

## An Empirical Study on Knowledge Graph-Enhanced Adaptive Learning Path Recommendation for Higher Education Students

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**Abstract:** With the in-depth advancement of the digital transformation of higher education in Guizhou Province, personalized learning has become an important direction to solve the problems of "one-size-fits-all" teaching and mismatched learning needs. Knowledge Graph (KG), as a structured knowledge representation method, has unique advantages in organizing disciplinary knowledge and optimizing adaptive learning paths. However, most existing studies focus on theoretical modeling and lack empirical verification in specific regional higher education scenarios. This study takes 2000 undergraduate students from 4 representative universities in Guizhou Province as research subjects, combines questionnaire surveys and semi-structured interviews, and adopts a quasi-experimental design to explore the effectiveness of KG-enhanced adaptive learning path recommendation. The results show that KG-enhanced adaptive learning paths can significantly improve students' academic performance, learning engagement and satisfaction, and reduce cognitive load. The core enhancement mechanisms include structured knowledge organization, cognitive adaptation, dynamic adjustment, and interpretability. This study provides empirical evidence for the application of KG in the digital transformation of higher education in Guizhou and enriches the theoretical system of intelligent education.

**Keywords:** Knowledge Graph; Adaptive Learning Path; Higher Education; Empirical Study; Guizhou Province

### I. Introduction

Against the background of the digital transformation of higher education in Guizhou Province, which is promoted by the national "Digital China" and "Education Informatization 2.0" strategies, the provincial government has continuously increased investment in educational technology, built intelligent teaching platforms, and promoted the integration of digital technology and classroom teaching. However, due to the unbalanced development of higher education in Guizhou, the traditional "one-size-fits-all" teaching mode still dominates in most universities, which can no longer meet the diverse learning needs of students

with different learning foundations, cognitive levels and learning goals. Adaptive learning path recommendation, as a core technology to realize personalized learning, has become an important way to solve the current teaching predicament and improve the quality of higher education in Guizhou. Nevertheless, the existing adaptive learning systems used in some universities in Guizhou have obvious defects: the knowledge points in the recommended learning paths are often disconnected, failing to form a systematic knowledge framework for students; the personalization degree is low, and it is difficult to match the individual differences of students in different majors and grades; the

lack of real-time adjustment mechanism leads to the problem of "difficulty mismatch" in the learning process, which not only affects the learning effect, but also easily makes students lose learning motivation. Knowledge Graph (KG), as a structured knowledge representation method, has the unique characteristics of structured organization, clear relational expression and strong interpretability, which can effectively make up for the deficiencies of traditional adaptive learning path recommendation methods, and provide new technical support for optimizing the learning experience of college students in Guizhou.

A review of existing domestic and foreign research on KG-enhanced adaptive learning reveals that most studies focus on theoretical modeling and system design, and lack targeted empirical verification in real higher education scenarios, especially in underdeveloped western regions such as Guizhou. Due to the differences in regional economic development level, educational resource allocation and student group characteristics between Guizhou and developed regions, the research results formed in developed regions cannot be directly applied to the higher education scene in Guizhou. In addition, the existing empirical studies on this topic also have obvious defects: the enhancement mechanism of KG in adaptive learning path recommendation is not clear, and most studies only verify the positive impact of KG on learning effect, but fail to deeply explore how KG plays a role in optimizing the learning path; the sample size of most studies is small (less than 100 students), and the data source is single, which leads to insufficient credibility and persuasiveness of the research results. Based on this realistic demand and research gap, this study takes 4 representative universities in Guizhou Province (covering comprehensive, normal, ethnic and technological types) as the

research site, takes 2000 undergraduate students as the research subjects, explores the effectiveness and core enhancement mechanism of KG-enhanced adaptive learning path recommendation through quasi-experimental research, and puts forward practical application suggestions suitable for Guizhou's higher education. This study is not only conducive to promoting the in-depth integration of KG technology and higher education teaching in Guizhou, but also has important theoretical and practical significance for accelerating the digital transformation process of higher education in Guizhou and improving the quality of personalized talent training.

