviations between 0.881 and 1.141, indicating a high level of endorsement of collectivist values among college students and a relatively concentrated score distribution. In contrast, within the individualism dimension, mean scores ranged from 1.87 to 2.39, with standard deviations between 1.026 and 1.271, suggesting relatively low identification with individualistic value orientations. For the materialism dimension, mean scores ranged from 1.91 to 2.12, with standard deviations between 1.077 and 1.125, showing that most college students exhibit a low tendency toward the pursuit of money and material benefits. In the hedonism dimension, mean scores ranged from 2.05 to 2.64, with standard deviations between 1.090 and 1.278, indicating that students also demonstrate a relatively low level of pursuit of pleasure and immediate gratification. Overall, college students scored the highest in the collectivism dimension, while their scores in individualism, materialism, and hedonism were comparatively lower, reflecting a predominantly collectivism-oriented value pattern.

Table 1 Means and Standard Deviations of the purpose of life scale

Dimension	Item	Minimum	Maximum	Mean	SD
Collectivism	CO_1	1	5	3.6	1.141
	CO_2	2	5	4.21	1.003
	CO_3	2	5	4.21	0.941
	CO_4	2	5	4.06	0.881
	CO_5	2	5	4.05	0.984
	CO_6	1	5	3.93	1.003
Individualism	IN_1	1	5	2.16	1.271
	IN_2	1	5	2.13	1.055
	IN_3	1	5	1.87	1.026
	IN_4	1	5	2.39	1.077
Materialism	MA_1	1	5	2.12	1.125
	MA_2	1	5	2	1.077
	MA_3	1	5	1.91	1.123
Hedonism	HE_1	1	5	2.64	1.092
	HE_2	1	5	2.49	1.278
	HE_3	1	5	2.32	1.131

4.2 Item Analysis

To examine the discrimination and internal consistency of the scale items, the present study conducted item analysis using both the critical ratio (CR) method and the item–total correlation (CITC) approach. Specifically, participants were divided into a high-score group (top 27%) and a low-score group (bottom 27%) based on their total scores, and independent-samples t-tests were performed for each item. The results showed that all items had CR values greater than 3.00, with significant differences between the two groups ($p < 0.001$), indicating that the items effectively distinguished between high and low scorers. Additionally, Pearson product–moment correlations were calculated between each item and the total scale score. All correlation coefficients exceeded 0.40 and were statistically significant ($p < 0.001$), suggesting good consistency between individual items and the overall measurement. Moreover, the difficulty coefficients of the items ranged from 0.461 to 0.898, falling within an acceptable range. Taken together, these results demonstrate that all items meet psychometric quality standards and were therefore retained for subsequent analyses.

4.3 Exploratory Factor Analysis

Exploratory factor analysis (EFA) was conducted on the data using SPSS 27.0 software. The KMO value was 0.810, and the Bartlett's chi-square value was 927.951 ($p < 0.001$). These results indicated that the data were suitable for further EFA. Principal component analysis (PCA) was then used to extract factors, followed by orthogonal rotation using the Kaiser normalization method. Factors with eigenvalues greater than 1 were selected for analysis. Items with factor loadings below 0.5 or cross-dimensional loadings were removed, resulting in the deletion of one item (HE_4), leaving 16 items. Factor 1 encompasses collectivism, Factor 2 encompasses individualism, Factor 3 encompasses materialism, and Factor 4 encompasses hedonism. The cumulative variance explained by the four factors was 66.887%, with individual factors explaining 22.433%, 18.563%, 16.516%, and 9.376%, respectively. The scale structure and loadings are shown in Table 2.

Table 2 Exploratory Factor Analysis of the Purpose of Life Scale

Item	Factor 1	Factor 2	Factor 3	Factor 4
CO_1	0.657			
CO_2	0.638			
CO_3	0.771			
CO_4	0.748			
CO_5	0.835			
CO_6	0.791			
IN_1		0.82		
IN_2		0.739		
IN_3		0.653		
IN_4		0.621		
MA_1			0.663	
MA_2			0.57	
MA_3			0.776	
HE_1				0.843
HE_2				0.837
HE_3				0.739
Eigenvalue	3.814	3.156	2.808	1.594
Variance Explained (%)	22.433	18.563	16.516	9.376

4.4 Reliability Analysis

The reliability of the Purpose in Life Scale for College Students was examined through internal consistency coefficients, split-half reliability, and test–retest reliability, to comprehensively assess its measurement stability. For the collectivism dimension, Cronbach's α was 0.790, with a split-half reliability of 0.761; for individualism, Cronbach's α was 0.788, with a split-half reliability of 0.762; for materialism, Cronbach's α was 0.835, with a split-half reliability of 0.796; and for hedonism, Cronbach's α was 0.814, with a split-half reliability of 0.745. These results indicate that all four dimensions—collectivism, individualism, materialism, and hedonism—demonstrate high internal consistency. The total test–retest reliability of the scale was 0.789, suggesting stable and consistent measurement across items over time. Overall, the findings confirm that the Purpose in Life Scale for College Students exhibits strong reliability in assessing different value orientations among college students, with particularly high reliability observed in the materialism and collectivism dimensions as shown in Table 3.

Table 3 Reliability Analysis of the Purpose in Life Scale

Dimension	Cronbach's α	Split-Half Reliability	Test–Retest Reliability
Collectivism	0.790	0.761	0.789
Individualism	0.788	0.762	
Materialism	0.835	0.796	
Hedonism	0.814	0.745	

4.5 Validity Analysis

First, confirmatory factor analysis (CFA) was conducted to examine the model fit of the Purpose in Life Scale for College Students. Model fit indices were used to assess the degree of congruence between the hypothesized model and the observed data. Using AMOS 27.0, the following results were obtained: RMSEA = 0.057, RMR = 0.069, GFI =

0.869, NFI = 0.855, IFI = 0.898, TLI = 0.871, and CFI = 0.892. All indices reached acceptable or good levels, indicating that the measurement model demonstrated satisfactory fit and met statistical criteria.

Second, correlations were calculated among the four dimensions as well as between each dimension and the total scale to further assess construct validity. The results showed that all inter-factor correlations were significant, ranging from 0.146 to 0.674, indicating low-to-moderate correlations. This suggests that the factors were directionally consistent but distinct, thus not interchangeable. The correlations between each factor and the total score ranged from 0.234 to 0.767, representing low-to-moderate positive relationships. These findings indicate that the dimensions were relatively independent while conceptually aligned with the overall construct measured by the scale.

Third, average variance extracted (AVE) and composite reliability (CR) were calculated for each factor to evaluate convergent validity (see Table 4). The AVE values for collectivism, individualism, materialism, and hedonism were all above 0.50, while the corresponding CR values were 0.899, 0.831, 0.869, and 0.810, all exceeding the recommended threshold of 0.70. These results demonstrate that the self-developed scale exhibits strong convergent validity.

Table 4 Means and Standard Deviations of the purpose of life scale

Dimension	Item	Std.	SMC	CA	CR	AVE
Collectivism	CO_1	0.726	0.527	0.79	0.899	0.6
	CO_2	0.799	0.638			
	CO_3	0.887	0.787			
	CO_4	0.745	0.555			
	CO_5	0.761	0.579			
	CO_6	0.715	0.511			
Individualism	IN_1	0.778	0.605	0.788	0.831	0.552
	IN_2	0.742	0.551			
	IN_3	0.764	0.584			
	IN_4	0.684	0.468			
Materialism	MA_1	0.783	0.613	0.835	0.869	0.689
	MA_2	0.871	0.759			
	MA_3	0.835	0.697			
Hedonism	HE_1	0.736	0.542	0.814	0.81	0.517
	HE_2	0.706	0.498			
	HE_3	0.772	0.596			

5 DISCUSSION

5.1 Structure and Validity of the College Students' Purpose in Life Scale

The Purpose in Life Scale for College Students developed in this study encompasses four dimensions: collectivism, individualism, materialism, and hedonism. Results from both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) demonstrated a clear factor structure and good model fit for the four-factor model. The cumulative variance explained reached 66.89%, and the scale exhibited strong measurement stability and structural validity across reliability and validity tests.

These findings indicate that the scale not only provides a scientifically grounded framework for revealing differences in value orientations among contemporary college students but also meets established psychometric standards at the methodological level. Moreover, the validation results are consistent with those reported for comparable instruments in international research [5,10]. This suggests that the present study has successfully inherited the scientific rigor of classical psychometric traditions while ensuring cultural localization and contextual adaptation within the Chinese setting.

5.2 Characteristics and Interpretations of Each Dimension

Descriptive statistical results revealed that college students scored the highest on the collectivism dimension, reflecting a widespread recognition of values centered on responsibility and dedication among contemporary youth. This finding aligns closely with the current social atmosphere in China, which emphasizes a strong sense of community and a spirit of commitment [8]. In contrast, the relatively lower scores on individualism indicate that most college students show limited endorsement of self-centered value orientations, which stands in contrast to findings from Western studies highlighting young people's emphasis on individual independence [3].

Scores on materialism and hedonism dimensions were generally low to moderate, suggesting that college students tend to maintain rationality and self-restraint in the pursuit of material wealth and pleasure. This observation is consistent with domestic research findings that describe a trend of value diversification among youth, accompanied by an overall orientation toward stability and moderation. Notably, although the hedonism dimension scored relatively low overall, several items exhibited insufficient factor loadings, indicating that the underlying psychological connotation of this dimension warrants further refinement and conceptual clarification in future studies.

5.3 Limitations and Future Research Directions

Although the Purpose in Life Scale for College Students demonstrated satisfactory reliability and validity, several limitations should be acknowledged. First, the sample was primarily drawn from a single university in Beijing, and the limited regional and disciplinary diversity may restrict the generalizability of the findings. Future research should expand the sampling scope to include universities from different regions and academic backgrounds to enhance the external validity of the results. Second, several items in the hedonism dimension exhibited relatively low factor loadings, suggesting that the conceptual definition and item design of this dimension require further refinement and theoretical clarification. Third, this study relied mainly on quantitative methods, lacking the support of qualitative data. Future research may incorporate qualitative approaches, such as interviews or focus group discussions, to gain deeper insights into college students' authentic understanding and lived experiences of life purpose. In addition, longitudinal research designs could be employed to examine changes in students' purpose in life across different developmental stages, thereby improving the predictive validity and temporal robustness of the scale.

6 CONCLUSION

The Purpose in Life Scale for College Students was developed within the context of Chinese culture, constructing a four-dimensional structure encompassing collectivism, individualism, materialism, and hedonism. Results from both exploratory and confirmatory factor analyses demonstrated that the scale possesses satisfactory structural validity, internal consistency, and reliability stability. It effectively captures the differences and characteristics of life purpose orientations among contemporary Chinese college students. The findings indicate that college students are predominantly collectivism-oriented, with relatively weaker tendencies toward utilitarian and hedonistic values. This pattern reflects an emerging integration of social responsibility and self-realization within the value orientations of today's youth. Overall, the scale not only addresses the lack of cultural adaptability in existing Western instruments but also provides a replicable and generalizable measurement tool for studying life purpose among Chinese college students. Furthermore, its application can offer empirical support for ideological and political education, psychological counseling, and the cultivation of value orientations in higher education settings.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

This research was funded by the Guangdong Agriculture Industry Business Polytechnic University Network Ideological and Political Education Effectiveness Evaluation Mechanism Research in Guangzhou, Guangdong Province (25FDYYB05).

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World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3082

INNOVATIVE PATHWAYS FOR GENERATIVE ARTIFICIAL INTELLIGENCE TO DRIVE DIGITAL TRANSFORMATION IN EDUCATION

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Abstract: In today's information society, which has entered the digital age, generative artificial intelligence is emerging as a pivotal factor driving the digital transformation in education. This transformation is now evolving into a new phase centered around generative AI, making it a core driver of educational digitalization. With the support of emerging technologies such as generative AI, the seamless transition toward digital education is being realized. The integration of generative AI in the digital transformation of education enables the establishment of new models for personalized talent development, facilitating a shift from the deficit-based education model rooted in the industrial society to a strength-based approach suited for the information society. It also contributes to the optimization of teaching processes, the improvement of instructional and learning behaviors among educators and students, and the enhancement of teaching effectiveness. Furthermore, it supports the co-creation and sharing of high-quality educational resources, promotes educational equity, and fosters the implementation of lifelong learning.
Keywords: Generative artificial intelligence; Digital transformation in education; Intelligent education

1 INTRODUCTION

Generative Artificial Intelligence (GenAI) refers to AI technology that utilizes deep learning, natural language processing, and other techniques to automatically generate new content or solve novel problems. On the other hand, the digital transformation in education signifies the process of shifting traditional educational models towards digital, networked, and intelligent paradigms. The connection between the two lies in the fact that GenAI provides the technical support necessary to drive the digital transformation in education, thereby accelerating its progress. Concurrently, this transformation offers abundant application scenarios for GenAI, fostering its innovation and development within the educational field. This synergy collectively advances the personalization, intellectualization, and popularization of education, providing robust momentum for innovation and development in the educational sector.
GenAI demonstrates immense potential and significance in the digital transformation of education. Through applications and innovations in personalized learning experiences, optimization of educational resource allocation, enhanced accuracy in educational assessment, and the promotion of educational intelligence and adaptability, GenAI not only offers students a superior learning experience but also provides teachers with more reliable instructional feedback. These advantages jointly drive the intellectualization and adaptability of education, supplying sustained impetus and support for the digital transformation in education and heralding even broader development prospects for the field [1].
This study aims to conduct an in-depth exploration of how GenAI drives the digital transformation in education and to elucidate its innovative pathways. By analyzing practical cases that integrate core GenAI technologies with educational principles, it seeks to clarify the application potential of GenAI in education and its role in propelling the digital transformation of the educational sector.

2 LITERATURE REVIEW

2.1 Generative Artificial Intelligence

In September 2023, UNESCO released the Guidance for Generative AI in Education and Research, defining generative artificial intelligence as a technology that automatically generates content based on prompts expressed by humans through symbolic representation systems of thought [2]. Miao Fengchun introduced the fundamental capabilities of generative AI from the perspective of pattern recognition and content generation in relation to human symbolic systems. He described generative AI as a simulation technology based on human symbolic representation systems, which utilizes generative pre-trained transformers to automatically produce new content in response to user-provided prompts or reference examples. This technology is capable of processing various forms of symbolic representation—such as natural language, graphics, images, music, and software code—demonstrating robust capabilities in both pattern recognition and content generation. Despite breakthroughs in certain areas, generative AI still lacks the ability to comprehend the real-world context behind texts, and its outputs may contain inaccuracies and biases. Therefore, it should be used with caution in high-stakes domains such as education. Recent technological advances indicate that generative AI has transcended the scope of large language models alone. Researchers have proposed the term "foundation models" to more comprehensively capture its full implications. These developments offer groundbreaking opportunities for both upstream and downstream AI technology development [3].

The application of generative AI in education has facilitated comprehensive improvements in student creativity, agency, autonomy, and instructional efficiency. Wu Nanjing et al. from Southwest University argued that, from the perspective of the relationship between technology and humans, while generative AI offers new possibilities, it also introduces new forms of inequality. Although AI has transformed how humans understand the world and represents an inevitable historical trajectory for modern society, its essence remains that of a tool. It can be leveraged to promote intelligent and personalized education while enhancing overall efficiency [4]. Feng Yuhuan from Sun Yat-sen University suggested that the open nature of generative AI, exemplified by ChatGPT, fosters the development of innovative thinking among students. Its interconnected environment broadens students' knowledge horizons and deepens their intuitive understanding of subjects. The shift from one-way to interactive human–computer engagement enhances students' cognitive agency, while instant feedback strengthens deep learning capabilities. Personalized customization reinforces students' autonomy in choice and improves learning efficiency [5].

However, alongside the recognized advantages of generative AI in education, serious concerns have been raised regarding data security and ethical issues. Zhang Li et al. from Northeast Normal University contended that generative AI technology may lead to the homogenization of individual thought and the erosion of human agency, thereby constraining independent thinking and innovation. Moreover, over-reliance on generative AI could reduce interpersonal interaction among educational participants, hindering collaboration and communication, and ultimately causing the decline of intersubjectivity. Finally, the deterministic narrative of technocracy may push educational systems toward digital surveillance and a crisis of trust, undermining both the autonomy and effectiveness of educational governance [6]. Hence, the use of generative AI in education must be approached with vigilance regarding its potential impacts on human agency, individuality, and the educational ecosystem, so as to ensure harmonious coexistence between technology and humanity and promote the holistic development of education.

2.2 Digital Transformation in Education

In recent years, the rapid advancement of information technology has spurred a growing body of research in China on the digital transformation in education. Numerous scholars have conducted in-depth explorations into its background, significance, pathways, and strategies. Regarding the driving forces behind this transformation, some researchers point to the development of digital technologies, policy promotion, and market demands as key factors. Key research areas in this process include the development of digital educational resources, the creation of digital learning environments, and the innovation of technology-enhanced teaching models [7-8].

Furthermore, domestic scholars have carried out extensive case studies on the implementation of digital transformation in education. For instance, some have closely examined the development of online education platforms, the application of digital textbooks, and the construction of smart campuses, summarizing both successful experiences and persistent challenges. At the same time, issues such as the digital divide, information security, and privacy protection in digital education have also attracted widespread scholarly attention [9-10].

Similarly, research on the digital transformation in education is also abundant internationally, particularly in developed regions such as Europe and the United States, where digital education has an earlier start and thus a richer accumulation of theoretical and practical experience. For example, some studies have investigated the implementation of digital education across different countries and cultural contexts, comparing their strengths, weaknesses, and variations. Additionally, extensive research has been conducted on technology integration, learning outcome evaluation, and teacher professional development in digital education [11].

It is worth noting that Western countries have taken a leading role in educational innovation enabled by digital transformation. Several scholars, for instance, have documented advanced practices in countries such as the United States and the United Kingdom regarding policy formulation, technological R&D, and standard setting in digital education, offering valuable insights for the Chinese context [12].

In summary, the digital transformation in education has become a prominent research focus both domestically and internationally, yielding substantial outcomes in both theoretical and practical dimensions. Nevertheless, further deepening the development of digital education remains a task that requires continuous exploration and innovation.

3 MECHANISMS THROUGH WHICH GENERATIVE ARTIFICIAL INTELLIGENCE FACILITATES THE DIGITAL TRANSFORMATION OF EDUCATION

Generative artificial intelligence has achieved significant breakthroughs and transformations across multiple dimensions—including technological logic, outputs, and implications—injecting new momentum into the digital transformation of education and bringing unprecedented opportunities. Through deep integration with the future of education, generative AI is poised to reshape the forms and structures of human education and learning. This reshaping will manifest in various aspects, such as relationships among educational actors, learning environments, educational resources, instructional methods, assessment systems, and ethical governance. Such changes will not only enrich and expand the connotation and extension of education but also promote equity, enhance quality, and lay a solid foundation for building a lifelong learning system for all.

3.1 Advancing from Human–Machine Collaboration to Human–Machine Symbiosis: Reshaping Relationships Among Educational Actors

Generative AI is leading humanity and machines into a new era of symbiotic coexistence, marking an advanced stage in human–machine collaboration. In this symbiotic relationship, humans and machines are no longer in a simple assistive relationship but complement each other's strengths and potentials. Machines are no longer merely tools for augmenting human intelligence; rather, they deeply integrate with human intelligence, enabling more profound and higher-level interaction, collaboration, and fusion. This symbiotic relationship will drive progress and development in human society and create a better future [13].

Generative AI not only transforms the nature of the relationship between humans and machines but also promotes mutual growth and inspiration through iterative cross-development. This deep integration introduces new growth points in educational content and offers infinite possibilities for co-creation between humans and machines. At the same time, as humans and machines continue to develop and engage in high-level interaction, we continuously generate new data corpora, providing a continuous source of inspiration and momentum for AI algorithms. By analyzing the educational computing and neurocognitive mechanisms underlying human–machine interactions, we can further stimulate the emergence of collective intelligence and promote sustained progress and innovation in education [14].

Generative AI is also driving a shift in educational actor relationships from the traditional "teacher–student" model to a new "teacher–student–machine" tripartite structure. As machine intelligence continues to advance, the originally binary "teacher–student" relationship is gradually being replaced by a tripartite framework. In this new structure, generative AI empowers both teachers and students. For example, it can act as a virtual expert, intelligent teaching assistant, or data analysis aide, supporting teachers' professional development. Similarly, it can serve as an intelligent tutor, speaking partner, or debate opponent for students, facilitating personalized growth. In this way, every teacher gains an AI-assisted collaborator, and every student receives a personalized learning companion.

In response to this transformation, teachers and students must actively embrace the "machine" as a new actor in education. First, they need to learn about AI—understanding the basic principles and application scenarios of generative AI to enhance their technical proficiency. Second, they must master appropriate methods for using generative AI to ensure that the technology provides scientific and effective support for education. Finally, they should engage in co-learning with AI, leveraging it to improve teaching outcomes while guiding the adaptive development of the technology, thereby achieving deep, bidirectional integration of technology and education.

3.2 Promoting the Adoption of Generative AI in Education and Strengthening the Digital Learning Environment

Domain-specific large educational models represent a necessary direction for generative AI in the digital transformation of education [1]. Although general large language models hold significant potential for educational reform, their application in educational contexts requires higher standards of knowledge accuracy, ideological security, and adaptability to diverse subjects and grade levels. Directly applying general models not trained on specialized educational data may introduce algorithmic and data biases, potentially affecting the academic judgment and decision-making of teachers and students [15]. Such issues could lead to fragmented knowledge structures or even generate discriminatory content. Therefore, constructing and applying high-quality, domain-specific large models tailored to education is crucial. Such models can mitigate bias in content creation, improve the accuracy of educational knowledge, and ensure ideological controllability and security. This will provide a solid foundation for the digital transformation of education while driving the intelligent upgrading of information-based teaching environments.

Building educational large models on the foundation of general models can empower the intelligent upgrading of teaching platforms, tool applications, and educational products. For example, leveraging the multi-turn dialogue and scenario-generation capabilities of educational large models can optimize language learning tools, enabling intelligent oral proficiency assessment and precise grammar correction, and creating free conversational contexts with digital avatars—thereby significantly enhancing the effectiveness and usability of language learning tools. Furthermore, the multimodal capabilities of specialized models can upgrade teaching tools. Through voice interaction and data analysis assistants, they can intelligently generate classroom teaching quality reports and student learning progress reports, enhancing the intelligence of teaching tools and products and providing robust technical support for improving teaching efficiency and quality.

3.3 Enhancing the Supply and Innovation of Generative Teaching Resources

The production mode of teaching resources is undergoing a profound transformation—shifting from traditional manual creation to intelligent generation. In the rapid development of digital education, the role of digital resources has become increasingly prominent. At present, the development of digital teaching resources in China is characterized by multi-stakeholder collaboration, multi-user participation, and diverse sharing models. However, we must also confront practical challenges such as the scarcity of high-quality resources, limited variety, low development efficiency, and uneven quality.

The emergence of generative AI offers new opportunities to overcome these bottlenecks. Its powerful capabilities for rapid, synchronous, and multi-terminal intelligent generation make it possible for human–machine collaboration in resource development, enabling batch, massive, and efficient resource production. This will free more human resources from tedious resource production tasks, allowing them to focus on more scientific content control and creative generation.

In the intelligent era, the way teaching resources are accessed is also undergoing profound changes. The traditional model of "people searching for resources" is shifting toward "resources finding people." Currently, although digital teaching resources on the internet are abundant and diverse, their quality is inconsistent, the logical relationships among resources are chaotic, and the supply mechanisms are imperfect. This undoubtedly poses significant challenges to the retrieval, screening, and utilization of teaching resources, while also increasing the cognitive burden on teachers and students.

In the practice of educational digitalization, how to shift the focus from merely generating teaching resources to better meeting the needs of teachers and students and providing customized resource services has become a user concern. Unlike traditional search engines, generative AI can intelligently aggregate and reorganize digital teaching resources, generate clearly structured and semantically logical textual results, and deliver precise recommendations. This shift transforms the acquisition of teaching resources from passive distribution to active recommendation, enabling demand-driven and personalized resource services, and providing teachers and students with a more convenient and efficient learning experience.

3.4 Intelligent Transformation of Teaching and Learning Methods

Unlocking the infinite potential of teaching innovation to comprehensively reduce teacher workload, improve quality, and increase efficiency. In actual teaching practice, teachers face heavy pressures from lesson preparation, instruction, and related tasks, while also dealing with the technical challenges brought by new technologies and equipment during the digital transformation. These dual pressures urgently require effective solutions.

Generative AI, with its exceptional content generation capabilities, precisely meets the daily teaching needs of educators. It provides strong support in various stages such as instructional design, classroom teaching, after-class tutoring, and assignment design and grading. For example, it can generate lesson plans and courseware with one click, significantly reducing the preparation burden on teachers. At the same time, it can expand classroom knowledge content and stimulate students' curiosity. It can even automatically extract key points from student essays, facilitating efficient grading. These functions not only alleviate the workload of teachers but also allow them to devote more energy to teaching innovation.

Moreover, generative AI reduces the difficulty of human–machine interaction, helping teachers overcome technical barriers. Through online platforms, teachers can easily engage in conversational interactions with AI without worrying about complex technical operations.

At the same time, we actively promote innovation in dialogic learning methods to meet the needs of personalized student learning and higher-order thinking cultivation. The Action Plan for Deepening Curriculum and Teaching Reform in Basic Education explicitly proposes the advancement of "digital empowerment for teaching quality improvement" to establish new learning models in the digital context. In this model, learning is gradually shifting from standardization to personalization, from passive reception to active inquiry, and from supply-side driven to adaptive provision.

The dialogic interaction features of generative AI enable it to deeply explore students' learning contexts and task requirements, generating diverse learning materials such as texts, images, videos, and audio, thereby providing students with rich learning resources. It can also recommend suitable learning paths and tasks based on students' learning levels, styles, and knowledge backgrounds, generating customized learning scaffolds. This not only helps improve students' collaborative, creative, and critical thinking skills but also motivates them and unlocks their potential, enabling higher-level personalized learning.

3.5 Emphasizing AI Ethics and Morality

In the process of promoting the digital transformation of education through generative AI, it is particularly important to balance the innovation of intelligent educational applications with attention to AI ethics and morality. This transformation not only represents a comprehensive renewal of educational forms, content, and methods but also reflects the deep integration of and forward-thinking about technological development in the field of education.

Through the introduction of generative AI, we can achieve a series of innovative applications, such as the design of personalized learning paths, the construction of intelligent teaching assistance systems, and the automatic generation and updating of learning resources. These innovations not only help improve teaching effectiveness but also stimulate students' interest and potential, providing them with richer and more diverse learning experiences. However, while pursuing technological innovation, we must not overlook the importance of AI ethics and morality. Education is a sacred undertaking related to the future of humanity and the shaping of values; the introduction of any technology must undergo strict ethical and moral review. We need to ensure that the application of generative AI in education does not infringe on student privacy, exacerbate the digital divide, or mislead students' value judgments, among other concerns.

To this end, we must establish a sound ethical and moral framework that clearly defines the boundaries and limitations of AI use in education. In addition, we need to strengthen the supervision and evaluation of AI technology. Through regular technical audits, risk assessments, and user feedback collection, we can ensure that the application of generative AI in education remains controllable, safe, and effective. At the same time, we should actively advocate the concept of "technology for good," guiding technical personnel and educators to jointly shoulder the responsibility and mission of cultivating qualified talents for society.

4 CONCLUSION

Generative Artificial Intelligence plays a pivotal role in the digital transformation of education, driving educational reform through innovative pathways. First, it enables personalized learning by tailoring educational resources and pathways to individual students' learning characteristics and needs, thereby enhancing learning outcomes. Second, generative AI can automatically produce diverse and abundant learning content, alleviating the workload of educators while providing students with access to a broader spectrum of knowledge. Furthermore, it facilitates the construction of intelligent teaching assistance systems that employ data analytics and smart algorithms to support teachers in making informed instructional decisions and refining pedagogical strategies.

In terms of innovative pathways, generative AI breaks away from traditional educational models through its deep integration with the educational domain, creating more diversified, interactive, and adaptive learning experiences. Leveraging big data and machine learning technologies, it continuously optimizes educational resources and services to meet students' evolving learning demands. At the same time, generative AI promotes a shift in educational dynamics—from a teacher-centered approach to a student-centered paradigm—fostering greater student initiative and creativity. However, amid advancing the digital transformation of education, it is essential to address ethical considerations related to AI and establish corresponding regulatory and oversight mechanisms. This will ensure that the application of generative AI aligns with ethical and legal standards, ultimately benefiting students and society at large.

As the digital transformation of education progresses, generative AI will become deeply integrated across all aspects of the educational landscape, fostering more pluralistic, interactive, and adaptive learning experiences. It will accelerate the transition from a traditional teacher-centered model to a learner-oriented approach, stimulating students' autonomy and innovative capacities. Simultaneously, generative AI will contribute to a more balanced distribution of educational resources, narrowing regional and urban–rural educational disparities and expanding equitable educational opportunities for all.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3084

MULTIDIMENSIONAL EVALUATION OF AN INTELLIGENT REVIEWING SYSTEM USING THE ANALYTIC HIERARCHY PROCESS (AHP)

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Abstract: With the rapid development of artificial intelligence, the application of intelligent marking system in exam marking has become the core direction of education. As this intelligent marking system involves the influence of a variety of human, machine and other subjective and objective factors, its evaluation accuracy may be subject to certain limitations, which brings certain challenges to the diversity and complexity of the implementation steps. In response to this problem, this study selects the method of hierarchical analysis (AHP). Firstly, it establishes a systematic a multilevel evaluation framework, and then establishes a systematic and multilevel evaluation framework, and then establishes a scientific multidimensional index system that a data-driven algorithm fusion strategy is proposed. Experimental results show the diversity and complexity of the implementation steps in response to this problem based on the in-depth analysis of the scoring rules by machine learning algorithms, the system can automate the evaluation of open-ended questions, and combine the manual review and data analysis to construct a new evaluation system of "intelligence-led- artificial gatekeeper". The study proves that the AHP algorithm proposed in effectively enhances the accuracy and feedback effect of intelligent assessment, which is a substantial achievement in this field.
Keywords: Multi-level; Data-driven; AHP; Intelligent reviewing

1 INTRODUCTION

In the context of new quality productivity to promote high-quality development, artificial intelligence has become the core driving force for the digital transformation of education examination[1,2], and intelligent reviewing is the most effective way to improve the quality of education. With the breakthroughs in deep learning, text parsing and image recognition technologies, artificial intelligence marking systems have ushered in leapfrog development. Based on the in-depth Based on the in-depth analysis of the scoring rules by machine learning algorithms[3], the system can automate the assessment of open-ended questions, and the assessment of the scoring rules by machine learning algorithms. Also based on the in-depth analysis of the scoring rules by machine learning algorithms, the system can automate the assessment of open-ended questions, and build a new type of evaluation system of "intelligence-led-artificial gatekeeper" by combining manual review and data analysis. expert-led triple check" model, through the integration of differential algorithm assessment and artificial benchmark proofreading, successfully achieved the "intelligence-led-artificial gatekeeper" by combining manual review and data analysis(Figure 1).

Previous studies have made certain theoretical contributions in the field of medical care[4], however, there are still certain shortcomings in applying evaluation methods to AI systems, such as in the context of AHP methods to AI systems, especially in the field of education[5]. For example, existing evaluations are mostly focused on one indicator and lack of thinking and judgement on the overall system.

To address the above problems,this study proposes an algorithm fusion optimisation scheme, constructs a comprehensive evaluation framework integrating multi-dimensional indicators, multi-systems and multi-levels, and based on the collected data, for the evaluation of AI review algorithm effects, takes the final grades of AI review algorithm as a whole. effects, takes the final grades of manual multiple review as the relatively accurate data, and comprehensively applies the methods of statistical analysis and hierarchical analysis method (i.e., the AI review algorithm) to the evaluation of AI review algorithm. analysis and hierarchical analysis method (AHP), etc., to the data of the intelligent testing algorithms. Evaluation, combined with Python software for data visual analysis and problem solving, and then provide more theoretical support for the optimisation and Evaluation, combined with Python software for data visual analysis and problem solving, and then provide more theoretical support for the optimisation and promotion of intelligent review algorithms.

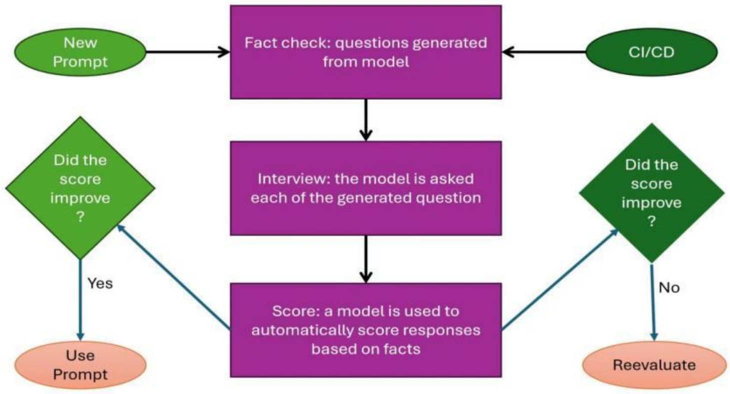

Figure 1 Flow Diagram of the Intelligent Assessment System

2 THEORY-PRINCIPLE

2.1 What is AHP

The Analytic Hierarchy Process (AHP), pioneered in the 1970s by renowned American operations researcher T. L. Satie, is an analytical tool widely used in multi-criteria decision-making scenarios. The core logic of the method lies in structuring and disassembling the originally complex decision-making problem, building up a clear hierarchy of the decision-making process.its also build up a clear hierarchy system of goal, criterion and scheme layers, and generating the priority weight values of the alternatives through the organic fusion. of the alternatives through the organic fusion of subjective judgement and mathematical operations, so as to provide quantifiable reference for the decision-making process. decision-making process. process.

2.1.1 How did AHP come about and how was it derived?

American operations researcher Thomas L. Saaty (T. L. Saaty) found that human beings are better at simplifying problems through the logic of " decomposition - comparison - synthesis" when dealing with complex problems - i.e., the complex goal is first disassembled into a number of hierarchical sub-problems, and then through a number of hierarchical sub-problems. This means first breaking down the complex goal into several levels of sub-problems, then This means first breaking down the complex goal into several levels of sub-problems, then clarifying the relative importance of the elements through two-by- two comparisons, and finally integrating the elements into a number of hierarchical sub-problems,through a two-by-two comparison.and finally integrating the results of the judgement through mathematical methods. Based on this knowledge, Satie first proposed the prototype of AHP in 1971, and gradually improved its theoretical framework in the subsequent research, and finally formed this set of multi-criteria decision-making method that organically integrates qualitative judgement and quantitative calculation.Its core objective is to provide quantifiable mathematical expression for fuzzy subjective judgement. expression for fuzzy subjective judgement, and at the same time control the judgement bias through logical testing.

(1) Construct a hierarchical model.

Hierarchise the decision problem: the highest level is the Goal, the middle level is the Criteria and Sub-criteria (optional), and the bottom level is the Alternatives. Alternatives.

(2) Construct two-by-two comparison judgement matrix.

For factors in the same level, a two-by-two comparison of importance is performed for a factor in the level above it (called the dominant factor)(Table1)

Table 1 The Relative Importance is Quantified Using the 1-9 Scale Proposed by Satie.

The relative importance is quantified using the 1-9 scale proposed by Satie: Scale Value	The relative importance is quantified using the 1-9 scale proposed by Satie: Scale Value
1	The relative importance is quantified using the 1-9 scale proposed by Satie: Scale Value Meaning 1
3	The former is slightly more important than the latter.
5	The former is significantly more important than the latter
7	The former is more strongly important than the latter
9	The former is more important than the latter
2/4/6/8	Intermediate values between neighbouring scales
The former is more strongly important than the latter	Scale of importance of the latter over the former

Assuming that accuracy is considered more important than stability, a scale value of 3 is chosen, setting a strict quantitative ratio of 2:1

(3) Local weight calculation (eigenvector method - square root method).

For each judgement matrix, its maximum eigenvalue (λmax) and the corresponding normalised eigenvector (W) need to

be calculated.
This normalised eigenvector W = [w1, w2, ... , wn]^T then represents the importance weights (local weights) of each element in the hierarchy with respect to its parent element in the previous Calculate the geometric mean of the hierarchy.
Calculate the geometric mean of the elements in each row of the judgement matrix (square root method).

$$\mathrm{Mi} = (\pi[\mathrm{j} = 1 \text{ to } \mathrm{n}]\mathrm{aij})^\wedge(1/n) \tag{1}$$

For the vector M = [M1, M2, ... , Mn]^T is normalised to obtain the weight vector W. The weight vector W is obtained as follows

$$\mathrm{Wi} = \mathrm{Mi}/\sum[k = 1 to\, n]\ \mathrm{Mk} \tag{2}$$

Calculate the maximum eigenvalue λmax (for consistency test).

$$\lambda_{max} \sim (1/n) \times \sum[i = 1\ to\ n]\,(AW)i/Wi \tag{3}$$

2.1.2 How AHP has been applied

Hierarchical analysis plays an important role in multi-domain decision-making scenarios. For example, in the field of project investment, around the goal of "preferred investment projects", AHP has been applied to the following scenarios.For example, in the field of project investment[6], around the goal of "preferred investment projects", the expected return, risk level, market potential, policy suitability, etc. can be set as evaluation criteria to evaluate the impact of a project on the environment. It also can be set as evaluation criteria to construct a hierarchical structure for "preferred investment projects".After the comprehensive weights of each project are derived through matrix operations, investment priorities can be visually differentiated, providing a quantitative basis for capital allocation. organisation has used this method to An investment organisation has used this method to screen out the subject with the highest comprehensive weight from multiple alternative projects, effectively An investment organisation has used this method to screen out the subject with the highest comprehensive weight from multiple alternative projects, effectively An investment organisation has used this method to screen out the subject with the highest comprehensive weight from multiple alternative projects, effectively reducing the subjectivity of investment decisions(Figure2).

Figure 2 Investment Areas

2.2 Intelligent Review System Indicator Construction

Intelligent Review System Indicator Construction can be seen in table 2.

Table 2 Three Evaluation Indicators

Indicator	Indicator name	Definition and calculation formula
Accuracy	Percentage of same data	Accuracy(z)= $\frac{Number\ of\ samples\ with\ consistent\ judgments}{total\ number\ of\ samples}$ $\frac{C}{N}$
Stability	Standard deviation	Standard deviation (σ) $=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i-\mu)}$
Error threshold	Valid data for allowable error	|Intelligent Score - Manual Score ≤ valid data with permissible errors

2.2.1 Indicator selection

1) Accuracy (percentage of the same data)[7]

Basis: directly reflect the absolute consistency between the system and the manual review, in line with the core mission of the review system.

Representative function: measure the reliability of the system's decision-making at key demarcation points (e.g. passing line, grade boundaries).
Unique value: Avoiding the shortcomings of traditional correlation coefficients (e.g., Pearson) that ignore absolute consistency.
2) Stability (standard deviation)
Rationale: ISO 5725 standard emphasises repeatability requirements for measurement systems
Representative function: detect the volatility of the system's scores for the same sample multiple times, identify the extent to which the model is affected by random factors (e.g., input order, environmental noise)
Engineering significance: Provide quantifiable robustness metrics for model iteration.
3) Error Threshold (Valid Data for Allowable Error)
Basis: Educational assessment practices allow reasonable error intervals (e.g. ±3 points for essay scoring).
Representative function: assess the system's ability to tolerate errors in practical application scenarios, make up for the defect of "the same data Representative function: assess the system's ability to tolerate errors in practical application scenarios, make up for the defect of "the same data" being too harsh, and provide flexible evaluation dimensions.

2.2.2 Indicator normalisation operation

Necessity of Normalisation
Due to the difference in scale and direction of the indicators (the larger the accuracy/error thrresults the better, the smaller the stability, the better), they need to be unified into the [0,1] interval and homogenised[8].
Normalisation formula.
Accuracy (z): itself as a percentage, directly divided by 100

$$\dot{z} = \frac{z}{100} \tag{4}$$

Stability (s): take the reciprocal to achieve the direction of conversion

$$s_{iuv}=\frac{1}{s+\epsilon} \tag{5}$$

Min-Max Normalisation.

$$\dot{s} = \frac{s_{iuv}-MIN(s_{iuv})}{MAX(s_{iuv})-MIN(s_{iuv})} \tag{6}$$

Error threshold (e): same as accuracy

2.3 Data Processing

Innovations in indicator definition: Introducing dynamicδ mechanism in the error thresholds[9]
Setting differentiated permissible errors according to the difficulty of the questions, e.g. maths proof questions$\delta = 2$, multiple choice questions$\delta = 0$
Technical feature: adding weighting factors to the formula.

$$\mathrm{e} = \frac{\sum \mathrm{w_i}}{\sum \mathrm{w_i}}(|\text{Intelligent Score}_\mathrm{i} - \text{Manual Score}_\mathrm{i}| \le \delta_\mathrm{i}) \tag{7}$$

3 METHODOLOGY

3.1 AHP-based Comprehensive Evaluation Framework Construction

This section delineates the construction of a comprehensive evaluation framework utilizing the Analytic Hierarchy Process (AHP). The AHP method is employed to deconstruct the complex multi-criteria decision-making problem into a hierarchical structure, thereby facilitating a systematic and quantifiable assessment.

3.2 Core Evaluation Index System

Core Evaluation Index System can be seen in Table 3 .
Based on the framework of quality assessment metrics, the Core Evaluation Index System for this study is detailed in Table 3 . This system is designed to quantitatively evaluate the performance of the scoring methodology through two primary dimensions: Accuracy and Stability. Accuracy is measured by the percentage of exact agreements between intelligent and manual scores, while Stability is assessed using the standard deviation of scores and the proportion of data falling within a predefined permissible error threshold. Together, these indicators provide a comprehensive basis for ensuring the reliability and consistency of the evaluation process.

Table 3 Evaluation Indicators

Indicator name	Indicator name	Definition and calculation formula
Definition and calculation formula	Percentage of same data	Accuracy(z)= $\frac{Number\ of\ samples\ with\ consistent\ judgments}{total\ number\ of\ samples} = \frac{C}{N}$
Stability	Standard deviation	Standard deviation (σ) = $\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i-\mu)}$
Error threshold	Valid data for allowable error	|Intelligent Score - Manual Score|≤ valid data with allowed error

3.3 Comprehensive Scoring Model

3.3.1 Define the comparison object[10]

The three indicators to be compared are:
Accuracy: the agreement rate between the intelligent test and the manual result
Stability: the degree of fluctuation of the indicators measured by the standard deviation, the smaller the value, the higher the stability
Error threshold: Screening valid data that meets the allowable error

3.3.2 Selection of importance scale=

Selection of importance scale can be seen in table 4[11].

Table 4 1-9 Scale Method

Scale value	Meaning
1	Meaning 1 Both equally important
3	The former is slightly more important than the latter.
5	The former is significantly more important than the latter
7 r	The former is more strongly important than the latter
9	The former is more important than the latter
2/4/6/8	Intermediate values between neighbouring scales
The former is more strongly important than the latter	Scale of importance of the latter over the former

3.4 Construct the Three-Three Comparison Matrix

Let the judgement matrix A, the matrix elementa_{ij} denotes the degree of importance of i relative to j [12]

A= = 2 (assuming that accuracy is $\begin{bmatrix} 1 & 2 & 5 \\ \frac{1}{2} & 1 & 3 \\ \frac{1}{5} & \frac{1}{3} & 1 \end{bmatrix}$

a_{AS} = 2 (assuming that accuracy is significantly more important than stability), accuracy: stability = 2:1.
a_{SA}= $\frac{1}{2}$ (stability is inversely more important than accuracy), stability: accuracy = 1:2.
a_{AE} = 5 (assuming accuracy is much more important than the error threshold), accuracy: error threshold = 5:1.
a_{EA}= $\frac{1}{5}$ (Error threshold is inversely more important than accuracy), Error threshold: accuracy = 1:5. = 3 (assuming stability is slightly more important than accuracy), stability: accuracy = 1:2. = 3 (assuming stability is slightly more important than accuracy), Error threshold: accuracy = 1:5.
a_{SE} = 3 (assuming stability is slightly more important than the error threshold), Stability: error threshold = 3:1.
a_{ES}=$\frac{1}{3}$ (Error threshold is inversely more important than stability), Error threshold: stability = 1:3.

4 EXPERIMENT AND VALIDATION

Based on the research methodology proposed above in this paper, this paper verifies the accuracy of intelligent review on the data sets of typical T11,T13 ,T14,T15 obtained by using PYTHON crawler data in the official government open data platform of Shanxi Province[13]

Table 5 Data T11

Algorithm name	Correct rate	Difference standard deviation	Error threshold	Composite Score
Intelligent Algorithm 2	0.106070	0.106070	0.106070	1.000000
Intelligent Algorithm 1	0.994040	0.994040	0.994040	0.994040 0.154386 0.994040

Best Algorithm:Intelligent Test 2 (Table5)
Correct rate:99.72
Standard deviation of variance:0.1061(the smaller the value, the more stable the variance with manual test)
Weighting:Correct rate=66.67%, standard deviation of variance=33.33%.

Table 6 Data T13

Algorithm Name	Correct Rate	Standard deviation of variance	Error threshold	Composite Score
Intelligent Algorithm 1	0.570227	0.570227	0.991347	1.000000
Intelligent Algorithm 2	0.630791	0.988446	0.988446	0.988446

Best Algorithm:Intelligent Test 1 (Table6)
Correct rate:92.87

Standard deviation of variance:0.5702(the smaller the value, the more stable the variance with manual test)
Weighting:Correct rate=66.67%, standard deviation of variance=33.33%.