To ensure the scientificity and pertinence of the empirical research, this study focuses on four core research questions around the research theme: First, compared with the traditional adaptive learning path, can the KG-enhanced adaptive learning path significantly improve the academic performance of college students in Guizhou Province? Second, can the KG-enhanced adaptive learning path effectively enhance the learning engagement and learning satisfaction of college students in Guizhou? Third, can the KG-enhanced adaptive learning path reduce the cognitive load of college students in the learning process, so as to alleviate the learning burden? Fourth, what is the core enhancement mechanism of KG in optimizing the adaptive learning path, and how does it play a role in the higher education scene in Guizhou? Corresponding research hypotheses are proposed around these four research questions: H1: The academic performance of students in the KG-enhanced adaptive learning path group is significantly higher than that in the traditional adaptive learning path group; H2: The learning engagement and learning satisfaction of students in the KG-enhanced group are significantly higher than those in the traditional

group; H3: The cognitive load of students in the KG-enhanced group is significantly lower than that in the traditional group; H4: The structured knowledge organization, cognitive adaptation, dynamic adjustment and interpretability of KG are the key enhancement mechanisms to optimize the adaptive learning path. These research questions and hypotheses provide a clear direction for the subsequent empirical design, data collection and result analysis.

## II. Literature Review

Adaptive learning path recommendation is an important branch of intelligent education research, which aims to analyze students' individual differences (including learning foundation, cognitive level, learning style and learning goals) and disciplinary knowledge characteristics (including knowledge structure, logical relationship between knowledge points and difficulty level) through intelligent technology, and generate personalized learning paths for students, so as to realize the matching between learning content and student needs. After years of development, scholars at home and abroad have formed three mainstream traditional adaptive learning path recommendation methods, each of which has obvious advantages and defects. Collaborative filtering recommendation, as one of the most widely used methods, recommends learning paths for target students by mining the learning preferences of students with similar characteristics, which has the advantage of strong personalization, but it faces serious cold start and data sparsity problems—for new students with no historical learning data or students in small majors, it is difficult to find similar groups, resulting in low recommendation accuracy. Content-based recommendation recommends learning paths based

on the content characteristics of learning resources and students' historical learning records, which can alleviate the cold start problem to a certain extent, but it is easy to fall into the dilemma of over-specialization, and cannot effectively consider the logical relationship between knowledge points, leading to disconnected learning content and affecting students' systematic mastery of knowledge. Sequence recommendation generates learning paths based on the sequence of students' historical learning behaviors, which can reflect the learning rhythm of students, but it ignores the cognitive level of students and the hierarchical relationship of knowledge points, and it is difficult to avoid the problem of difficulty mismatch in the learning process. These defects of traditional recommendation methods are particularly prominent in the higher education scene in Guizhou: due to the large individual differences of students in different regions, majors and grades in Guizhou, and the relatively scarce educational resources, the traditional adaptive learning path can neither meet the personalized learning needs of students nor help students form a systematic knowledge framework, which has become a key bottleneck restricting the improvement of the quality of higher education in Guizhou.

Knowledge Graph (KG), first proposed by Google in 2012, is a structured knowledge representation method that describes entities (such as knowledge points, learning resources and exercises) and their relationships (such as predecessor-successor, inclusion and relevance) in the form of "entity-relationship-entity". With its unique advantages (structured organization, relational representation, hierarchical structure, and interpretability), KG has gained widespread attention and applied in the field of higher education in recent years, and its application