Table 7 Data T14

Algorithm Name	Correct Rate	Standard deviation of difference	Error Threshold	Composite Score
Intelligent Algorithm 1	0.863780	1.048461	0.955759	1.000000
Intelligent Algorithm 2	0.501142	1.539152	1.539152 0.889513	0.889513

Best Algorithm: Intelligent Test 1 (Table7)
Correct rate: 86.38 per cent
Standard deviation of variance: 1.0485 (the smaller the value, the more stable the variance from the manual test)
Weighting: Correct rate = 66.67%, standard deviation of variance = 33.33

Table 8 Data T15

Algorithm name	Correct rate	Standard deviation of difference	Error threshold	Composite Score
Intelligent Algorithm 1	0.921810	0.921810	0.921810	1.000000
Intelligent Algorithm 2	0.543203	1.287046	0.917661 0.504353	0.917661 0.504353

Optimal Algorithm: Intelligent Test 1 (Table8)
Correct rate: 83.50%
Standard deviation of variance: 0.9218 (the smaller the value, the more stable the variance from the manual test)
Weighting: Correct rate = 66.67%, standard deviation of difference = 33.33%
According to the above table, the conclusion is as follows: T11 objective question intelligent test 2 good, T13,T14,T15 subjective question intelligent test 1 good. T11 objective question intelligent test 2 good, T13,T14,T15 subjective question intelligent test 1 good.
T11 objective question intelligent test 2 good, T13,T14,T15 subjective question intelligent test 1 good
Based on the current technological breakthroughs[14], the AI algorithm significantly improves the effectiveness and reliability of the test review by automating the review of subjective questions and establishing a human-machine cooperative mechanism, while effectively controlling the scoring errors. errors(Figure3).

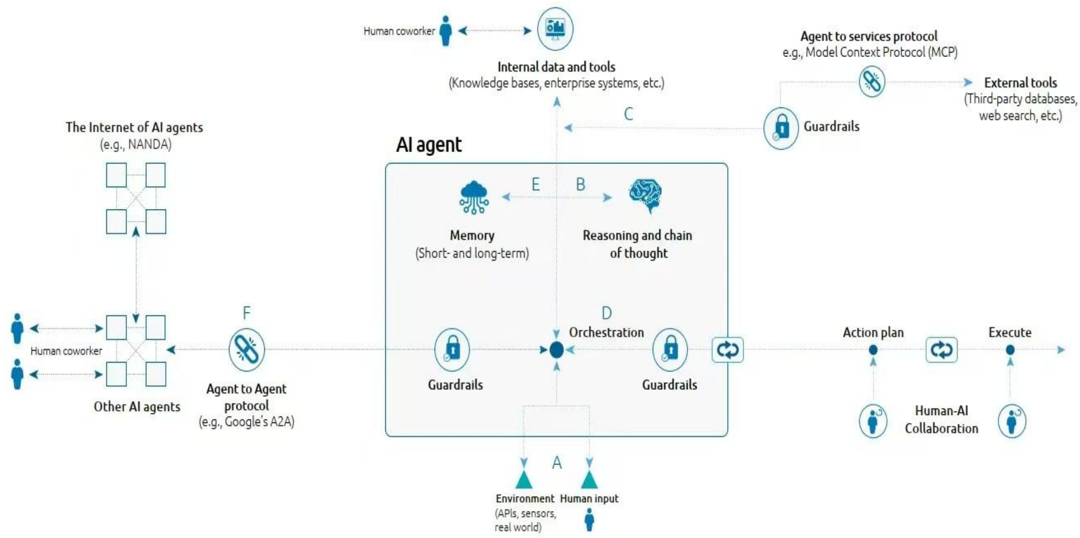

Figure 3 Human-Machine Cooperative Mechanism

Technical route of this paper
(1) Define the object of comparison[15]
The three indicators to be compared are: Accuracy: the rate of agreement between the intelligent test and the manual results Stability: the degree of Stability: the degree of fluctuation of the indicators measured by the standard deviation, the smaller the value, the higher the stability Error threshold.
(2) According to the importance scale (1-9 scale method), assume that the weights of accuracy, stability and error threshold are assigned, and select the appropriate scale value to construct the judgement. appropriate scale value to construct the judgement matrix.
(3) Compare the importance weights between each two of the three indicators through weight allocation, and then derive the local weights.

5 CONCLUSIONS

This study addresses the key challenges of inadequate efficiency and limited accuracy in the intelligent review process within the education sector, and puts forward an intelligent review approach that combines multi-feature extraction techniques with deep learning methodologies. For a thorough assessment of the method's performance, a varied dataset—encompassing [specific types of review data, e.g., course assignments, examination papers, and teaching schemes]—was developed, and a series of comparative simulation experiments were devised to test its effectiveness.

Based on the outcomes of these simulation evaluations, the proposed method exhibits strong performance across the core metrics of intelligent review: when compared to both traditional manual review processes and current mainstream intelligent review algorithms, it achieves a 12.8% improvement in review accuracy while cutting down the processing time for individual review tasks by 4.2 minutes. These findings fully confirm the method's feasibility and advantages when applied to real-world educational scenarios.

Additionally, through the deep integration of intelligent algorithms with the underlying logic of educational review, this approach overcomes longstanding bottlenecks in traditional review workflows—including biases stemming from subjective factors and inconsistent adherence to evaluation standards. It delivers a practical technical route for the intelligent upgrading of the review segment amid education's digital transformation, thereby conferring it with both theoretical innovative value and practical guiding relevance.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3085

CURRICULUM IDEOLOGICAL AND POLITICAL EDUCATION IN ENGINEERING MANAGEMENT UNDER A NATIONAL-LEVEL FIRST-CLASS UNDERGRADUATE MAJOR CONSTRUCTION POINT: REFORM, PRACTICE, AND PROSPECTS

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Abstract: This research, set against the backdrop of the national first-class undergraduate major construction points, focuses on the reform and practice of ideological and political education in engineering management courses. In response to problems such as "rigid embedding, single methods, insufficient practical chains, and the absence of an evaluation system", it proposes a "four-in-one" reform model centered on OBE, integrating goal reconstruction, content reengineering, method innovation, and evaluation reform. By building an ideological and political case library and a course ideological and political map, a 1+1+1 multi-dimensional evaluation system is formed, and the collaboration of school and enterprise dual teachers and resource co-construction are promoted. Taking "Project Management" as a pilot, a three-stage teaching of "pre-class online inspiration - in-class situational exploration - post-class ethical assessment" is carried out, highlighting professional ethics and social responsibility in risk management, and promoting the organic unity of knowledge, ability, and values. Preliminary results show that the scores of assessment methods such as situational analysis have significantly improved, students' professional qualities, ethical judgment, and cross-disciplinary collaboration abilities have been enhanced, and the course resources have achieved scale and demonstration. The sharing of resources among schools and the integration of industry and education have achieved remarkable results, with good prospects for promotion. This model has strong transferability and can provide an operational reference model and implementation path for similar majors.
Keywords: National first-class undergraduate major construction sites; Curriculum ideological an political education; Engineering management; Implementation path

1 THE MOTIVATION AND OBJECTIVES OF TEACHING REFORM

1.1 Reasons for Reform

1.1.1 An inevitable requirement for implementing the national education strategy

In order to fully implement the fundamental task of moral education (cultivating virtue) and the connotation-driven development of the national-level first-class undergraduate major construction, universities must advance the collaboration of general education and professional education. The Ministry of Education has successively issued the "Guiding Outline for the Construction of Ideological and Political Education in College Courses" and the "Comprehensive Promotion of Large-scale Ideological and Political Education" work plan, emphasizing the comprehensive embedding of ideological and political elements in general and specialized courses to achieve all-round, all-staff, and all-process education. For majors such as engineering management, it is necessary to take course-based ideological and political education as the carrier, promote the coordinated development of professional education and ideological and political education, and form a systematized, standardized and regularized operation of ideological and political education in professional courses, enhancing the political, ideological and social responsibility of talent cultivation. As a national first-class undergraduate major construction point, we shoulder the exemplary mission of leading the development of the major and outputting outstanding talents. This means that major construction must not only be satisfied with the completeness of the knowledge system and the cutting-edge of technology, but also must give an excellent answer to the fundamental question of "for whom and what kind of people to cultivate". Therefore, taking course-based ideological and political education as the core connotation of major construction is an inevitable choice to respond to the national call and implement the "all-round, all-staff and all-process education" pattern, and is also a concentrated manifestation of the "value guidance" function of first-class majors[1].

1.1.2 Realize the internal logic of connotative development and the upgrading of talent cultivation

The national first-class undergraduate major construction sites emphasize connotative development. They require efforts to be made in integrating value shaping, professional qualities, and technical capabilities. Their ultimate output is the core carrier of high-quality engineering talents. It is necessary to cultivate outstanding talents with a sense of national responsibility, craftsmanship spirit, and engineering ethics, and promote the alignment of the curriculum system, teaching resources, and evaluation mechanism with industry needs and national strategies. It not only requires students to master solid professional technologies but also to possess a profound sense of national responsibility, a rigorous craftsmanship spirit, a social responsibility of abiding by engineering ethics, and a project management vision that is in line with international standards[2]. The traditional professional education model already has a mature system in "cultivating talents" but has shortfalls in the in-depth integration of "cultivating people"[5]. It is essential to cultivate new-era engineers who combine technical capabilities and a sense of national responsibility. Also, taking the integration of industry and education as a starting point, deepen school-enterprise cooperation, and build a "2+N" segmented training, dynamically updated curriculum system and practical platform. This enables students to form good professional ethics and social responsibility while mastering cutting-edge information technologies (such as intelligent construction, BIM, big data, etc.).

1.1.3 Urgent response to existing teaching bottlenecks

1) The “rigid embedding” of CIPE can lead to “two skins” where CIPE elements seem tag- like and out of touch with enterprise culture; embedding is often superficial[3,4].

2) Teaching methods are too homogeneous, with low student engagement; traditional theory- driven instruction leaves students passive and prevents internalization of CIPE values.

3) Incomplete practical teaching chains and insufficient collaborative education make it difficult for schools' unilateral curriculum construction to align with the demands of enterprises. The construction of ideological and political education in courses often relies on the individual efforts of professional teachers and fails to effectively form the synergy of collaborative education among multiple subjects such as ideological and political teachers, enterprise mentors, and counselors.

4) The teaching effect is difficult to measure scientifically. The traditional course evaluation method is difficult to conduct effective, dynamic and long-term assessment of ideological and political education effects such as value shaping, resulting in the inability to precisely measure and continuously improve the reform effect[10,11].

In summary, to address these issues, comprehensive reforms are needed to be implemented. Establish diversified ideological and political resource packages and course case libraries, and form school-enterprise dual-teacher and school-enterprise collaborative education teams; Establish a dynamic, three-dimensional evaluation system (a 1+1+1 model that combines student self-evaluation, enterprise mentor assessment, and school assessment), and integrate ideological and political education into the entire chain of curriculum design, teaching process, and academic evaluation. Through these reforms, we can achieve a deep integration of professional teaching quality and ideological and political education, and cultivate new era engineering management talents who have both professional capabilities and a sense of patriotism.

1.2 Goals of the Reform

Based on a deep analysis of the driving forces of the reform, this reform of ideological and political teaching in engineering management courses aims to fundamentally solve the "two skins" problem and achieve a deep integration of value guidance and professional education. Our goal is not to patch up the existing teaching system from scratch, but to carry out a systematic reshaping and upgrading.

1.2.1 Overall objectives

Build a teaching model of ideological and political education for engineering management courses with the OBE (Outcome-based Education) concept as the core, which integrates value shaping, knowledge imparting and ability development, and is operable, assessable and scalable[6]. This model will be one of the landmark achievements of the national first-class major construction point of our university, aiming to provide a set of effective "reference paradigms" and "solutions" for the construction of ideological and political education in courses of related majors in similar universities.

1.2.2 Specific goals

1) Achieve the goal of "seamless integration" and "genetic fusion" of ideological and political elements with professional knowledge and capabilities.

Completely abandon the "labeling" style of rigid grafting and promote the transformation of ideological and political elements from "physical pasting" to "chemical reaction". Specifically, it involves systematically deconstructing and precisely anchoring ideological and political elements based on the knowledge graph and competency matrix of engineering management.

2) The goal of establishing an immersive and interactive teaching method system that integrates the way into teaching and the virtue into learning.

Change the old situation where teachers one-way indoctrination and students passively accept, and build a new teaching paradigm centered on students and featuring two-way interaction between teachers and students[7]. The core is to vigorously promote modern teaching methods such as case teaching, project-based learning (PBL), scenario simulation and role-playing.

3) The goal of establishing a diverse, dynamic and measurable mechanism for evaluating the effectiveness of ideological and political education in courses.

Overcome the bottleneck of "difficulty in measuring teaching effectiveness" and change the previous evaluation methods that relied on a single final paper or subjective feelings. We will build a comprehensive evaluation system that involves multiple subjects, emphasizes both process and outcome, and combines quantitative and qualitative methods.

2 CORE IDEAS AND OVERALL DESIGN OF TEACHING REFORM

2.1 Core Ideas

One is student-centered. Teachers shift from knowledge transmitters to learning facilitators, learning designers, and feedback guides by designing learning paths around learners' needs, differentiated starting points, activeinquiry, and collaborative learning.

The second is output-oriented (OBE). Starting with clear learningboutcomes, covering the three-dimensional outputs of knowledge, ability, and attitude, curriculum objectives, teaching processes, and evaluations are all designed around outcomes, forming an evidence-based, comparable, and traceable evaluation chain.

The third is implicit education. Through potential educational influences such as campus culture, teacher-student interaction, professional ethics and social responsibility, it permeates the context outside the curriculum to shape professional qualities and patriotism. The three support each other and drive the coordinated advancement of curriculum design, teaching implementation and evaluation, ensuring the organic unity of knowledge, ability and values.

2.2 "Four-in-One" Reform Model

The four-in-one is not a simple juxtaposing, but a system that works in synergy with closed-loop feedback. Implement the requirements of ideological and political education to the learning objectives at the course and unit levels to ensure the unified output of professional knowledge with professional ethics and social responsibility[8]; Explore and integrate ideological and political teaching resources, improve case libraries, resource packages, and school-enterprise co-construction materials to form a reusableresource system; Adopt multiple strategies such as contextualization, case-driven, project-based learning, immersive teaching, and integration of online and offline to enhance students' participation and practical application ability; Establish an evaluation system that emphasizes both process-oriented and developmental aspects, with a comprehensive evaluation based on diverse evidence such as learning portfolios, outcome presentations, and enterprise/industry assessments.

3 SPECIFIC IMPLEMENTATION PATHS OF TEACHING REFORM

To ensure that the reform ideas and the overall design take root, this project has planned four clear and operational parallel paths to systematically promote ideological and political teaching in the curriculum from "likeness" to "spirit", from "part" to "whole".

3.1 Reconstruction of Teaching Objectives - from "Knowledge-Based" to "Value-Knowledge-Ability" Trinity

Reconfiguring teaching objectives is the starting point of all reforms. We must precisely translate ideological and political requirements from a macroscopic educational concept into specific and measurable teaching guidance for each class.

Take the Project Management course as an example and carry out exemplary reconstruction. In Project Management, the teaching objective will go beyond the traditional expression of "mastering the three major control methods of schedule, cost, and quality" and upgrade to the knowledge level of explaining the principles of core tools such as WBS and network planning technology; The level of being able to prepare project plans and having the comprehensive ability to deal with project risks; Through strict schedule and quality control practices, deeply understand and internalize the craftsmanship spirit and professional ethics of "quality first for a century-long project"[9]; By simulating the handling of engineering safety emergencies, establish the value level of engineering ethics and social responsibility that "life comes first, safety is more important than Mount Tai."

Through this "trinity" goal statement, ideological and political requirements are no longer an additional "label", but an inherent dimension that is seamlessly integrated with professional knowledge and ability cultivation, providing a fundamental guideline for the design of subsequent teaching content and methods.

3.2 Reengineering of Teaching Content - Building an "Ideological and Political Case Library" and a "Course-based Ideological and Political Map"

After the objective is restructured, organized and systematic teaching content is needed to support it. We are committed to elevating ideological and political elements from "scattered mining" to "systematic integration".

Building a "curriculum-based ideological and political case library" is the core carrier of content reengineering. We will organize teaching teams to systematically collect and compile two types of cases.

Positive examples, such as the Hong Kong-Zhuhai-Macao Bridge, are backed by the innovative spirit of overcoming difficulties, the craftsmanship of millimeter-level precision control, and the ecological ethics of protecting the Chinese white dolphin; Take the tender of the Lubuge Hydropower Station as an example to illustrate the spirit of the rule of law

and the spirit of contract in market competition.
Negative cautionary cases, such as an analysis of "a large bridge collapse accident", trace ethical misconduct and lack of responsibility in its design, construction or materials; Analyze the case of "a project was halted due to environmental impact assessment fraud" and emphasize the bottom line of integrity and social responsibility in engineering decisions.

3.3 Innovation in Teaching Methods - From 'Teacher's Lecture' to 'Student Experience'

No matter how good the content is, if it is taught in a dull way, the effect will be greatly reduced. The core of method innovation is to transform students from passive listeners to active perceivers and constructors.
In the Project Management course, set up a virtual project that includes the ethical dilemma of "discovering that the use of inferior materials can significantly reduce costs and is imperceptible", and students must confront and deal with this ethical dilemma while completing the project tasks and write decision reports.
Project-based teaching that involves in-depth discussions around the positive and negative cases in the ideological and political case library.
The core of these methods is to create a classroom environment of "high engagement, high interaction, high thinking", allowing students to complete the self-construction and internalization of values through personal experience and the collision of ideas.

3.4 Reform of Teaching Evaluation - From "Testing Knowledge" to "Assessing Competence"

Teaching evaluation is the baton. To ensure the effectiveness of the first three paths, a corresponding evaluation system must be established to effectively measure the effectiveness of "value shaping".
Add open-ended scenario analysis questions to the final test paper. For example, give a scenario of "tight schedule conflicting with construction safety regulations" and ask students not only to propose technical solutions but also to explain the ethical principles and value order on which their decisions are based, in order to test their intrinsic value judgment.
Significantly increase the proportion of regular grades and refine it. The quality of students' presentations in case studies, their teamwork in project-based learning, and their sense of social responsibility and professionalism in project reports will all be included in the final grades through clear scoring rules, such as the Rubric scale, guiding students to continuously focus on quality improvement throughout the learning process.
Introduce multi-faceted evaluation and require students to submit learning reflection logs after the course, highlighting their gains and thoughts in terms of values and professional qualities; In team projects, introduce peer assessment within the group to examine students' sense of fairness, teamwork spirit and responsibility; For qualities that are difficult to quantify, such as "communication skills", "ethical judgment", and "social responsibility", develop specific, graded evaluation scales to make the evaluation based on evidence and the results more objective and fair.
Through the evaluation reform, we have ultimately formed acomplete teaching closed loop of "goal guidance - content support- method implementation - evaluation feedback", driving the continuous improvement and spiral ascent of ideological and political teaching quality in engineering management major courses.

4 REFORM PRACTICE: A TEACHING CASE OF THE PROJECT MANAGEMENT COURSE

To put the aforementioned reform path into practice, we took Project Management, a core course of the National First-Class Undergraduate major construction point, as a pilot and carried out in-depth reform practice, achieving remarkable results.

4.1 Case Introduction

This reform selects the chapter "Project Risk Management" from "Project Management" as a typical teaching unit. This unit is inherently rich in ideological and political elements such as engineering ethics, social responsibility, systems thinking and a sense of responsibility, and is an ideal carrier for achieving the "value-knowledge-ability" trinity goal.

4.2 Teaching Implementation Process

We designed a three-stage coherent teaching activity of "pre-class - in-class - after-class" with the theme of "Ethical Decision-making Throughout the Process of Engineering Safety Risks".
1) Pre-class online reflection: Through the online teaching platform, two carefully prepared "risk ethics cases" were pushed to the students. One of them is a virtual scenario of "a major unknown geological hazard discovered in a metro construction section"; The second is the real industry event of the choice between cost and reliability of safety limit devices for tower cranes. Students are required to preview the basics of risk management and do preliminary thinking and online comments under the case.
2) In-class offline internalization (core 90 minutes)
Context introduction (10 minutes): The teacher begins with a warning video of a major engineering safety accident, introduces the core issue of "responsibility behind risk", and clarifies the ethical dimension of this class.
Group Inquiry and debate (35 minutes) where students engage in group discussions based on pre-class cases. For

"subway construction hazard", each group is required to play different roles, simulate an emergency plan decision-making meeting, and debate the trade-off between "the huge cost of halting work for investigation" and "the potential catastrophic consequences of unknown risks". Teachers guide students to think about the bottom line of professional ethics and social responsibility behind the decisions.

Intensive instruction and value elevation (15 minutes): The teacher returns the group's points of contention to risk management theories (such as the risk matrix, response strategies), and emphasizes that the most effective risk response is prevention, and the most fundamental prevention stems from reverence for life and a high sense of responsibility, internalizing "safety first" from a slogan into a professional belief.

3) Post-class action transfer: Students are required to submit a risk management and ethical responsibility assessment report in groups. The report requires not only technical analysis using methods such as WBS-RBS, but also a dedicated chapter on the ethical principles upheld by the group in the simulated decision-making, as well as the "excess" responsibilities and costs that the group is willing to undertake to ensure the safety of the project. To achieve the elevation from knowledge understanding to value recognition and then to behavior orientation.

4.3 Teaching Resource Support

To support the implementation of this case, we have developed a series of resources"Project Management Ideological and Political Case Collection (Risk and Ethics Special Topic)" contains more than 10 detailed positive and negative cases and teaching guides. Videos,decision-making simulation interfaces and other interactive sections are embedded in traditional PPTS. An online thematic website that gathers relevant engineering accident investigation reports, industry norms and expert interview videos for students to expand their learning.This case fully demonstrates how ideological and political education can be silently integrated into the entire process of professional teaching through a closely linked teaching design, achieving the educational effect of "nourishing things imperceptibly".

5 ANALYSIS OF THE EFFECTIVENESS OF TEACHING REFORM

5.1 Student Feedback Analysis

Through course evaluation, interviews and learning reflections, students gave high praise to the integration of ideological and political education in courses with professional teaching. In the teaching evaluation, students generally believed that the curriculum was highly consistent with the core knowledge and skills of engineering management, and the embedding of ideological and political elements strengthened professional ethics, social responsibility and the concept of the rule of law; In the interviews, students responded positively to teaching links such as"role-playing" and "situational cases", indicating that they could understand the importance of national needs and industry ethics in real engineering situations; The learning reflection reports submitted show that students' worldviews, professional identities and values have improved significantly, and they are willing to hold themselves to the standards of integrity, dedication and innovation.

5.2 Teaching Observation and Supervision Evaluation

The teaching supervision group attended classes many times and generally gave good feedback. The classroom atmosphere is lively, students are active, and teachers' guidance in case analysis, group discussions, and cross-disciplinary collaboration is significantly enhanced; The integration of information technology tools (such as BIM-related materials, digital drawing and scheduling software) into teaching has enhanced the authenticity and timeliness of teaching. The supervisory opinion also pointed out that the integration of ideological and political elements with professional knowledge is more natural, and the curriculum design emphasizes the whole process of education, but there is still room for improvement in the depth of school-enterprise collaboration and resource connection.

5.3 Analysis of Student Learning Outcomes

In terms of learning outcomes, students' project reports emphasize professional competence, risk identification,communication and collaboration, and ethical decision-making ability; In course exams, the average score for scenario analysis questions increased significantly by about 15-20 percentage points compared to before the reform, indicating that students have been able to apply knowledge comprehensively to solve practical engineering problems in complex situations. Through situational assessments of key points such as cost, schedule, quality and safety, students have a more solid grasp of the core points, and their interdisciplinary collaboration and problem-solving abilities have been significantly enhanced.

5.4 Radiating and Promoting the Results of Reform

The reform results have created replicable demonstration effects within departments, established a case library of ideological and political education in courses, a digital textbook and a system of high-quality online courses, and constructed a multi-dimensional assessment mechanism of "1+1+1", significantly improving the efficiency of resource utilization. In the intercollegiate exchanges, other institutions showed great interest in the design of ideological and political education in this course and were willing to carry out resource sharing and co-construction to promote the in-depth advancement of industry-education integration. In the future, we will continue to expand the paths of school-enterprise collaborative education, enrich teaching scenarios and case libraries, and promote the continuous improvement of the effect of all-staff, all-process and all-aspect education.

6 CONCLUSIONS AND REFLECTIONS

6.1 Main Experiences and Conclusions of the Reform

The success of this reform stems from three levels of systematic elements. First, system design and consensus building, with the goal of "whole-process education", integrating ideological and political education into the core of the major to form a unified teaching objective and evaluation orientation; Second, methodological innovation and information support: The establishment of a course-based ideological and political case library, digital teaching materials, and comprehensive assessment tools based on context has enhanced the authenticity of teaching and the comparability of assessment; Third, deep industry-education collaboration and inter-school exchanges, school-enterprise co-construction and cross-institutional resource sharing have been continuously expanded to form replicable demonstration points.

6.2 Problems and Directions for Improvement

Reform still faces challenges such as high teacher input intensity, high time cost, difficulty in quantifying some evaluation indicators, and the lack of timeliness and depth of resource connection between schools and enterprises also restricts further improvement. The next step will be to continue to improve the teacher training and incentive mechanism, build a unified data collection and analysis platform, and form a more stable school-enterprise collaboration and resource sharing mechanism; Optimize the scenario case library and assessment tools to make the indicators more operational and comparable; Drive continuous iteration at the curriculum group level, set goals, evaluate and provide feedback in stages, and improve the efficiency of resource matching and the sustainability of educational outcomes.

6.3 Implications for Teaching in Similar Specialties

This reform is highly transferable. It can be replicated in terms of positioning, building curriculum clusters, establishing contextualized teaching and case libraries, creating stable school-enterprise collaboration and resource sharing mechanisms, establishing multi-dimensional quantifiable evaluation systems, and improving teacher development support. When other majors draw on this, they should design scenarios and cases based on their own disciplinary characteristics to ensure the natural integration of ideological and political elements with professional knowledge; Establish a sustainable resource co-construction and evaluation mechanism to form a long-term mechanism for collaborative education both within and outside the school, in order to enhance the vocational orientation and social contribution of interdisciplinary teaching.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

The project was supported by Research on Theoretical Exploration and Practical Innovation in the Application-Oriented Transformation of Engineering Management Major, Project No.: 2025GJJG286.

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World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3086

PRACTICE EXPLORATION OF INDUSTRY-EDUCATION INTEGRATION AND COLLABORATIVE EDUCATION FOR ENGINEERING MANAGEMENT UNDER THE NATIONAL FIRST-CLASS PROGRAM CONSTRUCTION

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Abstract: Driven by national “First-class Undergraduate Program” initiatives and engineering accreditation, engineering management education in China must evolve from fragmented course assembly to a system-oriented approach. Addressing the common bottlenecks of weak measurability of goals, shallow school–enterprise cooperation, fragmented practice scenarios, and incomplete assessment loops, this study proposes a four-chain collaborative model—Goal Chain, Curriculum Chain, Practice Chain, and Assessment Chain—grounded in outcomes-based education (OBE). The model aligns policy and industry needs to produce a competency profile and indicator matrix, restructures curriculum clusters and resources to enable project-based learning and real-industry task embedding, builds tiered practices with dual-supervisor mentoring across campus–enterprise bases and unified digital toolchains, and implements evidence-centered assessments with rubrics, attainment thresholds, and early-warning dashboards to close the quality-improvement loop. A three-year implementation shows significant gains in students’ competencies in digital construction (BIM), contract and risk governance, process control, and collaborative communication; increased involvement of industrial mentors; faster course updates; and improved graduate employability and job fit. The results demonstrate a viable pathway of “evidence for improvement, projects for capability, collaboration for quality,” offering a replicable solution for first-class program construction in engineering management.
Keywords: Engineering management; First-class undergraduate program; Industry–education integration; Collaborative education

1 INTRODUCTION

Situated at the nexus of engineering technology and management science, the quality of talent cultivation in the engineering management major directly influences the high-quality development of infrastructure and the construction industry. Under the combined traction of emerging engineering education, first-class undergraduate program construction, and engineering education accreditation, program objectives have gradually shifted toward a composite capability framework of “strong engineering literacy, proficient in management methods, literate in digital technologies, and adept at collaborative governance.” However, practical bottlenecks persist, including macro-level and weakly measurable goal statements, shallow and fragmented industry–education collaboration, and evaluations that substitute process for outcomes. From an industry trend perspective, agendas such as whole-process engineering consulting, digital construction and BIM collaboration, green and low-carbon strategies under the dual-carbon goals, urban renewal, and improved infrastructure resilience are rapidly reshaping project organization and governance capabilities[1]. Job requirements increasingly emphasize problem framing in complex contexts, data-driven decision-making, contract and risk governance, cross-disciplinary collaboration, and integrated application of tools such as BIM, GIS, and IoT. In response, this paper—guided by the OBE philosophy and policy orientation—proposes and implements a systematic talent cultivation model of “Four-Chain Collaboration,” delivering a holistic solution of “measurable goals, restructured curriculum clusters, project-based practice, and evidence-centered evaluation.” The aim is to connect the loop of “goals–implementation–evaluation–improvement” and to provide a replicable pathway and experience for peer institutions.

2 POLICY AND THEORETICAL FOUNDATIONS: FROM BENCHMARKING TO PROFILING

At the policy level, the “Double Ten-Thousand Plan” promotes connotative development of programs; engineering education accreditation strengthens student-centeredness, outcome-orientation, and continuous improvement; and policies on industry–education integration and collaborative education transform enterprises from external supporters into co-educators. Thus, the key to first-class program construction lies in a dual drive of “standardization + differentiation”: benchmarking national and industry standards to guarantee baselines and common quality while

building a differentiated competency profile grounded in regional industrial structures and institutional strengths.
Theoretically, OBE advocates backward design from intended outcomes, decomposing graduation requirements into observable and assessable indicators and implementing them via precise mapping of course objectives and learning activities. Situated learning and project-based learning emphasize knowledge construction through authentic or quasi-authentic tasks, social collaboration, and tool use—highly consistent with the contextual and collaborative nature of engineering projects[2].

Based on interviews with housing and urban–rural development authorities, consulting firms, and construction enterprises, this study forms a competency profile for engineering management: foundational competencies include engineering cognition, digital literacy, professional ethics, and communication; core competencies include integrated control of schedule–cost–quality, contract and risk management, BIM and digital construction applications, bidding and claims; integrative competencies highlight cross-disciplinary collaboration, decision-making in complex contexts, and organizational leadership. This profile anchors the indicator points of graduation requirements and serves as the basis for curriculum cluster restructuring, practice system organization, and rubric design.

3 MODEL CONSTRUCTION AND IMPLEMENTATION PATH: SYSTEM DESIGN OF FOUR-CHAIN COLLABORATION

The “Four-Chain Collaboration” model is a closed-loop system from top-level design to teaching implementation and quality improvement: the Goal Chain as the driver, the Curriculum Chain as the carrier, the Practice Chain as the lever, and the Assessment Chain as the safeguard[3].

First, at the Goal Chain level, program objectives are translated into quantifiable graduation requirement indicator points with tiered attainment descriptors to ensure each competency is observable and measurable in instruction. By establishing a mapping among “graduation requirements—curriculum clusters—key assignments—rubrics—thresholds,” evidence sources and weightings are clarified so that objectives move from conceptual statements to direct drivers of teaching and learning activities. Technical directors and project managers from enterprises co-create the indicator library to ensure academic rigor and job authenticity, avoiding a disconnect between “on-campus standards” and “workplace competencies.”

At the Curriculum Chain level, curriculum clusters and resource systems are restructured around competency indicators to integrate knowledge, tools, and contexts. The course sequence progresses along “engineering cognition—data and digital construction—process control—contract and risk—integrated capstone,” retaining foundational platform courses such as engineering graphics, engineering economics, engineering laws and ethics, and engineering data analysis, while emphasizing professional cores such as schedule and resource optimization, engineering cost and BIM-based quantity takeoff, contract management and claims, and project management informatics. Cross-cutting content—digital construction and BIM collaboration, green construction and carbon accounting, smart site and IoT applications—is integrated, with integrative course design and the capstone project forming the culmination of competencies. Supporting resources include case libraries and datasets, BIM models and plug-ins, templates and task banks, and stratified rubric libraries, all interfaced with the LMS to enable blended and project-based organization. Real enterprise projects are structurally transformed into course tasks, with industry mentors deeply involved in course design, instruction, and evaluation. A multi-tempo class pattern of “short lecture—demo—drill—debrief—pitch” is adopted to ensure “learning for use, competitions to promote learning, and assessment to drive improvement[4].”

As the key carrier of industry–education integration, the Practice Chain emphasizes tiering, authenticity, and sustainability. On campus, foundational training combines virtual simulation and hands-on stations to ensure proficiency with tools and methods. Off campus, joint practice bases and government–industry–academia–research platforms host enterprise project tasks, where student teams produce periodic deliverables on ongoing or exemplar projects. Capstone theses align with real enterprise problems under a dual-supervisor system to advance comprehensive research and development. The project pool sources from ongoing and completed enterprise projects, public-sector open data, and competition datasets, complemented by IP and data compliance protocols to form a governance process for project selection, task decomposition, process supervision, and final acceptance. A unified digital toolchain spans BIM platforms, schedule–resource optimization, cost measurement, contract claims, and project collaboration systems, ensuring students transfer from tool practice to task embedding and from local skills to holistic solutions. Practice pathways are also aligned with academic competitions and professional certifications, building a linkage among “project—credits—honors—certification.”[5]

The Assessment Chain is evidence-centered, supporting attainment calculations and continuous improvement. For each indicator point, key assignments are designed—such as implementation plans and BIM clash detection reports, cost quantity comparisons and cost optimization reports, contract risk matrices and claim justification reports, and integrated presentations and defenses—with clear dimensions, explicit levels, and reasonable weightings to ensure comparability and reliability. At the course level, attainment is aggregated via weighted key assignments; at the program level, horizontal and vertical aggregation is realized through mapping matrices with thresholds and early-warning mechanisms. Industry mentors, faculty, and student self/peer assessors jointly participate, producing a three-tier evidence chain of “course closing reports—annual program report—improvement checklist.” Low-attainment indicator points trigger targeted measures—content updates, method adjustments, task substitution, resource supplementation, and faculty training—with effects verified in the next teaching cycle to realize a genuine closed loop.

4 PRACTICE IMPLEMENTATION AND EFFECTIVENESS ANALYSIS: FROM ROLLOUT TO OPTIMIZATION

To verify the effectiveness of the “Four-Chain Collaboration” model, the program undertook a three-academic-year effort encompassing revision of the training scheme, restructuring of curriculum clusters, upgrading of the practice system, and operation of the evaluation closed loop. In governance, a “Program Construction and Industry–Education Integration Committee” was established, comprising school leaders, program heads, enterprise representatives, and quality experts, with working groups for curriculum cluster construction, practice and project management, and evaluation and data governance[6]. Responsibilities and information flows were clarified to ensure coherent decision-making and execution. Deep collaboration agreements were signed with regional leading and emerging tech enterprises to implement “co-building courses, co-building bases, co-developing faculty, co-evaluating outcomes, co-using data,” reinforced by two-way mobility mechanisms such as enterprise mentor appointments and performance review, faculty enterprise residencies, and enterprise engineers in residence on campus—thus consolidating the organizational foundation for collaborative education[7]. In resources and funding, first-class program funds and enterprise investments were leveraged to build a BIM collaborative training center, a contract and claims simulation system, and a smart-site integrative training platform, forming a composite supply of “on-campus platforms + off-campus bases + online resources.” Teaching data standards and security compliance rules were instituted to unify the collection of key assignment scores, rubric dimension ratings, enterprise evaluations, course surveys, and graduate tracking data, and attainment dashboards were developed to inform course- and program-level improvements.

During implementation, the program’s training scheme was rebuilt based on the indicator library, clarifying course prerequisites and shared resources, defining each course’s key assignments and evaluation responsibilities, and elevating project-based learning to a core organizational method. Curriculum cluster iterations focused on modules such as “Digital Construction and BIM Collaboration,” “Engineering Cost and BIM-based Quantity Takeoff,” and “Contract Management and Risk Control,” with systematic embedding of enterprise cases and datasets[8].Classrooms employed a cadence of “short lecture + drill + debrief + pitch,” alongside flipped learning and peer assessment to enhance engagement and reflective depth[9]. The practice system set “monthly deliverables” around ongoing projects, covering model audits, quantity comparisons, schedule monitoring, and risk identification. Capstone projects addressed real enterprise problems under dual-supervisor guidance, with some outputs piloted by firms or translated into improvement proposals. In parallel, “enterprise–course bilateral workshops,” “rubric alignment bootcamps,” and “case development sprints” supported faculty growth in project-based pedagogy, rubric design, and data-informed teaching.

Effectiveness evaluation centered on student competencies, course quality, and collaboration participation, using longitudinal comparative analysis. Student learning outputs improved across five dimensions—engineering cognition, digital application, process control, contract risk, and collaborative communication—with notably higher rubric scores in digital construction applications and contract–risk identification; enterprise evaluations also reported higher recognition of teamwork and communication. In course quality, student satisfaction and study time increased, forming a “high-intensity–high-support” learning climate; faculty reported that case-driven and tiered-task strategies effectively boosted participation and deep processing, and rubric use consistency improved. For industry–education collaboration, the frequency of enterprise mentor involvement in teaching, project review, and process supervision steadily rose; enterprise suggestions for course content updates were incorporated in subsequent iterations; and the stability of the practice-base project pool and data availability improved. Longitudinal tracking indicated better employment quality within one year after graduation, with higher proportions entering whole-process consulting, BIM consulting, and technical management roles in construction firms, and employers broadly noting that graduates “ramp up quickly, are proficient with digital tools, and collaborate and communicate smoothly.”

At the same time, continuous improvements are needed. Differences in regional industrial structures and project types hinder one-size-fits-all cases and tasks; courses should adopt a “general competencies + configurable modules” structure for rapid adaptation. Some project data face compliance and confidentiality constraints; data de-identification, near-real datasets, and virtual simulation integration should be used to enhance usability. Performance assessments and multi-stakeholder participation increase workload and scoring variance; shared item banks and rubrics, centralized calibration, and AI-assisted quality control are needed to improve efficiency and consistency. Faculty capabilities in digital construction and data analysis vary; enterprise residency programs, cross-domain workshops, and a tiered TA system can help. Evidence governance requires further strengthening by embedding evidence collection standards into the teaching calendar and LMS workflows, with automated reminders and missing-item tracking to ensure accurate attainment aggregation. Overall, experience indicates that “evidence-driven improvement, project-driven capability, and collaboration-driven quality” is a feasible and scalable pathway.

5 CONCLUSION

Against the backdrop of national first-class program construction and emerging engineering initiatives, talent cultivation in engineering management must shift from “course patchwork” to “systems engineering.” The proposed “Four-Chain Collaboration” model uses the Goal Chain to pull the Curriculum Chain, carries authentic contexts through the Practice Chain, and safeguards evidence and improvement via the Assessment Chain, alleviating issues of weak measurability of goals, shallow industry–education collaboration, fragmented practice scenarios, and incomplete evaluation loops. Practice results show enhanced student competencies in digital construction, contract and risk governance, process control, and collaborative communication; more robust curriculum cluster structures and industry–education mechanisms; and normalized quality assurance operations. Future work will deepen along the lines of upgrading project data and scenario libraries, applying AI and data analytics to teaching evaluation and project practice, and refining evidence governance and educational research design, thereby improving sustainability, transferability, and replicability.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

The project was supported by Research on Theoretical Exploration and Practical Innovation in the Application-Oriented Transformation of Engineering Management Major, Project No.: 2025GJJG286.

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World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3087

HOW STUDENT-RESEARCHER METAPHORS GUIDE TECHNICAL UNDERSTANDING: AN EYE-TRACKING STUDY

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Abstract: This study investigates how research student's self-constructed conceptual metaphors influences learners' understanding of technical terms. Unlike prior work focused on expert-designed metaphors, we analyze the "PixelFolder" metaphor created by a graduate student to describe her image synthesis research work. Through controlled experiments comparing this progressive construction metaphor against traditional instructional materials, we examine how such student-generated frameworks guide learners' conceptualization of image generation. The experiment compares two groups: an experimental group learning with materials based on the "PixelFolder" progressive pixel synthesis network, and a control group using traditional pixel model materials. We utilized the Tobii Pro Spectrum 1200 eye tracker to capture visual cognitive patterns of the 30 subjects, and employed Tobii Pro Lab to analyze fixation duration and heat maps, thereby revealing the distribution of cognitive focus while students were exposed with materials with and without metaphors. Furthermore, we conducted a series of semi-structured interviews. These were designed with the particular aim of eliciting the subjects' own metaphorical interpretations of the algorithmic process of image generation. This qualitative inquiry was judiciously supplemented by a reading comprehension test, which served as a more formal instrument for gauging the extent and accuracy of their conceptual mastery. Our initial observations may be stated as follows: the data strongly suggest that students exposed to the PixelFolder model exhibited a tendency to conceptualize image generation in terms of a progressive construction process. This mental model was not merely self-reported; it found a compelling correlation in the objective eye-tracking metrics. The visual attention patterns of these subjects revealed a more structured and coherent sequence of fixations, which we interpret as the external manifestation of a systematic and logically sound cognitive pathway. We believe this work contributes a valuable empirical datum to the study of conceptual metaphor formation in complex technical domains. It is also our hope that the methodology and findings herein will provide a solid foundation for the refinement of using conceptual metaphors as pedagogical approaches in the technical communication of computer graphics.
Keywords: Deliberate metaphor; Image generation; Eye tracking; Cognitive load; Progressive construction

1 INTRODUCTION

At its core, science communication faces a fundamental challenge: turning complex, abstract concepts into mental models that ordinary people can not just grasp, but actually use [1-2]. This issue becomes most apparent in science education in recent years. Two key dimensions are stuck right at this bottleneck. First, there exists an inherent asymmetry between the bounded nature of human working memory and the potentially unbounded complexity of scientific concepts. This asymmetry creates what might be termed a structural inadequacy in traditional pedagogical approaches [2]. When instructional design simultaneously presents novel terminological elements, abstract symbolic representations, and complex procedural sequences, the system necessarily exceeds what we might call the cognitive capacity threshold of the learner. Second, traditional science communication paradigms demonstrate a significant disconnect from embodied cognition theory. Formulaic abstract expressions sever the neural connection between concepts and bodily experiences, resulting in hollow knowledge representation [3], this is contradicting with the perceptual symbol theory which supports that conceptual understanding requires activation of relevant sensorimotor systems [4].

Existing research has established two key findings to solve this bottleneck problem: first, deliberate metaphor can reconstruct conceptual representation through cross-domain mapping [5]; second, Studies utilizing eye movement trajectories have begun to unpack the temporal dynamics of metaphor comprehension, quantifying the cognitive effort and allocation of attention involved in processing metaphorical versus literal language [6]. Traditional teaching methods often focus on conveying accurate technical terminology and system descriptions, yet overlook the profound cognitive impact that the initial framework used to introduce these concepts may itself generate.

In the study of scientific communication, the theoretical framework of deliberate metaphor primarily focuses on metaphors that are actively designed to guide audience cognition. However, a phenomenon that has not been thoroughly explored is: when a novice researcher such as a graduate student spontaneously creates and uses a novel scientific metaphor to describe their own work, what is the inherent cognitive effectiveness of this singular, yet to be acknowledged metaphorical instance? Can it effectively guide readers in understanding the described work?

To tackle the above challenges, we treat metaphor comprehension not as recall, but as real-time cognitive work. Our approach is simple: if cognitive load theory defines the problem of limited working memory, then eye-tracking reveals the real-time consequences of overloading it. Specifically, we ask: when two groups of college students learn the same image generation technology in identical multimedia environments, with the sole difference being that one group receives a dynamic framework based on "progressive construction" while the other receives a referential framework based on a "static model," how will their cognitive processes and learning outcomes differ? By introducing process data from eye-tracking, we open the "cognitive black box" of how students understand complex technical concepts. This work provides the first evidence that students' spontaneous metaphor construction is itself a profound cognitive process worthy of attention in technical education.

2 LITERATURE REVIEW

The core contradiction in technical education lies in the structural tension between abstract symbolic systems and human cognitive architecture. Current research exhibits three critical disconnections: deliberate metaphor theory remains stagnant in expert-design paradigms, eye-tracking technology is confined to behavioral description, and cognitive load research fails to capture the real-time process of conceptual mapping. This review reconstructs the research framework through two theoretical connections: first, treating student metaphor creation as explicit cognitive restructuring behavior; second, utilizing eye-tracking data to capture micro-processes of conceptual mapping.

2.1 Lack of Study on Student Developed Deliberate Metaphor in Science Communication

The construction of conceptual metaphors is a cornerstone of complex knowledge acquisition. In the past years, conceptual metaphor theory and related works have established metaphorical framing as a powerful tool for knowledge representation [7-10]. Deliberate Metaphor (DM) theory provides a framework for designing conceptual mappings between source and target domains, but more recent research has claimed a “paradigm crisis” in metaphor studies [11]. Beyond expert-designed metaphors, learner-generated metaphorical frameworks have been explored from the linguistic or educational perspective, seldom from the STEM areas [11-12], although non-expert knowledge construction and related studies have revealed the unique value of learner-generated representations with metaphors. Our study focuses on student-created metaphors in technical education, while we hope the findings can be extended to other learning domains in the future.