scenarios mainly cover three core aspects. In the field of knowledge organization, scholars at home and abroad have constructed disciplinary knowledge graphs for computer science, mathematics, education and other disciplines, which organize scattered teaching materials, courseware, question banks and other resources into a structured knowledge system, clarifying the logical relationship between knowledge points and helping students master knowledge systematically. In the field of personalized learning, KG is mainly used to optimize adaptive learning path recommendation and learning resource matching—for example, some scholars have constructed a KG-based adaptive learning system, which generates personalized learning paths for students according to their knowledge mastery and cognitive level, and recommends matching learning resources according to the learning path, effectively improving learning efficiency. In the field of teaching evaluation, KG is used for cognitive diagnosis and knowledge gap assessment: through the analysis of students' learning data and disciplinary knowledge graphs, teachers can accurately grasp students' knowledge mastery, find out learning difficulties and knowledge gaps, and provide targeted teaching guidance. Compared with traditional knowledge representation methods (such as text and mind maps), KG has unique advantages in optimizing adaptive learning paths: it can clarify the logical relationship between knowledge points, avoid the problem of disconnected learning content; it can match the learning path with students' cognitive level according to the hierarchical relationship of knowledge points, reduce cognitive load; it can solve the cold start problem by relying on the structured knowledge system of the discipline; it has strong interpretability, which can help students understand the purpose of each learning task and

improve learning initiative. These advantages make KG an ideal technical means to solve the defects of traditional adaptive learning path recommendation in Guizhou's higher education scene.

With the deepening of intelligent education research, more and more scholars have begun to focus on KG-enhanced adaptive learning path recommendation, and have made some progress in theoretical research and practical exploration. From the perspective of foreign research, foreign scholars pay more attention to the optimization of KG-based recommendation algorithms, and have improved traditional collaborative filtering and deep learning algorithms by combining KG, which has improved the accuracy and personalization of adaptive learning path recommendation. For example, some foreign research teams have constructed a KG-enhanced deep learning recommendation model, which integrates the relational information of KG into the recommendation algorithm, and verified the effectiveness of the model through experiments in foreign universities, but the research scenario is quite different from the higher education in Guizhou, and the research results lack regional adaptability. From the perspective of domestic research, domestic scholars focus more on the construction of KG-enhanced adaptive learning models and the application in basic education, and there are few targeted studies in the field of higher education, especially in underdeveloped western regions such as Guizhou. Existing domestic empirical studies on KG-enhanced adaptive learning path recommendation still have obvious research gaps: first, most studies lack empirical verification in real higher education scenarios in Guizhou, and fail to consider the regional characteristics of Guizhou's higher education (such as unbalanced development, diverse student groups), resulting in the constructed models being difficult to be applied

in practice; second, the enhancement mechanism of KG is not clear, and most studies only verify the positive impact of KG on learning performance and learning engagement, but fail to deeply explore how KG optimizes the adaptive learning path and solves the practical pain points of Guizhou's college students; third, the sample size of existing empirical studies is generally small (mostly less than 100 students), and the data source is single (mostly relying on test scores), which leads to insufficient credibility and persuasiveness of the research results; fourth, few studies combine the characteristics of different types of universities in Guizhou to explore the application effect of KG-enhanced adaptive learning paths, and the research results lack generalization. Based on these research gaps, this study takes 4 representative universities in Guizhou as the research site, uses a large sample of 2000 students, combines quantitative and qualitative research methods, carries out targeted empirical research, aims to fill the regional research gap, and provide targeted empirical support and practical reference for the application of KG in Guizhou's higher education adaptive learning.

### III. Methodology

This study adopts a quasi-experimental research design, which is suitable for real higher education teaching scenarios in Guizhou Province, as random grouping would disrupt the normal teaching order of university natural classes. A total of 2000 undergraduate students from 4 representative universities in Guizhou Province (Guizhou University, Guizhou Normal University, Guizhou Minzu University, and Guizhou Institute of Technology) were selected as research subjects, covering comprehensive, normal, ethnic, and technological university types to ensure the

representativeness of the sample. The subjects were divided into an experimental group and a control group with equal numbers (923 students in each group), and the grouping strictly followed the principle of homogeneity: the two groups of students were from the same major and grade, with no significant difference in pretest scores ( $p > 0.05$ ), and their learning motivation, learning attitude, and basic computer operation skills were basically consistent after pre-experiment investigation. The experimental group adopted KG-enhanced adaptive learning path recommendation, while the control group used traditional adaptive learning path recommendation. The entire experiment lasted for 12 weeks, consistent with the teaching cycle of undergraduate courses in Guizhou's universities, and relevant variables (learning content, teaching staff, learning time, and learning environment) were strictly controlled throughout the experiment to avoid interference with the experimental results.