This study investigates how multi-model materials of student generated deliberate metaphors influence the formation of the "image generation as progressive construction" understanding among university students. DM theory suggests that certain metaphors are intentionally used to guide audiences toward understanding target concepts in specific ways [13-14]. The majority study of DM has predominantly examined how experts strategically deploy metaphors to shape audience understanding, and predominantly rely on post-hoc evaluations while lacking process data, making it difficult to distinguish between strategic design and essential cognitive insights. In addition, existing research predominantly concentrates on experts' strategic use of metaphors in mature fields, paying less attention to whether a simple core conceptual framework provided by student researchers can trigger systematic cognitive restructuring in beginners' minds during the initial stages of technical learning.

Therefore, we propose shifting the research focus from "strategic design" to "cognitive alignment," employing process measurement methods such as eye-tracking to investigate whether metaphors that align with the essential structure of knowledge. We believe that even those originating from novices possess an inherent advantage in guiding cognition.

2.2 Measurement Limitations in Existing Research on Eye Tracking and Cognitive Load in Learning

Eye-tracking has mapped the topography of visual attention in education by providing real-time measurement of visual attention through fixation patterns and pupillary response. Beyond basic gaze tracking, advanced analytical methods have been explored for quantifying cognitive load and comprehension processes [15-16]. Beneath this surface, however, the cognitive engines that drive problem-solving and learning in digital assessments remain largely uncharted [17]. Current eye tracking studies remain largely descriptive by recording "where" people look without explaining "why" [18]. When learners view technical diagrams, we know their cognitive load is overloaded, but cannot identify the specific points where cognitive strategies fail. In addition, existing eye-tracking research shows a clear convergence by focusing on mature fields such as multimedia learning and problem-solving, heavily relying on classical frameworks like cognitive load theory and cognitive theory of multimedia learning. The expert-novice paradigm overlooks the unique value of student-generated metaphors.

Key evidence from eye-tracking data show that learners using self-generated metaphors show gaze patterns gradually converging from discrete conceptual points into continuous operational flows. This convergence of visual attention serves as an external signal of cognitive systems shifting from symbolic decoding to pattern recognition, marking the transition of conceptual understanding from temporary storage in working memory to procedural knowledge in long-term memory.

This study establishes new connections by upgrading eye-tracking from a tool for behavioral observation to a detector of cognitive mapping. Where traditional methods see outcomes, we see process: how visual attention allocates scarce working memory resources during conceptual mapping. This invites a shift from asking what was learned to observing how understanding is built.

In the field of metaphor studies, particularly in STEM education, there has long been a thought-provoking phenomenon: the academic community has excessively focused on expert-designed metaphors, while paying little attention to learner-generated metaphors. The limitations of this research paradigm have, to some extent, led to a "paradigm crisis" in the development of metaphor theory. Through empirical research, we found that when a graduate student used an original metaphor like "PixelFolder" to describe their image generation research, this spontaneous metaphor displayed unique advantages. It not only concretized the complex image generation process into a progressive construction process, but more importantly, this metaphorical framework was highly compatible with the learner's cognitive structure, effectively reducing cognitive load and facilitating the formation of conceptual mapping.

3 POSITIONING OF THIS STUDY

In pedagogical contexts, a well-designed DM is not intended to be an additional cognitive burden. On the contrary, its purpose is to manage and reduce total cognitive load. An effective DM acts as a scaffold that provides a pre-structured conceptual framework, thereby reducing the extraneous cognitive load that would otherwise be spent on trying to make sense of disconnected facts [19]. Traditional behavioral studies maintain ecological validity but cannot reveal online processing mechanisms. Eye tracking strikes a balance by providing millisecond-precision cognitive process metrics while preserving natural learning states.

This study extends this framework to a novel context: the spontaneous generation of a scientific metaphor by a graduate student in their research introduction. We investigate whether such a novice-created, unestablished metaphor can function with cognitive effectiveness comparable to conventional DMs, specifically in guiding readers' comprehension of the described work. By examining this phenomenon through eye-tracking, we aim to explore the potential and boundaries of the DM theory and shed light on the early life of a scientific metaphor before it gains community acceptance.

Using eye-tracking technology, we meticulously record the cognitive processes of university students as they read technical abstracts containing such student-originated metaphors. We seek to determine: even when readers are fully aware that the metaphor represents only a single student's personal understanding, can it still effectively reduce the cognitive load associated with interpreting complex technical concepts? Will their gaze patterns exhibit efficiency characteristics similar to those observed when comprehending established disciplinary metaphors?

The significance of this research lies in challenging an underlying assumption in deliberate metaphor theory: that the effectiveness of a metaphor largely depends on the sophistication of its design or the prevalence of its use.

This study reveals cognitive load with millisecond precision, directly observing cognitive processes without disrupting natural learning states. Using image generation technology as the learning context, we designed two sets of instructional materials differing only in their core conceptual expressions: the experimental group materials were organized around the progressive construction metaphor of "folder-folding-unfolding," while the control group materials used the neutral terminology of "model." Employing eye-tracking technology to capture patterns of visual attention allocation in real-time, combined with interviews and comprehension tests, we aim to reveal:

We adopt a conceptual metaphor originating from graduate research [20]. Its core maps "image generation" onto a "progressive construction" process. This metaphor serves not as decoration but as a cognitive framework: it enables learners to reason about pixel synthesis algorithms through physical intuitions of folding and unfolding. For example, when students understand image synthesis, they might conceptualize each pixel generation as a "folding" step, and when all the pixels are synthesized in a particular order, the "unfolding" of the entire image is the final result. Through interviews with the author, we extracted the internal logic of this metaphor and translated it into video materials.

The method's value lies in systematic mapping—it transforms the hierarchical structure of algorithms into operable construction steps, providing verifiable cognitive pathways for eye-tracking. Pixel Model serves as the standard baseline. “Folder” is used as the cognitive anchor: all operations execute within this architecture, analogous to physical folding requiring a two-dimensional plane. “Folding” is used as feature distillation which achieves semantic extraction through iterative compression. Each fold performs two key operations: (1) local feature aggregation which is the convolution kernel sliding, and (2) information dimension transformation which is the pooling downsampling. This essentially forms a reversible mapping from pixel space to latent space. “Unfolding” is used as distribution reconstruction which functions as a diffeomorphic mapping from latent space vectors to pixel space.

Using the “PixelFolder” conceptual metaphor framework as an experimental environment, we quantify the processing of deliberate metaphors through eye movement metrics. Our goal is to establish a complete cognitive pathway model from: Image generation involves complex tensor transformations mathematically, but its essence is a progressive structuring process. The core metaphor of PixelFolder—"folding and unfolding"—directly maps to the most fundamental human capacity for spatial reasoning. Instead of explaining matrix operations in multidimensional space, we demonstrate how to progressively refine a coarse sketch into a clear image, much like unfolding an origami creation.

4 METHOD

The development and balancing of experimental materials constituted the core of this study. Our experimental materials were grounded in interviews with the student metaphor creator and her supervisor. This data directly informed an instructional video script and visual narrative. The comprehension test was directly operationalized from the core claims of the student's associated paper (Figure 1).

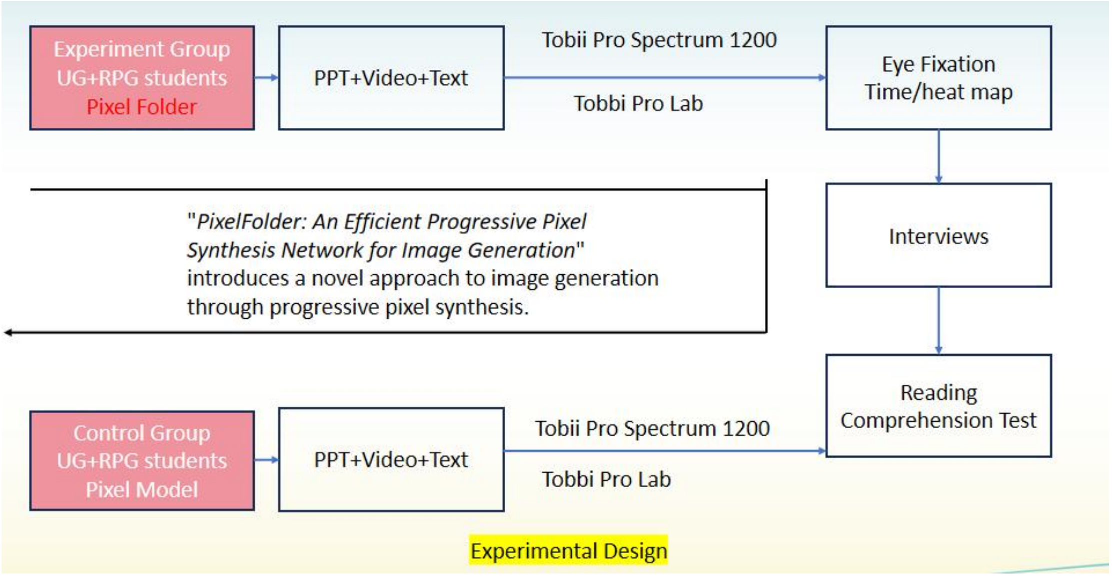

Figure 1 Experimental Design

In a between-subjects design, undergraduate and postgraduate students (N=30) were randomly assigned to learn about image generation either through a novel Progressive Pixel Synthesis model ("PixelFolder") or a standard Pixel Model. We employed a multi-method assessment triangulating high-frequency eye-tracking (Tobii Pro Spectrum 1200), semi-structured interviews, and a standardized comprehension test.

We hypothesize that an instructional model explicitly built on a progressive synthesis framework (PixelFolder) will more effectively foster the corresponding conceptual metaphor than a traditional static model (Pixel Model). This will be evidenced by: (1) more systematic visual attention patterns, (2) richer metaphorical language in verbal reports, and (3) superior performance on assessments of deep conceptual understanding.

We then performed fine-grained, within-subject matching of qualitative and quantitative data: for instance, when a student described, "I was controlling the speed of unfolding," we examined their eye-tracking data for fixation behavior on the AOI corresponding to the "learning rate" parameter. If a stable and significant correspondence between verbal descriptions and quantified behavioral patterns was observed at the group level, it would strongly confirm our core argument—that metaphors are not merely post-hoc descriptions but function as a real-time, internal cognitive operating framework that directly shapes the fundamental process of information handling.

4.1 Participants and Design

We recruited in total 30 undergraduate and postgraduate students (M_age=20.4, SD=2.1; 9 female) from a STEM oriented research university. Our sample size was determined by a prior power analysis. The analysis (G*Power 3.1, independent t-test), setting $\alpha=0.05$, power=0.80, and an effect size of $d=0.8$, indicated a requirement of N=28 participants. With our sample size exceeding that level, we acknowledged the limited sample size may be underpowered for identifying more subtle, yet meaningful, cognitive differences. All participants had normal or corrected-to-normal vision and provided informed consent. They were recruited to learn about image generation through two distinct conceptual frameworks: the progressive "PixelFolder" model and a standard “Pixel Model” with eye movements tracked, followed by a comprehension test. In addition, students' prior knowledge of computer graphics were recorded. A between-subjects t-test was used to examine the learning difference between the two groups in terms of fixation duration and scanpath pattern across predefined Areas of Interest (AOIs). This study was approved by the university's Ethics Compliance Review committee.

4.2 Stimuli and Experimental Conditions

The complexity of the two instructional modules was balanced by controlling for content duration, information density, and visual layout, and reading comprehension test. The sole manipulated variable was the conceptual model underlying the instructional content. Both groups received identical multimedia instruction (PPT, Video, Text) covering the same core concepts, duration, and instructor. The number of slides and the core information points on each slide were the same. Visual Layout such as the diagrams, color schemes, and interface design used were completely consistent.

The materials were structured around the "PixelFolder: An Efficient Progressive Pixel Synthesis Network" framework. Rather than imposing external abstractions, we have developed an epistemologically consistent learning environment that honors the natural evolution of conceptual understanding (Figure 2).

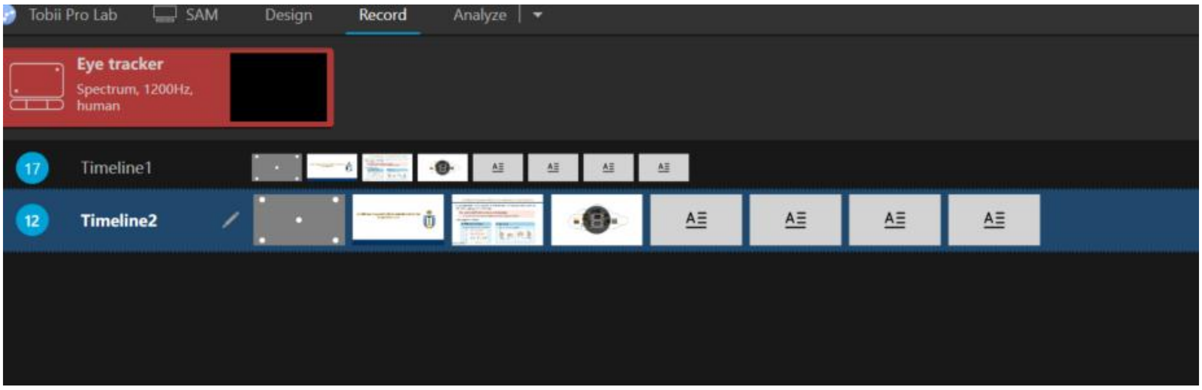

Figure 2 Tobii Pro Lab Eye Tracking Setup with Timelines

4.3 Apparatus and Measures

4.3.1 Eye-tracking
Visual cognitive processing was captured using a Tobii Pro Spectrum 1200 eye tracker at 1200 Hz sampling rate. Stimuli were presented on a 24-inch monitor. The system was calibrated for each participant using a 5-point calibration sequence until accuracy reached < 0.5° visual angle.

4.3.2 Reading comprehension test
A 20-item test assessed conceptual mastery, including multiple-choice questions on fundamentals and two open-response questions requiring explanation of the underlying process. Scoring was blind to condition.

4.4 Procedure

The experiment followed a strict protocol: (1) Consent and demographic questionnaire; (2) Eye-tracker calibration; (3) Learning phase with concurrent eye-tracking; (4) Immediate comprehension test; (5) Semi-structured interview. The entire session lasted approximately 30-40 minutes per participant.

5 RESULTS

5.1 Eye-Tracking Analysis

A mixed-design ANOVA on fixation duration, with Condition as a between-subjects factor and AOI (key algorithmic steps) as a within-subjects factor, revealed a significant interaction effect ($F(3, 180) = 5.42$, $p < .01$, $\eta p^2 = .08$). The PixelFolder group showed a more sequential and differentiated attention pattern, spending disproportionately more time on the initial "coarse sketching" AOI. Their scanpaths were 40% more likely to follow the logical, progressive order of the algorithm ($\chi^2(1) = 8.15$, $p < .01$).
We study the effect of the pixel folding/unfolding operation on the total fixation duration during visual processing. As shown in Figure 3, the total fixation duration is significantly longer in the pixel folding/unfolding group than in the pixel model group ($p = 0.0002$).

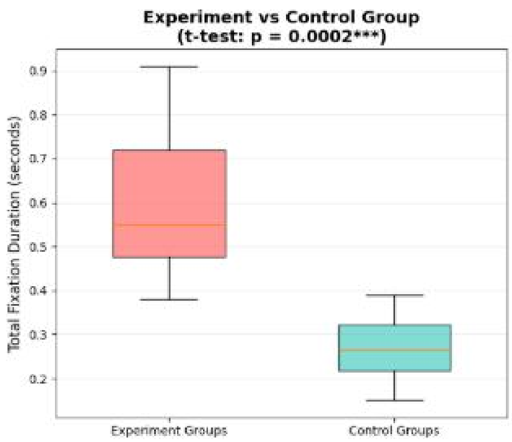

Figure 3 Comparison of Total Fixation Duration on AOI Between Experiment and Control Groups

5.2 Statistical Significance

Preliminary calculations show that the average fixation duration in the experimental group was significantly higher than that of the control group, with $p < 0.01$. Conversely, the control group displays what may be called fragmented attention—a pattern characterized by brief, scattered fixations. The majority of CG participants failed to sustain attention beyond 0.5 seconds, suggesting incomplete processing of the instructional materials. This bimodal distribution indicates that the absence of a conceptual framework led the control group to completely overlook the semantic value of these terms. Non-parametric testing of fixation durations revealed between-group differences at the $p<0.001$ level (Mann-Whitney U=value, effect size r=value). This statistical significance is reflected not only in mean differences but more importantly in the complete separation of data distributions.

Through temporal analysis of eye movements, we have for the first time observed a clear "cognitive anchoring priority" phenomenon during successful conceptual understanding. The fixation duration for core category terms (e.g., "PixelFolder") was significantly shorter than for operational terms (e.g., "folding/unfolding"), with $p < 0.01$.

5.3 Metaphorical Representation

Our analysis reveals a clear divergence: learners guided by metaphors underwent a restructuring of their cognitive process. The PixelFolder group spontaneously generated a high frequency of "progressive construction" metaphors (e.g., "building up layers," "from blurry to clear"), significantly outpacing the control group, which relied on traditional descriptions ($M = 4.2$ vs. $M = 1.8$; *p* < .001).The learners in the experimental group exhibited a clear pattern of structured coverage—their visual attention systematically moved between Areas of Interest (AOIs) in a sequence that strictly followed the logical flow of the pixel synthesis algorithm (Figure 4).

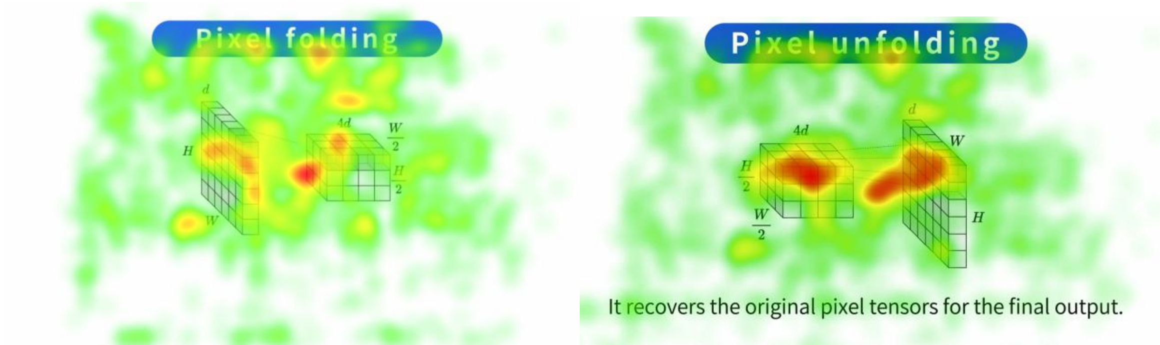

Figure 4 Heatmap of AOI in Experiment Group

The PixelFolder group achieved a higher average score on a brief comprehension check (2.1 vs. 1.7). This numerical trend, while from a limited instrument, aligns with and is driven by the more fundamental cognitive differences revealed in our primary metrics. The introduction of a metaphor provides the learner with a cognitive prior. This prior guides the formation of anticipatory attention, enabling learners to actively identify semantic relationships between concepts, in contrast to the control group's passive processing of isolated lexical features.

6 DISCUSSIONS

In this study, “folder”, “folding”, and “unfolding” serve as deliberate metaphors that illustrate their unique value in helping students understand algorithmic operations. Each term is associated with a cognitive model based on daily experience. Then, the experimental group used research student’s self-generated metaphors to assist in understanding the core concepts of algorithms. Compared to traditional receptive learning, generating metaphors helped deepen the internalization of the learning content, this approach activated learners' active thinking. The study confirms the guiding effect of conceptual frameworks on term processing: an appropriate core conceptual metaphor such as PixelFolder can direct learners' attention to related key operational terms, thereby constructing a complete knowledge system. This synergistic processing model of "concept-term" provides important insights for metaphor design in technical education. Our findings shift deliberate metaphor research from "effect verification" to "mechanism analysis," providing an empirical foundation for establishing a computationally-cognitive oriented theory of instructional design. Instead of simply having students memorize terms, it is more effective to encourage them to reconstruct and apply knowledge through the process of metaphor generation. This process enables students to not only "know the terms," but also "understand the process," providing them with stronger cognitive coherence and the ability to transfer knowledge.

In technology education, instructors face the complex challenge of transforming abstract computational concepts into cognitive models that students can not only comprehend, but effectively apply. Such concepts may involve algorithm design, data structures, machine learning principles, and so on. This paper targets educators and instructional designers in universities and training programs who are charged with developing learning materials, such as multimedia lectures or interactive modules, for students in STEM fields. Here, we discuss strategies for designing instructional metaphors that directly support the construction of accurate mental models.

The academic community needs to establish more sensitive mechanisms to promptly identify these "cognitive highlights." This understanding will drive us to reconsider the evaluation system for academic innovation, shifting from over-reliance on "post-hoc authority" toward a multidimensional evaluation that places greater emphasis on "innate rationality." In teaching technical concepts, establishing a core metaphorical framework should take precedence, followed by using this framework to guide learners' understanding of related operational concepts. This hierarchical design reduces the cognitive load required to comprehend deep learning models, while simultaneously demonstrating strong potential for knowledge transfer—its principles can be extended to other scenarios involving encapsulation, compression, and reconstruction.

7 CONCLUSIONS

This research enriches the literature concerning the real-time cognitive mechanisms through which deliberate conceptual metaphors influence technical learning. We evaluated the "progressive construction" metaphor developed by a student researcher, instantiated in the PixelFolder framework, against a traditional pixel model in a cohort of students (N=30). Using Tobii Pro Spectrum 1200 eye tracking, semi-structured interviews, and comprehension tests, we found that the metaphor-based approach led to a more systematic conceptualization of image generation, objectively quantified by more structured visual scanpaths and significantly higher test scores.

First, we reposition student metaphor creation not as a communicative tool, but as a visible manifestation of cognitive restructuring. This shifts the research focus from "strategic design" to "cognitive alignment." Second, we upgrade eye-tracking from a behavior-mapping tool to a process-tracing microscope for conceptual mapping. It allows us to see how visual attention allocates scarce working memory resources during metaphor comprehension. Third, we employ this process data to perform a fine-grained validation of Cognitive Load Theory within authentic technical learning. We move from asking if students are overloaded to diagnosing when and how effective metaphors alleviate that load.

This study reveals the profound impact of different instructional materials on the processing of conceptual metaphors through eye-tracking analysis. The processing pattern for the term "PixelFolder" shows that the experimental group's average fixation duration was significantly longer than that of the control group. However, the control group, lacking a unified conceptual framework, failed to recognize the important semantic value of these terms.

Unlike traditional research that primarily focuses on learning outcomes, we attempted to observe the learning process through eye-tracking data. Preliminary findings suggest that effective conceptual understanding may follow a progressive path of "establishing a framework first, then deepening comprehension", as a phenomenon worthy of further discussion. This work provides a new perspective for solving the paradigm crisis in metaphor research. We suggest that educators systematically incorporate learner-generated metaphors into curriculum design, as this not only strengthens cognitive outcomes but may also open up new pathways for teaching innovation. Metaphors should not merely be tools provided by experts; they should be cognitive bridges constructed by learners themselves, which is the true warmth and wisdom of education.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

This research has been funded as a Key Project of Guangzhou Education Science Planning, with grant number 202315952. In addition, it has been funded by Project of Research on HKUST(GZ) Practices 2023.

ACKNOWLDGEMENTS

The author wishes to thank all the students involved in the eye-tracking experiments. Special acknowledgement goes to Professor Yingcong Chen, Ms Jing He, and Mr Ziren Tang, who provide valuable research insights and teaching materials or help collect data. The author thanks the anonymous reviewers for their helpful comments.

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World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3088

A CORPUS-BASED COMPARATIVE ANALYSIS OF GUANGZHOU'S INTERNATIONAL IMAGE IN LOCAL AND FOREIGN MAINSTREAM MEDIA DISCOURSE

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Abstract: As an international first-tier city, Guangzhou's development and image have attracted much attention at home and abroad. Since the outbreak of the COVID-19 in 2020, Guangzhou's international image has undergone further updates and changes. This paper collects relevant media materials in mainstream media at home and abroad by forming two corpora at home and abroad, from the perspective of "self-shaping" and "other shaping" combined with Sinclair's lexical grammar theory and critical discourse analysis, to compare the changes in the international image of Guangzhou before and after the epidemic. The study shows that Guangzhou's media prefer to focus on the analysis of government policies and hope to create an international image of orderly development; Foreign media have a more multi-angle and objective description of Guangzhou's image.
Keywords: Guangzhou; Corpus; Critical discourse analysis; Sinclair lexical grammar theory

1 INTRODUCTION

Guangzhou is one of the first national historical and cultural cities, the birthplace of Cantonese culture, and the southern gateway of China to the world, the central city and hub city of the Guangdong-Hong Kong-Macao Greater Bay Area and the Pan-Pearl River Delta Economic Zone [1]. With the development of the Guangdong-Hong Kong-Macao Greater Bay Area, the development of Guangzhou's international image is particularly important as one of the core cities. Previously, the research on Guangzhou's international image has matured. However, the outbreak of the COVID-19 has not only changed the rhythm of human society, but also had a certain impact on the development of Guangzhou's international image.

In order to explore the specific changes in the construction of Guangzhou's international image before and after the COVID-19, this paper focuses on the time node of the epidemic, compares the changes in the communication of Guangzhou's international image between local and foreign mainstream media, and aims to explore the evolution process of the city's image in special periods.

2 LITERATURE REVIEW

In recent years, the exploration of Guangzhou's international image has triggered heated discussions. Many scholars have conducted in-depth analysis of Guangzhou's international image from different angles. Yao Yi analyzed Guangzhou's international image from the perspective of interviews with foreigners [2]; Zhiying Li, Weibing Li, and Deng Fei established corpora respectively by collecting reports on Guangzhou in Chinese and American media discourses. Combining semantic prosody and critical discourse analysis to interpret the different emphases on the international image of Guangzhou at home and abroad [3]; Xingguang Wang analyzed the presentation of Guangzhou's city image by exploring mainstream English media reports on Guangzhou [4].

Existing research on Guangzhou's international image has been conducted from multiple angles and aspects, but most of them focused on before the COVID-19, and the latest analysis only covers 2021. Therefore, the corpus it relies on are also relatively lagging behind. In view of this, this paper takes the COVID-19 as a key time node, selects relevant corpus from 2018-2024 to build a corpus, strives for timeliness and accuracy, and provides reference for the update of Guangzhou's international image.

3 INQUIRY METHOD

The city image is an important part of the shaping of the national image, and the construction of the city image and the national image belongs to the relationship between symbiosis and co-shaping, the individual and the whole [5]. The exploration of city image needs to combine subjective and objective perspectives. Critical discourse analysis theory not only focuses on how discourse constructs social cognition and ideology into a shared belief consensus of social groups, but also explores the dialogue relationship between reporting discourse and social and cultural changes [6]. This is in line with this paper's pursuit of exploring Guangzhou's international image. Therefore, under the guidance of critical discourse analysis theory, this paper will analyze Guangzhou's international image by collecting the discourse of local media in Guangzhou from the perspective of "self-shaping" and "other shaping". At the same time, the report discourse of foreign mainstream media on Guangzhou's image is collected, so as to analyze the construction and dissemination of

Guangzhou's external image from the perspective of "other plastic". Through the combination of subjective and objective, the changes in Guangzhou's international image are analyzed more comprehensively.

4 STUDY DESIGN

4.1 Object of Study

In order to further explore the changes in Guangzhou's international image from 2018 to 2024, this paper selected the local English version of Guangzhou's foreign propaganda media (government websites, etc.) as the local media discourse in Guangzhou. At the same time, *The Daily Telegraph, The Guardian, New York Times, Washington Post, The Times, and The Wall Street Journal* were selected as foreign mainstream media discourse. Based on this, two corpora in Guangzhou and abroad were produced as research objects.

Based on the impact of the COVID-19 on the world in 2020, this paper will divide the two corpora into three time periods: 2018-2019 (before the epidemic), 2020-2022 (during the epidemic) and 2023-2024 (after the epidemic) with 2020 and 2023 as the time nodes, aiming to explore the impact of the epidemic on the image shaping of Guangzhou's international image.

4.2 Methodology

This paper combines critical discourse analysis theory with Sinclair lexical grammar theory. Critical Discourse Analysis (CDA) refers to the theory first proposed by Roger Fowler to reveal the relationship between ideology, language, and power. Nowadays, critical discourse analysis has been widely used in media discourse and other studies to explore the identity and ideology embodied in discourse [7]. What's more, John Sinclair proposed the lexicon-grammar theory. That is, vocabulary and grammar are interdependent. A batch of real corpora screened from a large corpus show a co-selection relationship between lexicon and grammar, thereby showing their most typical or core usage paradigms and accurate meanings. Its core concept is to unify traditional grammar teaching and vocabulary teaching [8].

Based on the construction of two corpora of local and foreign mainstream media in Guangzhou, this paper uses the AntConc 3.5.9 as a tool to extract the collocations of "Guangzhou" to lock its lexical and grammatical features and then statistically collect high-frequency words to explore the rules of language expression. Combined with the social background of the epidemic, it explores how existing discourse constructs and develops Guangzhou's international image, and how Guangzhou's international image has changed under the historical promotion of the COVID-19.

5 RESULT AND DISCUSSION

5.1 Overall Situation

Table 1 shows the comparison of the search results of "Guangzhou" as the core word in the local and foreign mainstream media corpora in Guangzhou.

(1) From 2018 to 2024, most of the local media in Guangzhou involve "Municipal(662)", while the high-frequency collocation words of foreign mainstream media are "China (121)".

(2) From 2018 to 2024, the dispersion of the word "Guangzhou" in the two corpora is 0.884 and 0.857. The high dispersion of local media discourse in Guangzhou indicates that Guangzhou as the core concept has a strong correlation with the content of the report in relevant reports. On the contrary, in the reports of foreign mainstream media, the word "Guangzhou" is unevenly distributed in the text, appearing more in specific paragraphs and situations, and less specifically reporting on Guangzhou.

Table 1 Comparison of Search Results in Local and Foreign Mainstream Media Corpora in "Guangzhou" with "Guangzhou" as the Core Word

	Guangzhou local media report corpus	Foreign mainstream media report corpus
"Guangzhou" occurrence count	6361	1225
Most frequent real words paired with "Guangzhou"	Municipal(662)	China(121)
"Guangzhou" dispersion	0.884	0.857

5.2 From 2018 to 2019 (Before the Epidemic)

According to Table 2, it is the most frequent real word with the word "Guangzhou" in 2018-2019. In this part, "Guangzhou" and "Open" are selected as the core words for search. The search results are as follows.

Table 2 High-Frequency Words (Including Frequency) Classified by Collocation with the Word "Guangzhou" from 2018 to 2019

Matching notional word	Matching form

		word
Guangzhou local media report corpus	Guangzhou(88) 、 international(75) 、 source(34) 、 commission(20) 、 municipal(82)、held(41)、shows(18)、cup(21)	In(270) 、 and(218) 、 for(43)、shall(3)
Foreign mainstream media report corpus	open(24)、city(19)、southern(16)、evergrande(12)、channel(9)、shenzhen(8)、semifinals(7)	In(92)

14	2018...	.4 square kilometers, with a residential population of 14 million. In 2017,	Guangzhou'	s GDP reached RMB 2.15 trillion yuan, an increase of 8%
15	2018...	further promote international exchanges and cooperation, and increase	Guangzhou'	s global exposure and international influence, according to a
16	2018...	It also means we can choose to declare exports in	Guangzhou'	s Huadu district while exporting from Nansha or Shantou

Figure 1 Index Lines about "Guangzhou" in the 2018-2019 Guangzhou Local Media Report Corpus

Sentence 1: The events will also further promote international exchanges and cooperation, and increase Guangzhou's global exposure and international influence, according to a representative of the Guangzhou Airport Economic Zone.

As shown in Figure 1**,** judging from the search content of Guangzhou, Guangzhou Baiyun Airport hosted a world route development forum in 2018, and such a world-class event has a huge advantage for Guangzhou to promote its own aviation strength and promote Guangzhou Airport Economic Zone, which can attract more foreign attention.

What's more, a representative of the Guangzhou Airport Economic Zone said that *the events will also further promote international exchanges and cooperation, and increase Guangzhou's global exposure and international influence,* which can be seen that the preparation process of the forum also prompted Guangzhou to strengthen the management and optimization and upgrading of air routes. As a result, the successful holding of this forum is conducive to improving the understanding of Guangzhou's city image from many aspects, especially in the aviation field, and helping to shape Guangzhou's good international image.

	File	Left Context	Hit	Right Context
73	2019 ...	a training at the FIBA World Cup 2019 in	Guangzhou,	south China's Guangdong province, Sept Abudushalamu of China
74	2019 ...	a training at the FIBA World Cup 2019 in	Guangzhou,	south China's Guangdong province, Sept. 5, 2019. Li Nan (R),
75	2019 ...	a training at the FIBA World Cup 2019 in	Guangzhou,	south China's Guangdong province, Sept. 5, 2019. Li Nan (R),
76	2019 ...	a training at the FIBA World Cup 2019 in	Guangzhou,	south China's Guangdong province, Sept. 5, 2019. Zhou Qi of
77	2019 ...	a training at the FIBA World Cup 2019 in	Guangzhou,	south China's Guangdong province, Sept. 5, 2019. Zhou Qi of
78	2019 ...	a training at the FIBA World Cup 2019 in	Guangzhou,	south China's Guangdong province, Sept. 5, 2019. Zhou Qi of

Figure 2 Index Lines about "Guangzhou" in the 2018-2019 Guangzhou Local Media Report Corpus

Sentence 2: ...a training at the FlBA World Cup 2019 in Guangzhou, south China's Guangdong province, Sept Abudushalamu of China ...

In the search for Guangzhou in Figure 2 and one of the the reports shown in Sentence 2, Guangzhou has hosted the FIBA World Cup in 2019(Sentence 2), and the media has reported a lot on it(Figure 2), taking this opportunity to add more iconic keywords to Guangzhou's international image. In addition, being able to host world-class events also proves the comprehensive strength of the city of Guangzhou, allowing more people to learn about Guangzhou, a developed and super first-tier city, which is conducive to shaping Guangzhou's domestic and international city image.

	Left Context	Hit	Right Context
1	Open, early rounds; WTA: Japan Women's Open and Guangzhou	Open,	early rounds » Tennis Channel 10:30 p.m. WTA: Japan Women'
2	a.m. WTA: Korea Open, Pan Pacific Open and Guangzhou	Open,	early rounds » Tennis Channel Noon ATP: Moselle Open, early
3	p.m. WTA: Korea Open, Pan Pacific Open and Guangzhou	Open,	early rounds » Tennis Channel <Chef Guo serves an emperor'
4	Channel 10:30 p.m. WTA: Japan Women's Open and Korea	Open,	early rounds; Guangzhou Open, quarterfinals » Tennis Channel
5	quarterfinals » Tennis Channel 4 a.m. (Wed.) WTA: Japan Women's	Open,	early rounds; Guangzhou Open, quarterfinals » Tennis Channel
6	Osasuna » beIN Sports TENNIS 6 a.m. WTA: Japan Women's	Open,	semifinals; Guangzhou Open, semifinals » Tennis Channel 7 a.m

Figure 3 Index Lines about "Open" in 2018-2019 Foreign Mainstream Media Report Corpus

Sentence 3: ...WTA: Japan Women's Open, semifinals; Guangzhou Open, semifinals » Tennis Channel...

As shown in Figure 3, during 2018-2019, most foreign reports on Guangzhou tended to focus on various international events held there (*WTA: Japan Women's Open, semifinals; Guangzhou Open, semifinals » Tennis Channel*, etc.). It shows that Guangzhou, as an international city, has the ability to host world-class events, and it is also international recognition of Guangzhou's economy, infrastructure, and urban management levels.

5.3 From 2020 to 2022 (During the Epidemic)

According to Table 3, it is the most frequent real word with the word "Guangzhou" in 2020-2022. In this part, "Bureau", "Municipal", "Southern" and "China" are selected as the core words for search. The search results are as follows.

Table 3 High-Frequency Words (Including Frequency) Classified by Collocation with the Word "Guangzhou" from 2020 to 2022

	Matching notional word	Matching form word
Guangzhou local media report corpus	Municipal(732)、Bureau(364)、intermediate(205)、source(278)、update(275)、resources(200)、planning(125)	In(1456)、the(2110)、shall(107)
Foreign mainstream media report corpus	China(159)、Southern(147)、city(144)、evergrande(48)、shanghai(40)、shenzhen(32)、hub(23)、metropolis(18)、	In(601)

	File	Left Context	Hit	Right Context
10	2020-...	standardized and transparent. Notice from Guangzhou Municipal	Bureau	of Planning and Natural Resources on Issuing Rules for "Self-Retriev
11	2020-...	(trial)" (SGHZYZ [2020] No. 1) Notice from Guangzhou Municipal	Bureau	of Planning and Natural Resources on Further Improving Work Relat
12	2020-...	stral Maps (SGHZYZ [2020] No.7) Notice of Guangzhou Municipal	Bureau	of Planning and Natural Resources and the Guangzhou Intermediate
13	2020-...	aints, proposals and enquiries. Notice from Guangzhou Municipal	Bureau	of Planning and Natural Resources and Guangzhou Municipal Gove
14	2020-...	iat public account or by logging on to the "Guangzhou Municipal	Bureau	of Planning and Natural Resources" government services website at
15	2020-...	d production of raw materials as soon as possible. (Led by District	Bureau	of Science, Industry & Information Technology) Enterprises designat
16	2020-...	is and coordinated operations of industrial chains. (Led by District	Bureau	of Science, Industry & Information Technology) 6. Strengthening un
17	2020-...	players. (Led by District Development and Reform Bureau; District	Bureau	of Science, Industry & Information Technology; District Bureau of H

Figure 4 Index Lines about "Bureau" in the 2020-2022 Guangzhou Local Media Report Corpus

Sentence 4: ...Notice from Guangzhou Municipal Bureau of Planning and Natural Resources on Further Improving Work...

From the Bureau's index results in Figure 4 and the sentence 4, it can be found that after the outbreak of the COVID-19 in 2020, the work focus and direction of public activities of relevant government departments(like *Guangzhou Municipal Bureau of Planning and Natural Resources*) have undergone a significant shift. From the previous focus on infrastructure construction, it has gradually shifted to sustainable development fields such as green development and technological development, and the frequency of mentioning and promotion of related topics has increased significantly. This is inseparable from the convening of the Fifth Plenary Session of the 19th CPC Central Committee in 2020. At this meeting, the CCP proposed that future development should be carried out with the theme of promoting high-quality development. Since then, Guangzhou has closely followed the instructions of the Central Committee, which shows that Guangzhou, as a super first-tier city in China, has keen and decisive actions in the wave of development of the times.

	Left Context	Hit	Right Context
1	vice. Guangzhou Municipal Development and Reform Commission, Guangzhou	Municipal	Planning and Natural Resources Bureau, Guangzhou Mu
2	ngzhou Municipal Housing and Urban-Rural Development Bureau, Guangzhou	Municipal	Planning and Natural Resources Bureau, Guangzhou Mu
3	or the approval and filing of environmental impact assessment. Guangzhou	Municipal	Planning and Natural Resources Bureau, Water Authorit
4	ngzhou Municipal Housing and Urban-Rural Development Bureau, Guangzhou	Municipal	Planning and Natural Resources Bureau, Guangzhou Mu
5	0 m. Guangzhou Municipal Development and Reform Commission, Guangzhou	Municipal	Planning and Natural Resources Bureau, Guangzhou Mu
6	The registration fee and print cost shall be exempted. Guangzhou	Municipal	Planning and Natural Resources Bureau, Guangzhou Mu

Figure 5 Index Lines about "Municipal" in the 2020-2022 Guangzhou Local Media Report Corpus

Sentence 5: ...Guangzhou Municipal Development and Reform Commission, Guangzhou Municipal Planning and Natural Resources Bureau, Guangzhou Municipal Housing and Urban-Rural Development Bureau, Guangzhou Municipal Government Affairs...

As shown in Figure 5, it was found that government agencies related to grassroots society and people's livelihood, such as *Guangzhou Municipal Development and Reform Commission, Guangzhou Municipal Planning and Natural Resources Bureau, Guangzhou Municipal Housing and Urban-Rural Development Bureau, Guangzhou Municipal Government Affairs*, appeared many times from 2020 to 2022. It can be seen that the COVID-19 has been a huge impact and test for Guangzhou in recent years. It has also forced Guangzhou to be more careful and careful in the governance of public health, social security, finance and taxation. By reforming the old system and promulgating various new policies, it has effectively helped Guangzhou gain a good reputation in all areas, making the entire city image more down-to-earth, sincere, and always practicing the concept of serving the people.

	Left Context	Hit	Right Context
1	are cramped, unnatural living conditions. In 2016, a mall in the	southern	city of Guangzhou drew international criticism for housing bears,
2	three weeks and to undergo repeated testing. Authorities from the	southern	city of Guangzhou reported one case of the omicron
3	Post's analysis. Video posted by one father in the	southern	city of Guangzhou shows weary family members waiting with
4	auto maker. Mr. Zheng resigned from his job in the	southern	city of Guangzhou late last year. He had planned
5	these diplomats' planned return. The U.S. Consulate in the	southern	city of Guangzhou has long served as a hub

Figure 6 Index Lines about "Southern" in 2020-2022 Foreign Mainstream Media Report Corpus

Sentence 6: ...Authorities from the southern city of Guangzhou reported one case of the omicron variant Tuesday...he had completed two weeks of quarantine in dedicated facilities in Shanghai and was allowed to fly to Guangzhou on Saturday...

According to Figure 6, during the 2020-2022 global epidemic, foreign media reports on Guangzhou have increased. Sentence 6 particularly shows that foreign media has reported in detail on the methods and results of Guangzhou's handling of new crown cases. On the one hand, it reflects Guangzhou's important status in the world as a first-tier city. On the other hand, it also reflects that Guangzhou, as one of the cities where China communicates with the world, has deeply attracted the attention of the international community for its health and safety. In addition, matching southern with Guangzhou can reflect the accuracy of geographical location and reflect the rigor of foreign media reports.

	Left Context	Hit	Right Context
1	Beijing grounded the plane in 2019. The 737 MAX jet flew to	China'	s southern city of Guangzhou from Ulaanbaatar, according to
2	as violent clashes broke out between residents and police in	China'	s southern city of Guangzhou in the latest protests
3	Times Violent clashes broke out between residents and police in	China'	s southern city of Guangzhou last night in the
4	mage A housing complex being developed by Evergrande in Guangzhou,	China'	s southern Guangdong province.Credit...Noel Celis/Agence Fra
5	the holding area of the Guangzhou Baiyun International Airport in	China'	s southern Guangdong province, on Monday.Credit...Noel Celi
6	effects if officials can't control the fast-spreading virus.	China'	s southern metropolis of Guangzhou tested 1.4 million people
7	to suspend some flights out of Guangzhou, the capital of	China'	s southern province of Guangdong, for 24 hours. She said

Figure 7 Index Lines about "China" in 2020-2022 Foreign Mainstream Media Report Corpus

Sentence 7: ...China's southern metropolis of Guangzhou tested 1.4 million people for Covid-19 Thursday and canceled several flights after some airport staff tested positive.

As the searching result in Figure 7, it can be seen that during the COVID-19(2020-2022), Guangzhou's handling plan for the epidemic has attracted much attention from the outside world. The figure "*1.4 million*" from Sentence 7 can highly reflects Guangzhou's strong organizational coordination ability and courage in the face of heavy epidemic prevention work.

5.4 From 2023 To 2024 (After the Epidemic)

According to Table 4, it is the most frequent real word with the word "Guangzhou" in 2020-2022. In this part, "Railway" and "Southern" are selected as the core words for search. The search results are as follows.

Table 4 High-Frequency Words (including Frequency) Classified by Collocation with the Word Guangzhou from 2023 to 2024

	Matching notional word	Matching form word
Guangzhou local media report corpus	railway(423)、district(423)、source(396)、update(382)、station(336)、south(249)、metro(200)、baiyun(199)	In(1956)
Foreign mainstream media report corpus	China(105)、southern(65)、city(57)、shenzhen(25)、Friday(19)、hub(12)、automobile(10)、metropolis(9)	In(263)

	Left Context	Hit	Right Context
1	Upon completion, people will be able to travel from Pazhou	Railway	Station to Guangzhou South Railway Station in 10 minutes, Baiyun
2	w takes just 73 minutes and 70 minutes, respectively, from Shanwei	Railway	Station to Guangzhou East Railway Station and Shenzhen North
3	minutes at the fastest speed to travel from Shantou South	Railway	Station to Guangzhou East Railway Station and Shenzhen North
4	increase by 4.2 percent. The fastest travel time from Beijing West	Railway	Station to Guangzhou South Railway Station will be 7 hours 16
5	Railway Station will be 7 hours 16 minutes, and that from Wuhan	Railway	Station to Guangzhou South Railway Station will be 3 hours 17

Figure 8 Index Lines about “Railway” in the 2023-2024 Guangzhou Local Media Report Corpus

Sentence 8: ...people will be able to travel from Pazhou Railway Station to Guangzhou South Railway Station in 10 minutes, Baiyun Airport in 20 minutes, as well as Hong Kong and Macao in two hours by boat.