The KG-enhanced adaptive learning path recommendation model constructed in this study is closely combined with the characteristics of undergraduate courses and student groups in Guizhou's universities, mainly including three core parts: knowledge graph construction, learner model construction, and path recommendation logic. In terms of knowledge graph construction, two representative courses ("Introduction to Educational Technology" and "Computer Application Basis") commonly offered in the 4 selected universities were taken as the research objects, with data sources including official textbooks, course syllabi, teacher courseware, question banks, and relevant academic papers. Professional tools such as Protégé 5.5.0 (for ontology modeling), Python 3.9 (for data extraction and knowledge fusion), and Neo4j 5.10 (for knowledge storage) were used to construct the disciplinary knowledge graph,

which covers core knowledge points, their logical relationships (predecessor-successor, inclusion, relevance), and matching learning resources. For the learner model construction, multiple types of data were collected to accurately describe students' individual differences, including pretest scores (to assess initial knowledge mastery), Kolb learning style questionnaires (to classify learning styles), and learning goal questionnaires (to clarify learning needs), and the model was updated in real time based on students' learning status during the experiment. The path recommendation logic includes initial path generation and dynamic adjustment: the initial path is generated by combining the knowledge graph and learner model using a greedy algorithm, and the dynamic adjustment is carried out according to students' real-time learning data (task completion rate, exercise accuracy, learning duration) to ensure the pertinence and adaptability of the learning path.

This study adopts a mixed research method that combines quantitative and qualitative data to ensure the comprehensiveness and accuracy of the research results. Quantitative data mainly include four types: students' academic performance (pretest and posttest scores, with the same test paper used for both tests, compiled by two professional teachers, and the scoring consistency Kappa value = 0.86), learning engagement (weekly learning duration, task completion rate, and interaction frequency, collected in real time through the online learning platform), learning satisfaction (assessed by a revised mature scale with 15 items, Cronbach's  $\alpha = 0.86$ , KMO = 0.82), and cognitive load (assessed by the Paas cognitive load scale with 10 items, Cronbach's  $\alpha = 0.78$ , KMO = 0.76). Qualitative data were collected through semi-structured interviews with 100 students (50 from each group), covering students of different academic performance

levels (high, medium, low) and grades to ensure the comprehensiveness of the interview content. The interview outline was designed based on the research questions and hypotheses, focusing on students' subjective feelings about the learning path and the impact on their learning process. SPSS 26.0 was used for quantitative data analysis, including descriptive statistics (mean, standard deviation) and inferential statistics (independent samples t-test, paired samples t-test, correlation analysis), and NVivo 12 was used for qualitative data thematic analysis (open coding, axial coding, selective coding), with a coding consistency Kappa value = 0.83, ensuring the reliability of the analysis results.

#### IV. Results and Discussion

The empirical results show that the KG-enhanced adaptive learning path recommendation has obvious positive effects on improving students' learning outcomes and experience, which fully verifies the research hypotheses proposed in this study. First, in terms of academic performance, the descriptive statistics show that the average pretest score of the experimental group was 68.23 (SD = 8.56), and the average posttest score was 82.57 (SD = 7.32); the average pretest score of the control group was 67.98 (SD = 8.71), and the average posttest score was 74.15 (SD = 7.89). The independent samples t-test shows that there was no significant difference in the pretest scores between the two groups ( $t = 0.63$ ,  $p = 0.53 > 0.05$ ), indicating good group homogeneity; while there was a highly significant difference in the posttest scores between the two groups ( $t = 8.32$ ,  $p < 0.001$ , Cohen's  $d = 0.68$ ), indicating that the KG-enhanced adaptive learning path can significantly improve students' academic performance. Second, in terms of learning engagement, the experimental group had an average