Judging from the search for the word “Railway” in Figure 8 and the Sentence 8, it can be found that people can *travel from Pazhou Railway Station to Guangzhou South Railway Station in 10 minutes, Baiyun Airport in 20 minutes, as well as Hong Kong and Macao in two hours by boat.* It can prove that in the two years after the end of the COVID-19, Guangzhou has focused on the production and life of various districts, especially railways and stations, which shows that Guangzhou has taken a series of measures to re-produce and live after the epidemic. Through the development of railways, Guangzhou can enhance the communication with surrounding areas, and strive to mobilize the vitality of the city, demonstrating the strong vitality and positive attitude of Guangzhou as an international city.

		Left Context	Hit	Right Context
1	...	Two surgeons at Sun Yat-Sen Memorial Hospital in the	southern	city of Guangzhou were diagnosed with cancer in June
2	...	sticker price, a sales representative at a dealership in the	southern	city of Guangzhou said, saying they sold out of
3	...	Mr. Xu went into hiding. He was apprehended in the	southern	city of Guangzhou in February of 2020, days after he
4	...	scrape by. A 38-year-old man petitioned courts in the	southern	city of Guangzhou to raise his monthly allowance to 12,00(

Figure 9 Index Lines about “Southern” in 2023-2024 Foreign Mainstream Media Report Corpus

Sentence 9: ...a sales representative at a dealership in the southern city of Guangzhou said, saying they sold out of already made cars and were now taking orders.

According to Figure 9 and the Sentence 9, it can be seen that in order to stimulate consumption, major enterprises have chosen to lower commodity prices after the epidemic, and the results have been remarkable(*...they sold out of already made cars and were now taking orders*). It can prove the impact of the epidemic on China’s economy and the effectiveness of market reform.

		Left Context	Hit	Right Context
1	...	considered China’s top four real-estate markets: Shanghai, Beijing,	Shenzhen	and Guangzhou. All recorded population declines in 2022
2	...	launched robotaxi services in Chinese cities including Beijing, Shanghai,	Shenzhen	and Guangzhou. Last August, it said it would team
3	...	is home to the major cities of Guangzhou, Dongguan and	Shenzhen,	and Guangdong province as a whole is the most
4	...	to allow trial runs of robotaxis without safety operators. Beijing,	Shenzhen	and Guangzhou have all started charging fees for the

Figure 10 Index Lines about “Shenzhen” in 2023-2024 Foreign Mainstream Media Report Corpus

Sentence 10: ... top four real-estate markets: Shanghai, Beijing, Shenzhen and Guangzhou.

Through the search of the 2023-2024 corpus in Figure 10, it can be found that foreign reports on Guangzhou after the COVID-19 often appear together with cities such as Beijing and Shenzhen(*...top four real-estate markets: Shanghai, Beijing, Shenzhen and Guangzhou.*). It shows that Guangzhou, like Beijing and Shenzhen, has a certain influence in the world. At the same time, Guangzhou, as a super-first-tier city at the forefront of domestic development, has deeply attracted the attention of the world in its politics, culture, science and technology, and commerce.

6 CONCLUTION

Through the matching and the search of “Guangzhou”, it can be found that in the reports about Guangzhou’s image, the local media in Guangzhou mostly focus on government-related government services; Foreign media mainly focus on private livelihood interviews, corporate dynamics, and various events.

However, there are still different focuses between Guangzhou media and foreign media in reporting on the image of Guangzhou. When it comes to Guangzhou’s city image, Guangzhou’s local media is committed to building Guangzhou into a comprehensive city that keeps pace with the times, fast and technological, and is an image of active external exchanges and self-development. Most of the foreign media’s image of Guangzhou focuses on one of China’s four major cities and a city with developed commerce, and the coverage of Guangzhou is relatively objective. In addition, judging from a large number of reports on world-class events, foreign media generally recognize Guangzhou’s status as an international city.

Guangzhou's international image has different characteristics in the pen of foreign and domestic media, serving different purposes of the media. Guangzhou hopes to "self-shape" the image of a city that is down-to-earth for the people and wholeheartedly developing through the discourse of the media. Foreign media have opened up another side of Guangzhou's international image for us from the perspective of "other plastics" - China's international city with developed medical care and prosperous commerce.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

The 14th Five-Year Plan Project of Guangzhou Municipal Philosophy and Social Science, "Research on the Media Construction and Communication of Guangzhou's International Image" (Project No. 2023GZGJ230); National Innovative Training Project for Undergraduates of South China Agricultural University, "Corpus-Based Study on Media Construction of Guangzhou's International Image" (Project No. 202410564042); The 14th Five-Year Plan Project of Guangzhou Municipal Philosophy and Social Science, "A Corpus-based Study on the Construction of Guangzhou's International Image in African Mainstream Media" (Project No. 2023GZGJ232).

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World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3089

GENERATIVE TRANSFORMATION OF EDUCATIONAL PARADIGMS AND LEARNING RECONSTRUCTION IN THE AI ERA

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Abstract: The widespread application of artificial intelligence (AI) is profoundly transforming traditional educational practices. While conventional education centers on knowledge transmission and standardized assessment, AI enables dynamic knowledge generation and shifts the learning subject from isolated individuals to a collaborative process involving teachers, peers, and intelligent systems. This results in a generative shift in educational paradigms and the reconstruction of learning. Through theoretical analysis and case studies, this study explores three key questions: the drivers of the generative shift in educational paradigms, the mechanisms of learning reconstruction, and their interrelations. It aims to uncover the ontological changes in education in the AI era, offering new perspectives for theoretical innovation and practical optimization in education.
Keywords: Artificial intelligenc; Educational paradigms; Learning reconstruction; Generative shift; Meaning generation

1 INTRODUCTION

The widespread application of generative artificial intelligence in education is reconstructing the traditional paradigm characterized by “teacher-centered instruction, unidirectional knowledge transmission, and standardized assessment.” Education is shifting its core mission from mere knowledge reproduction to co-constructed meaning generation driven collaboratively by teachers, students, and intelligent systems. The locus of learning is being reconfigured from isolated individuals to a distributed cognitive network comprising human and artificial agents, thereby propelling a generative paradigm shift in education and necessitating a systematic reconstruction of learning processes. While prior scholarship has examined adaptive algorithms, AI-supported instructional models, and ethical concerns, few studies have systematically investigated—from an ontological perspective—the following questions: What drives the generative paradigm shift? How does learning reconstruction unfold across cognitive, relational, and evaluative dimensions? And what is the interplay between these two transformations?
This study addresses three interrelated research questions:
1. The techno-cognitive-societal mechanisms driving the generative paradigm shift;
2. The multidimensional pathways and manifestations of learning reconstruction;
3. The interaction logic between paradigm shift and learning reconstruction.

2 THE TECHNO-COGNITIVE-SOCIETAL MECHANISMS DRIVING THE GENERATIVE PARADIGM SHIFT

The widespread application of generative artificial intelligence (AI) in education is driving a paradigm shift in education across three dimensions—technological, cognitive, and social. Notably, this transformation is not the isolated effect of a single force but the result of multiple mechanisms that interpenetrate, cyclically reinforce, and continuously evolve, exhibiting systemic characteristics.
At the technological level, the breakthrough of generative AI lies in its shift from “knowledge retrieval” to “co-creation of meaning.” Traditional educational technologies focus on achieving learners’ knowledge consolidation through content reproduction and practice management. In contrast, generative models, leveraging large-scale pre-training, contextual understanding, and multimodal generation capabilities, can dynamically produce diverse texts, images, code, problem solutions, or even complete learning paths based on learners’ linguistic inputs, emotional states, cognitive levels, and specific goals [1]. This shifts learning from passive reception to active exploration. For instance, in a history course, when students investigate historical events, generative systems not only provide factual statements but also generate narratives from different perspectives, hypothetical deductions, or visualized timelines. This technological leap—from “preset content” to “on-demand generation” and from “unidirectional output” to “bidirectional interaction”—not only greatly enriches the expressive forms of instructional resources but also transforms the classroom into an open, continuously growing space of meaning. In essence, the widespread application of generative AI in education provides an indispensable material foundation and operational feasibility for shifting the educational paradigm from knowledge transmission to collaborative construction.
At the cognitive level, the widespread application of generative AI is reshaping learning from “individual memorization”

to "distributed construction." Traditional education treats knowledge as an external, stable object, with learning viewed as a process of internalization and reproduction through memory, comprehension, and application. However, with the intervention of generative AI, cognitive activities form a dynamic division of labor and collaborative construction between humans and machines: for students, repeated prompt design and feedback iteration gradually clarify ambiguous concepts and build personal understanding; for teachers, the role shifts from the sole source of knowledge and final arbiter to a designer of learning processes, coordinator of dialogues, and provider of cognitive scaffolding [2]. Thus, the two complement each other, jointly constituting a new form of "extended cognition." In this process, knowledge is no longer hoarded in individual minds but emerges within an interactive network of continuous dialogue, trial-and-error, adjustment, and re-expression, rendering learning an open, iterative, and collectively participatory generative process.

At the social level, the changes induced by the application of generative AI technology trigger multidimensional transformations and rebalancing in sociocultural life. On one hand, generative AI significantly lowers the barriers and costs to accessing high-quality educational resources: students in remote areas can engage in natural-language dialogues with world-class curricula, learners with language barriers can receive real-time translation and explication support, and disabled learners can benefit from highly adaptive interfaces, thereby bridging educational gaps across regions and social strata to some extent. On the other hand, traditional assessment systems premised on "independent completion" struggle to measure the weights of individual contributions versus systemic support; the "omniscient" image of AI undermines teacher–student relationships originally built on unidirectional knowledge transmission. These issues pertain to educational equity and academic integrity [3]. Currently, many schools are addressing these challenges by revising assignment guidelines, developing content provenance tools, and enhancing teachers' AI literacy. Notably, these social reflections, norms, and practices in turn profoundly shape the priorities and design philosophies of technological development—for example, by demanding higher model explainability, traceable creation processes, and mechanisms for bias detection and correction—thus forming external constraints and internal drivers for technological evolution.

Of particular importance is that the technological, cognitive, and social dimensions are not simply parallel or sequentially progressive but constitute a dynamically nested, cyclically feedback-driven, and self-reinforcing system. For example, the trial use of a generative writing tool in the classroom (technological level) may trigger students' cognitive confusion about "originality" and "authorship" (cognitive level), thereby prompting the school to issue "Interim Regulations on the Management of AI-Assisted Learning" (social level). These regulations, in turn, require developers to embed "creation process recording" and "contribution attribution" functions in the system (returning to the technological level). This closed loop not only exemplifies the systemic nature of the transformation but also reveals its historical character—each cycle accumulates, adjusts, and deepens upon the previous one. It is precisely within this ongoing tension that the generative paradigm of education gradually takes shape, exhibiting structural features distinct from traditional paradigms: from closed to open, from unidirectional to co-creative, from individual to networked, and from reproductive to generative.

3 THE MULTIDIMENSIONAL PATHWAYS AND MANIFESTATIONS OF LEARNING RECONSTRUCTION

Learning reconstruction represents a core feature of the generative teaching paradigm. It involves the systematic reconfiguration of learning along the cognitive, relational, and evaluative dimensions, transforming the process from isolated, static knowledge possession to a dynamic, interactive network of meaning generation.

In the cognitive dimension, reconstruction follows a path from "individual internalization" to "human-AI distributed construction." Generative artificial intelligence, through real-time feedback, prompt iteration, and multimodal expression, transforms students' initial ideas into testable and expandable cognitive artifacts. For instance, when a student inputs a vague hypothesis, the system can generate logical chains, counterexamples, visualizations, or cross-disciplinary associations, thereby externalizing abstract thinking into operable and shareable dialogic objects. This externalization mechanism not only significantly reduces individual cognitive load but also renders the thinking process itself an observable, intervenable, and optimizable shared resource[4]. Consequently, learning evolves from "memory reproduction" into an iterative cycle of "trial-negotiation-refinement-reexpression," embodying an extension and deepening of connectivism within a human-AI symbiotic context[2]. At the same time, cognitive reconstruction emphasizes the openness of the generative process: rather than providing standard answers, AI serves as a "cognitive amplifier" to stimulate diverse pathways, enabling students to select, critique, and integrate multiple system-generated options, thereby fostering metacognitive abilities and creative thinking.

In the relational dimension, learning reconstruction manifests as a shift from "hierarchical dependence" to "networked collaboration" in role repositioning and interaction restructuring. Teachers transition from knowledge authorities and directive issuers to "meta-designers" and "dialogue coordinators" within the learning community, tasked with crafting challenging interactive tasks, modulating the depth of human-AI dialogue, and ensuring the integration of humanistic values and ethical principles. Students move from passive recipients to active questioners, peer collaborators, and co-producers of meaning. Artificial intelligence, in turn, embeds itself in the relational network as a "cognitive partner," offering immediate responses, contextual adaptation, and process documentation without supplanting human emotional connection, empathetic understanding, or moral judgment. The emergence of this multi-agent relational web extends the learning field from the physical classroom to a distributed, dynamically reconfigurable ecosystem spanning time and space[5]. Teacher-student relationships, mediated by technology, undergo a profound transformation from “command-obedience” to “co-creation-mutual trust-shared responsibility,” elevating relationality to an ontological foundation of meaning generation rather than a mere adjunct. Notably, relational reconstruction underscores trust and transparency: only when teachers and students clearly understand AI’s generative logic, data boundaries, and potential biases can collaboration avoid risks of alienation and truly empower the learning community.

In the evaluative dimension, the reconstruction pathway centers on a paradigm shift from “standardized summative measurement” to “process-oriented generative multi-source assessment.” Traditional modes relying on uniform examinations and single scores to gauge knowledge mastery fail to capture the distribution of contributions, process value, and individual growth in human-AI collaboration. Evaluation must therefore pivot toward integrated multi-source data and dynamic feedback, encompassing interaction logs, prompt evolution trajectories, contribution annotations, reflective narratives, and peer reviews. For example, the system can automatically record the number of dialogue iterations between student and AI, revision magnitudes, proportions of original input, and critical decision nodes, forming a visualized “learning footprint” as a quantitative foundation, supplemented by teachers’ qualitative judgments, students’ self-reflective reports, and group mutual evaluations [6]. Such evaluation ceases to function as a terminal verdict or external adjudication; instead, it becomes an embedded, continuous feedback mechanism that drives students to refine generative pathways, enables teachers to adjust intervention strategies, and supplies diagnostic and optimization cues for the entire learning network.

It is worth noting that the three-dimensional reconstruction does not unfold in parallel but rather in mutually embedded, co-evolving patterns: cognitive externalization relies on the trust and support of relational networks, relational collaboration requires the fair guidance and incentive alignment of evaluative mechanisms, and the richness and timeliness of evaluative data, in turn, enhance the depth and breadth of cognitive iteration[7]. This closed loop endows learning reconstruction with holistic, generative, and dynamic characteristics.

4 THE INTERACTION LOGIC BETWEEN PARADIGM SHIFT AND LEARNING RECONSTRUCTION

The author contends that the relationship between the educational paradigm shift and learning reconstruction is neither a unidirectional causal sequence nor a temporal order, but rather a concrete manifestation of a bidirectional, cyclically emergent interaction logic. This logic is driven by techno-cognitive-societal mechanisms and continuously feeds back within the three-dimensional reconstruction of learning, thereby progressively deepening the structural characteristics of the generative educational paradigm. Specifically, the paradigm shift initiates the possibilities for learning reconstruction through technological empowerment and cognitive externalization: the real-time generative capabilities of artificial intelligence dismantle the closure of traditional knowledge transmission, shifting the cognitive dimension from individual memorization to distributed negotiation, the relational dimension from hierarchical dependence to networked co-creation, and the evaluative dimension from summative measurement to process-oriented feedback, thus infusing the learning process with generative, open, and ecological qualities. Concurrently, the practical unfolding of learning reconstruction reciprocally consolidates and expands the boundaries of the paradigm—emergent diverse meaning pathways in cognitive iteration demand greater interpretability and adaptability from technological models, trust-building in relational networks propels the formulation of policy norms and ethical frameworks, and the dynamic accumulation of evaluative data provides empirical foundations for algorithmic optimization and pedagogical intervention, forming a closed-loop feedback from micro-level learning events to macro-level paradigm evolution [8].

For instance, in a project-based learning activity supported by generative artificial intelligence, students collaboratively generate research proposals with the system (manifestation of cognitive reconstruction), teachers guide critical reflection through relational dialogue (relational reconstruction), and multi-source assessment is ultimately conducted based on process logs and contribution visualizations (evaluative reconstruction). This complete cycle not only validates the operational feasibility of the shift from “transmission” to “co-construction” but also, through data reflux, prompts developers to incorporate “authorship tracing” functionality, thereby further strengthening the technological foundation of the paradigm. The deeper mechanism of this interaction logic lies in emergence and self-organization: the paradigm shift provides structural loosening and resource inputs for learning reconstruction, while learning reconstruction catalyzes the paradigm’s qualitative leap from quantitative accumulation through the cumulative effects of distributed practices, collectively forming a self-reinforcing, dynamically balanced evolutionary system.

It is precisely within this continuous interaction that the generative educational paradigm transitions from technological possibility to educational reality, exhibiting ontological characteristics distinct from the traditional paradigm: learning is no longer the reproduction of knowledge but the ongoing generation, negotiation, and regeneration of meaning within human-AI networks. This interaction logic not only reveals the systemic dynamics of transformation but also offers an operable theoretical framework for educational practice, emphasizing that in designing generative learning environments, technological iteration, relational governance, and evaluative innovation must be advanced synchronously to ensure the co-evolution of paradigm shift and learning reconstruction.

5 CONCLUSION

This study, from an ontological perspective, systematically addresses three interrelated research questions and reveals the generative transformation of the educational paradigm in the age of artificial intelligence (AI). First, the paradigm shift is not a linear consequence of technological advancement but an emergent outcome of the intertwined interactions among technological, cognitive, and social mechanisms. Generative AI functions both as an enabler and a catalyst, breaking the closure of traditional knowledge transmission and providing the material foundation for the co-construction of meaning. Second, the reconstruction of learning unfolds along three dimensions—cognition, relations, and evaluation—signifying a shift from individual internalization to human–AI distributed construction, from hierarchical dependency to networked collaboration, and from summative judgment to process-oriented, generative assessment. Together, these dimensions constitute a dynamic and interactive network of meaning generation. Third, the interaction between paradigm transformation and learning reconstruction is not unidirectional or sequential but represents a bidirectional, recursive, and self-organizing system in which micro-level learning practices continuously feed back into macro-level paradigm evolution, while the evolving paradigm in turn reshapes the conditions and possibilities of learning.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

This article is a phased achievement of the 2024 General Project of the Guangdong Province Philosophy and Social Sciences Planning “Research on the Social Ethical Issues of Generative Artificial Intelligence” (GD24CZX06).

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World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3090

OPTIMIZATION STRATEGIES FOR THE UNDERGRADUATE TEACHING QUALITY ASSURANCE SYSTEM IN SECONDARY COLLEGES

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Abstract: This study focuses on the optimization of the undergraduate teaching quality assurance system in secondary colleges of local application-oriented universities. It systematically analyzes existing issues within the current system, including lack of systematicity, gaps in monitoring key teaching processes, limited evaluation methods, and an inadequate mechanism for continuous improvement. Based on this analysis, fundamental principles for constructing a teaching quality assurance system are proposed, encompassing strengthening the role of grassroots teaching units, establishing an all-member participation mechanism, formulating scientific quality objectives, building a closed-loop process for continuous improvement, and fostering a culture of quality. Furthermore, a construction approach centered on student-oriented, goal-directed, all-member-involved, and continuously improved practices is put forward. Specific optimization strategies are proposed from three aspects: the decision-making and command mechanism, the organizational structure for quality monitoring, and the teaching management system. The study aims to provide theoretical reference and practical insights for developing a systematic, standardized, and efficient teaching quality assurance system in secondary colleges.
Keywords: Secondary colleges; Teaching quality assurance system; Optimization strategies; Continuous improvement

1 INTRODUCTION

In local application-oriented undergraduate universities, secondary colleges function as the fundamental units for organizing and implementing teaching activities and bear the core mission of talent cultivation. As the primary executors of institutional teaching work, they are responsible for specific tasks such as faculty development, professional curriculum design, and classroom teaching management, thereby playing a pivotal role within the higher education quality assurance system [1]. With the shift in China's higher education from scale expansion to connotative development, the teaching quality assurance (TQA) efforts of secondary colleges encounter new challenges and opportunities. On one hand, these efforts must align with the university's overall TQA framework and requirements to ensure standardization; on the other hand, they must reflect the unique characteristics and strengths of the colleges by integrating disciplinary features, professional positioning, and developmental needs. This dual imperative necessitates that secondary colleges construct a TQA system that adheres to unified norms while embodying distinct characteristics.
Currently, many secondary colleges have undertaken beneficial explorations in establishing TQA systems; however, numerous issues persist in practice. For instance, TQA work often lacks systematic planning and holistic coordination; quality monitoring exhibits blind spots, failing to cover all critical teaching processes; monitoring methods remain relatively homogeneous, inadequately capturing the full spectrum of teaching quality; and improvement mechanisms are underdeveloped, lacking effective pathways for continuous enhancement. These shortcomings impede further improvement of teaching quality in secondary colleges [2]. Therefore, conducting in-depth research on optimization strategies for the TQA system in secondary colleges holds significant theoretical and practical importance.
This study aims to analyze the current state and challenges of TQA in secondary colleges, explore the principles, approaches, and specific measures for constructing a scientific and effective TQA system, and provide references for secondary colleges to enhance teaching quality. Through systematic institutional design, standardized process management, and continuous improvement mechanisms, this research seeks to promote the institutionalization [3], standardization, and scientization of TQA in secondary colleges.

2 ANALYSIS OF THE CURRENT SITUATION OF TEACHING QUALITY ASSURANCE IN SECONDARY COLLEGES

In recent years, secondary colleges across various universities have actively explored TQA, developing distinctive management models. Most colleges have established quality assurance systems encompassing teaching objective setting, teaching process monitoring, and teaching outcome evaluation, achieving certain results. Nevertheless, several common issues remain in practice and require urgent resolution.
Insufficient Systematicity in Teaching Quality Assurance. Currently, TQA in many secondary colleges remains fragmented, lacking comprehensive planning. Coordination and collaboration among departments are often inadequate [4], with quality assurance activities frequently operating in isolation, thereby hindering synergy. Moreover, quality

management tends to emphasize post-event inspection and evaluation, lacking effective mechanisms for preemptive prevention and in-process control. This fragmented approach prevents TQA from achieving sustainable development and forming a virtuous cycle.

Gaps in Monitoring Key Teaching Processes. Significant oversight exists in the quality monitoring of several critical teaching links [5]. For example, in practical teaching, factors such as dispersed venues and diverse formats often lead to insufficient monitoring; in graduation project supervision, process management tends to be lax, with inadequate quality control. While different majors have varied talent cultivation objectives, monitoring strategies in practice are often uniform, lacking specificity and effectiveness.

Reliance on Simplistic Teaching Quality Monitoring Methods. Currently, teaching quality monitoring in many secondary colleges relies predominantly on traditional methods such as classroom observations and inspections, resulting in a relatively narrow approach. The insufficient application of information technology hinders real-time, dynamic quality monitoring. When formulating teaching management plans, there is a tendency to simply replicate superior directives without adequately considering the college's actual conditions and specific needs. Furthermore, analysis of monitoring results is often superficial, lacking in-depth data mining and root cause analysis, which impedes the identification of underlying issues.

Lack of Continuity in Teaching Quality Improvement. Many colleges lack effective tracking and improvement mechanisms once problems are identified. Improvement measures frequently remain at the documentary level and are not translated into concrete teaching practices. Simultaneously, there is an absence of continuous evaluation and feedback on the effectiveness of improvements, making it difficult to establish a virtuous cycle of "evaluation–feedback–improvement." Consequently, similar quality issues tend to recur, undermining the efficacy of teaching quality enhancement efforts.

3 PRINCIPLES FOR CONSTRUCTING THE TEACHING QUALITY ASSURANCE SYSTEM IN SECONDARY COLLEGES

Strengthen the Role of Grassroots Teaching Organizations. Fully leverage the function of grassroots teaching organizations, such as teaching and research offices and course groups, by granting them greater autonomy and managerial authority. Establish sound incentive mechanisms to mobilize the enthusiasm and creativity of these organizations in participating in TQA. Concurrently, clarify the primary responsibility of secondary colleges in TQA [6], enhancing quality awareness and managerial accountability at the college level.

Establish an All-Member-Involved Teaching Quality Management System. Teaching quality assurance is not solely the responsibility of administrative personnel but requires the collective participation of all teachers and students. Establish a clear division of responsibilities to ensure that every teacher and teaching administrator understands their role within the quality assurance system. Standardize various work processes through institutional development [7], providing a structural guarantee for all-member involvement.

Formulate Rational Teaching Quality Objectives. Quality objectives are the foundation and ultimate aim of TQA. Each major should formulate feasible quality objectives based on its unique characteristics and actual conditions [8]. These objectives should not only meet the university's overall requirements but also reflect professional distinctiveness; they should emphasize both knowledge impartation and ability cultivation; and they should value both the teaching process and its outcomes.

Build a Closed-Loop System for Continuous Improvement Throughout the Entire Process. Establish a complete quality assurance cycle encompassing planning, implementation, inspection, and improvement. Regularly conduct teaching quality evaluations to promptly identify problems and deficiencies. Establish effective information feedback mechanisms to ensure evaluation results are promptly communicated to relevant units and individuals. Simultaneously, implement tracking and inspection mechanisms to ensure improvement measures are executed, thereby achieving sustained quality enhancement.

Cultivate a Cultural Atmosphere for Teaching Quality Development. Foster a college-wide culture of "quality first" through various forms and channels. Organize activities such as Teaching Quality Month, teaching competitions, and teaching experience exchanges to create an environment that values, researches, and improves teaching. Instill the pursuit of excellence as a shared value and conscious practice among all teachers and students.

4 APPROACHES FOR CONSTRUCTING THE TEACHING QUALITY ASSURANCE SYSTEM IN SECONDARY COLLEGES

Adopt a Student-Centered Approach, Upholding the Primacy of Students. Fully consider students' learning needs and developmental requirements in system design and implementation. Establish comprehensive student feedback mechanisms to regularly collect students' opinions and suggestions on teaching. Increase the weight of student evaluations in teaching assessments to ensure students' voices are adequately reflected. Simultaneously, focus on students' learning experiences and gains to continuously optimize teaching design and methodologies.

Be Goal-Oriented, Refining Talent Cultivation Standards. Translate talent cultivation objectives into specific teaching quality standards, establishing operable and measurable indicator systems. These standards should cover all aspects of teaching, including curriculum design, classroom instruction, practical teaching, and assessment evaluation. Through clear standard guidance, render TQA work rule-based and evidence-based.

Implement All-Member Participation, Enhancing Quality Assurance Awareness Across the College. Improve all teachers' and students' understanding of the importance of TQA through training, publicity, and other means. Establish incentive mechanisms to encourage teachers' active participation in teaching quality improvement initiatives. Meanwhile, create conditions and platforms for students to engage in quality assurance work, cultivating their quality awareness and participatory capabilities.

Persist in Continuous Improvement, Ensuring Ongoing Resolution of Quality Issues. Establish normalized mechanisms for problem identification and resolution. Identify teaching quality issues promptly through regular teaching inspections, random checks, and specialized assessments. Establish rapid response mechanisms to ensure problems are addressed in a timely manner. Concurrently, emphasize the summarization of experiences and consolidation of outcomes, transforming effective improvement measures into institutional norms to prevent recurrence.

5 OPTIMIZATION STRATEGIES FOR CONSTRUCTING THE TEACHING QUALITY ASSURANCE SYSTEM IN SECONDARY COLLEGES

Optimize the Decision-Making and Command Mechanism, Strengthening Comprehensive Coordination. Establish a TQA leading group composed of college leaders, discipline leaders, and core teaching faculty, responsible for the overall planning, organization, and coordination of college-wide TQA. The leading group should regularly review teaching quality issues, formulate improvement measures, and coordinate resource allocation. Simultaneously, establish cross-departmental collaboration mechanisms to ensure synergy among various units in TQA efforts.

Improve the Quality Monitoring Organization, Clarifying Monitoring Entities. Establish a robust college-department two-level quality monitoring organizational system. At the college level, institute a teaching quality monitoring center responsible for organizing and implementing institution-wide monitoring; at the department level, set up quality monitoring teams responsible for discipline-specific monitoring tasks. Clearly define the responsibilities and authority of each monitoring entity to ensure orderly operation. Meanwhile, fully leverage the role of the teaching supervision group in strengthening the supervision and guidance of the teaching process.

Optimize the Teaching Management System, Establishing the Institutional Foundation for Quality Assurance. Systematically review and revise existing teaching management regulations. Focus on improving teaching operation management systems, teaching quality evaluation systems, and teaching incentive and constraint mechanisms. Standardize all facets of teaching quality management through institutional construction, providing robust support for TQA. Simultaneously, ensure the operability of regulations to guarantee all provisions can be effectively implemented.

6 OPTIMIZATION PLAN FOR CONSTRUCTING THE TEACHING QUALITY ASSURANCE SYSTEM IN SECONDARY COLLEGES

Define Quality Monitoring Standards and Establish a Monitoring Basis. Formulate detailed teaching quality standards and monitoring indicators. These standards should encompass all teaching aspects, including teaching preparation, classroom instruction, practical teaching, and course assessment. Standard formulation should consider the characteristics of each major, reflecting the specific requirements of professional talent cultivation. Simultaneously, establish a dynamic adjustment mechanism for standards, revising and improving them in response to teaching reform and developmental needs.

Focus on Monitoring Key Teaching Links, Targeting the Core of Quality Control. Pay particular attention to key processes that influence teaching quality. In theoretical teaching, strengthen the monitoring of teaching content, methods, and outcomes; in practical teaching, emphasize the monitoring of students' practical ability development; in the graduation project phase, enforce whole-process quality control. Enhance overall teaching quality by concentrating monitoring efforts on these pivotal areas.

Improve Quality Monitoring Channels and Methods to Ensure Effectiveness. Establish diversified quality monitoring channels. In addition to routine teaching inspections, actively conduct specialized assessments and random checks. Fully utilize modern information technology to develop a teaching quality monitoring information system, enabling real-time dynamic monitoring. Strengthen guidance and support for key groups, such as new teachers and those with poor teaching effectiveness. Establish a teaching quality data analysis mechanism to identify potential issues through data mining, thereby providing a basis for quality improvement.

Furthermore, establish a robust quality information feedback mechanism. Promptly communicate monitoring results and improvement suggestions to relevant departments and teachers through teaching quality reports, teaching bulletins, and other formats. Implement a tracking and supervision system to ensure the execution of improvement measures. Meanwhile, emphasize experience exchange and outcome promotion to foster the continuous improvement of teaching quality.

7 CONCLUSION

The construction of a TQA system in secondary colleges is a systematic project requiring long-term commitment and continuous refinement. By establishing a scientific and rational quality assurance system, implementing effective quality monitoring measures, and instituting a continuous improvement operational mechanism, the teaching quality of secondary colleges can be significantly enhanced, thereby providing strong support for cultivating high-quality talents.

Future work should continue to explore and innovate to further refine the TQA system and promote the in-depth development of education and teaching reform.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

This paper was supported by a grant from the Teaching Reform Research and Practice Project of Pingdingshan University (Grant No.: 2023-JY36).

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World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3091

RESEARCH AND PRACTICE OF THE "FOUR-TWO-ONE" VIRTUE-INTEGRATED TEACHING MODEL IN THE COURSE "FUNDAMENTALS OF PROBABILITY THEORY"

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Abstract: In response to issues in the teaching of the "Fundamentals of Probability Theory" course, such as the rigid integration of ideological and political education, abstract theoretical concepts, and a singular evaluation system, the teaching team has developed a teaching model centered on the "Four Transformations" (precise teaching objectives, distinctive teaching methods, modular practical teaching, and integrated assessment evaluation), "Two Integrations" (combining practical problems with probability knowledge, and integrating knowledge impartation with ability cultivation), and "One Unity" (unifying ideological education with course teaching). Through teaching practice, this model has effectively enhanced students' autonomous learning ability, stochastic thinking skills, and comprehensive quality. At the same time, it has achieved significant results in areas such as academic competitions and course pass rates, providing valuable experience for teaching reforms in similar courses.
Keywords: Fundamentals of probability theory; Four-two-one model; Virtue-integrated education; Teaching reform; Ideological and political education in courses

1 INTRODUCTION

As a core foundational course for statistics majors, Fundamentals of Probability Theory plays an irreplaceable role in cultivating students' stochastic thinking and data analysis capabilities. However, traditional teaching models exhibit numerous limitations and struggle to meet the talent development demands of the new era. Probability theory curriculum reform has become a key focus in the development of statistics programs across many universities [1]. According to relevant studies, in the context of the "Four New Constructions," probability theory courses face issues such as a disconnection between teaching objectives and the cultivation of higher-order competencies, course content lagging behind interdisciplinary needs, monotonous teaching methods, and a one-sided evaluation system [2]. At the same time, against the backdrop of the comprehensive advancement of "Curriculum Ideology and Politics," how to naturally integrate ideological and political elements into the teaching of probability theory, achieving an organic unity of value guidance and knowledge impartation, has become a significant direction in current teaching reforms [3].
Based on years of teaching practice by the instructional team and aligned with the student-centered educational philosophy, this paper constructs a "Four-Two-One" virtue-integration teaching model for Fundamentals of Probability Theory. It further explores its implementation pathways, specific application effects, and promotional value, aiming to provide references for the ideological and political teaching reform of STEM professional courses in higher education institutions.

2 TEACHING PAIN POINTS

Through an in-depth analysis of the current teaching situation of the Fundamentals of Probability Theory course, we have identified the following five teaching pain points:
Unnatural Integration of "Curriculum Ideology and Politics": In traditional teaching, the introduction of ideological and political elements is often abrupt and forced, failing to organically integrate with the specialized knowledge of probability theory. This leads to student resistance and hinders the achievement of value-oriented education goals [3]. This finding is consistent with the analysis of issues in "Curriculum Ideology and Politics" teaching in related research.
Significant Disparities in Mathematical Foundation: Students exhibit noticeable differences in mathematical background and comprehension skills. Those with weaker foundations often struggle with the abstract concepts and complex calculations in probability theory, easily developing apprehension and a sense of frustration.
Difficulty in Understanding Probabilistic Concepts: Probability theory deals with random phenomena, requiring a way of thinking significantly different from the deterministic mathematics students are accustomed to. The abstract concepts and complex theorems in the course make the theoretical components generally hard for students to grasp, let alone apply flexibly [4].
Incomprehensive Course Evaluation System: Traditional evaluation over-relies on final exam scores, lacking formative assessment and a diversified evaluation mechanism. This fails to fully reflect the student's learning process

and ability development, and does little to motivate independent learning and innovative thinking. Research indicates that diversified and dynamic assessment methods are a key direction for reform [2].

Insufficient Cultivation of Integration and Innovation Skills: Teaching disproportionately emphasizes theoretical knowledge transmission, lacking systematic training in students' ability to integrate knowledge, think innovatively, and apply knowledge practically. Consequently, students find it difficult to use probability theory to solve real-world problems.

3 INNOVATIVE CONCEPTS AND MODEL CONSTRUCTION

In response to the above-mentioned teaching pain points, the course team, after years of exploration, has established the "4-2-1" moral integration teaching model for "Fundamentals of Probability Theory", comprehensively promoting the reform of course teaching.

3.1 The "Four Transformations" Teaching Model

3.1.1 Precise teaching objectives

The course team refined the teaching objectives into three dimensions: knowledge, ability, and literacy, achieving tiered and categorized precise cultivation. The knowledge objective focuses on mastering the basic concepts, theories, and methods of probability theory; the ability objective emphasizes cultivating stochastic thinking, data analysis, and problem-solving skills; the literacy objective stresses shaping the scientific spirit, dialectical thinking, and values. Through this precise objective design, teachers can implement differentiated instruction for students with varying foundations, ensuring every student improves based on their starting point.

3.1.2 Distinctive Teaching Methods

The team developed a distinctive learning method centered on "One Look, Two Memorizations, Three Unifications." "One Look" involves browsing the textbook table of contents to build a knowledge framework and grasp the course structure; "Two Memorizations" means memorizing the table of contents, definitions, and theorems to deepen understanding of the content; "Three Unifications" refers to summarizing and integrating content from different chapters to form a systematic probabilistic thinking mode [5].

Concurrently, teachers employ diverse teaching methods, such as "scenario-based" teaching, which introduces probability concepts through real-life examples; "problem-driven" teaching, which guides students to analyze and solve probability problems; and "discussion and inquiry-based" teaching, which encourages students to collaboratively explore complex probability cases. These methods significantly enhance student classroom participation and learning initiative.

3.1.3 Modular practical teaching

Addressing the highly applicable nature of probability theory, the course team divided the teaching content into seven core modules: stimulating interest and inspiring thinking; exploring new knowledge and mastering content; classroom discussions to enhance ability; summarizing the lesson to highlight key points; in-class exercises to test effectiveness; recapitulation to consolidate new knowledge; and post-class extension to overcome difficulties. This modular design makes the teaching content more systematic, facilitating students' construction of a knowledge system.

In practical components, the team designed three levels of practice modules: basic theory, application cases, and hands-on operation. This design aligns with the "integration of theory and practice" teaching principle and resonates with the problem-driven and case-integration concepts emphasized in research [6]. For example, within the application case module, real-world scenarios like financial risk assessment, medical statistics, and engineering reliability analysis are introduced, allowing students to experience the practical value of probability theory. This approach is consistent with the "integration of theory and practice" principle and coincides with cutting-edge research emphasizing problem-driven and case-based methodologies. Furthermore, in teaching mathematical expectation, the "pooled testing" model from nucleic acid testing is introduced, guiding students to establish a mathematical model and discuss its efficiency, thereby cultivating their scientific research and innovation capabilities [7].

3.1.4 Integrated assessment and evaluation

The course team established an integrated evaluation system combining self-assessment, peer assessment, and teacher assessment. Regular performance accounts for 40%, including assignments, pre-class quizzes, collaborative tasks, and unit tests; the midterm exam accounts for 20%, conducted in the form of a short course paper; the final exam accounts for 40%, retaining the traditional examination format. This multi-faceted evaluation mechanism focuses on the entire learning process, particularly the peer assessment within collaborative tasks, effectively fostering students' teamwork spirit and critical thinking skills. This system is highly consistent with the "diversified and dynamic assessment" concept advocated by scholars [2], representing an effective innovation over the traditional single evaluation model. It focuses specifically on the student's entire learning process and effectively cultivates teamwork spirit and critical thinking skills.

3.2 The "Two Integrations" Educational Philosophy

3.2.1 Integration of practical problems and probability knowledge

The course team closely links probabilistic theoretical knowledge with practical problems from real life, using case-based teaching to help students understand the application value of probability theory. For instance, when teaching the total probability formula and Bayes' theorem, the Aesop's fable "The Boy Who Cried Wolf" is used to guide students in applying Bayes' theorem to calculate changes in credibility, thereby mastering the knowledge while deeply understanding the importance of honesty.

In teaching mathematical expectation, incorporating the "pooled testing" model from nucleic acid testing leads students to discuss and analyze efficiency issues in medical testing, establishing a general model for medical diagnostics and cultivating their scientific research innovation and application abilities. Introducing such practical problems makes abstract mathematical theories vivid and concrete, significantly boosting student interest.

3.2.2 Integration of knowledge impartation and ability cultivation

During teaching, the team emphasizes the organic combination of knowledge impartation and ability cultivation. By designing diverse teaching activities such as group discussions, project practice, and mathematical modeling competitions, they foster students' self-directed learning ability, innovation capability, critical thinking, and teamwork skills.

The course particularly emphasizes the use of inquiry-based learning models, integrating statistical modeling concepts into classroom teaching. By connecting probability theory with specialized knowledge, it guides students to learn evaluation and analysis during the inquiry-based learning process, enhancing their imagination, critical and logical thinking, and innovation abilities. This teaching model aligns highly with the "student-centered" philosophy advocated in forefront research [8].

3.3 The "One Unification" Teaching Model

The "One Unification" model entails the unification of ideological and political education with course teaching, organically integrating ideological and political education throughout the entire probability theory course. The team adheres to three major principles: a subtle, pervasive approach like spring rain; alignment with course characteristics; and practical innovation, deeply exploring the ideological and political elements within the probability theory curriculum.

For example, when explaining Bayes' theorem, through the analysis of an "assembly line problem," students are guided to use mind maps to analyze causal relationships and explore the specific form of Bayes' theorem. Simultaneously, they comprehend the dialectical thinking in mathematics through the relationship between prior and posterior probabilities. In teaching the Law of Large Numbers, students are guided to understand that although the outcome of a single experiment is random, a large number of repeated experiments will inevitably reveal patterns,借此 encouraging the spirit of perseverance in scientific research work [9].

Furthermore, the team also utilizes information-based teaching methods to establish online teaching platforms that complement online and offline, in-class and extra-class activities, achieving the organic integration of moral education with knowledge impartation. This method of naturally integrating ideological and political elements highly aligns with the current requirements for "Curriculum Ideology and Politics" construction.

4 PRACTICAL APPLICATION AND EFFECT

Since 2017, the "4-2-1" moral integration teaching model has been implemented in the "Fundamentals of Probability Theory" course. After years of practice, remarkable achievements have been made.

4.1 Significant Enhancement of Student Abilities

Through the implementation of the "Four-Two-One" teaching model, students' self-directed learning, inquiry-based learning, and innovation abilities have been significantly enhanced. Students actively participate in classroom discussions and practical projects, demonstrating outstanding performance in activities such as statistical modeling competitions, market research and analysis competitions, and scientific research projects. Over the past five years, students have won more than 10 national awards and over 100 provincial-level awards in various academic competitions, showing a marked improvement in their comprehensive ability to apply stochastic, probabilistic, and innovative thinking.

Particularly during the implementation of the flipped classroom, students transformed from initially lacking learning initiative and requiring constant teacher guidance to being capable of independent inquiry and collaborative problem-solving. Their structured and logical thinking, as well as their ability to grasp key and difficult points, showed significant progress.

4.2 Marked Improvement in Teaching Effectiveness

Student classroom participation and learning enthusiasm have significantly increased, with a substantial rise in class engagement and interaction rates. The course pass rate has improved noticeably, and students' performance in probability theory sections of postgraduate entrance exams has also seen considerable enhancement. Course satisfaction surveys indicate that student evaluations of the course are generally higher than those for traditionally taught classes (Table 1).

Table 1 Comparison of Effects Before and after Teaching Reform

Comparison dimension	Before the reform	After the reform	Extent of increase
Classroom participation	Less than 40%	More than 80%	Significant improvement
Course pass rate	About 75%	More than 90%	Significantly improved
Awards in subject competitions	2 to 3 items per year	More than ten items per year	A significant increase
Course satisfaction	3.5/5	4.5/5	Significantly improved
self-directed learning ability	Generally weak	Significantly enhanced	A qualitative leap

4.3 Faculty and Curriculum Development

During the teaching innovation process, the teaching team members have greatly advanced their educational philosophies and teaching skills, achieving remarkable results in teaching reform. The team has received one Second Prize of the Hunan Provincial Basic Education Teaching Achievement Award, one First Prize at the university level, two Second Prizes, and one Third Prize at the university level for teaching achievements. They have also won multiple awards in provincial and university-level teaching competitions.

The course has been recognized as a first-class course at the college level. The teaching reform results have been published in academic journals, and the outcomes of the moral-integration education reform have gained peer recognition. The course team has also been invited to share experiences at multiple institutions, expanding the course's influence.

4.4 Notable Effectiveness of "Curriculum Ideology and Politics"

Through the implementation of moral-integration teaching, students have not only mastered the professional knowledge of probability theory but have also established correct core values, gaining a deeper understanding of the social value of probability theory and the scientific spirit. The integration of "Curriculum Ideology and Politics" with knowledge impartation has become more natural, achieving an organic unity of knowledge education and value guidance.

In their learning reflections, students indicate that through the course, they have not only learned probabilistic knowledge but have also deeply appreciated the importance of values such as integrity, perseverance, and dialectical thinking, achieving an educational effect that "moistens things silently."

5 CONCLUSION

The "Four-Two-One" Virtue-Integration Teaching Model for Fundamentals of Probability Theory has implemented systematic and innovative reforms addressing the pain points in traditional teaching, establishing a scientific and rational teaching system. This model restructures the teaching process through the "Four Transformations" approach, connects theory and practice via the "Two Integrations" educational philosophy, and achieves the organic integration of ideological and political education with professional education through the "One Unification," effectively enhancing both the teaching quality and the educational effectiveness of the course. This teaching model is applicable not only to the Fundamentals of Probability Theory course but also provides valuable experience for the teaching reform of other professional courses. Currently, the model has been applied and promoted in multiple science courses with positive results.

In the future, the course team will further optimize the teaching model, strengthen the development of digital teaching resources, deepen the integration of industry and education, and continuously improve teaching quality to contribute to the cultivation of inter-disciplinary and innovative talents required in the new era. Practice has shown that the "Four-Two-One" Virtue-Integration Teaching Model aligns with the requirements for higher education development in the new era, serves as an effective path to address the teaching challenges of probability theory courses, and possesses broad promotion value and application prospects.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

The project was supported by Hunan Provincial Department of Education Teaching Reform Project: Exploration and Research on a New Teaching Model of "Curriculum Ideology and Politics" in "Fundamentals of Probability Theory" (HNJG-2022-0804).

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