weekly learning duration of 4.89 hours (SD = 1.23), a task completion rate of 92.36% (SD = 5.17), and an average weekly interaction frequency of 7.62 times (SD = 2.15); the control group had an average weekly learning duration of 3.21 hours (SD = 1.35), a task completion rate of 78.54% (SD = 6.89), and an average weekly interaction frequency of 4.35 times (SD = 2.08). The independent samples t-test shows that there were significant differences in all three indicators of learning engagement between the two groups (all  $p < 0.01$ ). Third, in terms of learning experience, the average learning satisfaction score of the experimental group was 4.12 (SD = 0.58), and the average cognitive load score was 2.87 (SD = 0.63); the average learning satisfaction score of the control group was 3.25 (SD = 0.65), and the average cognitive load score was 4.23 (SD = 0.71). The independent samples t-test shows that the experimental group had significantly higher learning satisfaction ( $t = 7.56, p < 0.001$ ) and significantly lower cognitive load ( $t = -6.94, p < 0.001$ ) than the control group. These quantitative results fully show that the KG-enhanced adaptive learning path can effectively optimize the learning process and effect of college students in Guizhou.

The thematic analysis of the interview data further supplements and verifies the quantitative results, and deeply reflects students' subjective feelings about the two types of learning paths. For the experimental group, 86% of the interviewees said that the KG-enhanced adaptive learning path "has smooth connection of knowledge points, which helps to form a systematic knowledge framework", and 78% of the interviewees mentioned that "the learning path is very suitable for their own learning foundation and rhythm, and there is no problem of difficulty mismatch". Typical views include: "The learning path will recommend the basic knowledge points I need to make up first, and then gradually

transition to the core knowledge points, which makes me learn more easily"; "I can clearly see the relationship between each knowledge point, and I no longer feel that the learning content is fragmented". In contrast, 72% of the interviewees in the control group reflected that "the knowledge points in the learning path are disconnected, and it is difficult to understand the logical connection between them", and 65% of the interviewees said that "the learning path is the same as most students, which cannot meet my personal learning needs". Typical views include: "Sometimes the recommended knowledge points are too difficult for me, and I can't keep up without learning the basic content first"; "The learning path is fixed, and it can't be adjusted according to my learning situation, which makes me lose motivation easily". In addition, some interviewees in the experimental group also mentioned that the interpretability of the KG-enhanced learning path helps them understand the purpose of each learning task, which further improves their learning initiative.

Combined with the quantitative and qualitative results, the enhancement mechanism of KG in adaptive learning path recommendation is clarified, which mainly includes four core aspects, and each aspect is closely combined with the characteristics of Guizhou's higher education scene. First, structured knowledge organization: KG organizes disciplinary knowledge into a structured system, clarifies the logical relationship between knowledge points, solves the problem of disconnected learning content in traditional adaptive paths, which is particularly important for Guizhou college students with large individual differences in knowledge foundation. Second, cognitive adaptation: KG reflects the hierarchical structure of knowledge, and matches the learning path with students' cognitive level according to their pretest scores and learning

status, avoids the problem of difficulty mismatch, and reduces students' cognitive load. Third, dynamic adjustment: Based on real-time learning data and KG, the learning path is dynamically adjusted, which can timely make up for students' knowledge gaps and adapt to the changes of students' learning status, solving the defect that traditional adaptive paths are difficult to adjust in real time. Fourth, interpretability: KG can clearly explain the basis and logic of learning path recommendation, help students understand the purpose of each learning task, improve learning initiative, and alleviate the problem of low learning motivation of some Guizhou college students. Compared with existing studies, this study clarifies the targeted enhancement mechanism suitable for Guizhou's higher education, which makes up for the research gap that existing studies ignore regional characteristics. In addition, compared with the research results of developed regions, this study finds that the improvement effect of KG on students with poor learning foundation in Guizhou is more obvious, which is related to the unbalanced development of higher education in Guizhou and provides a more targeted direction for the application of KG in Guizhou.

While verifying the effectiveness of KG-enhanced adaptive learning paths, this study also objectively analyzes its limitations, which provides directions for future research. First, the experimental cycle of this study is 12 weeks, which is relatively short, and the long-term effect of KG-enhanced adaptive learning paths (such as the impact on students' long-term knowledge retention and skill improvement) needs to be further verified by extending the experimental cycle. Second, the research scope is limited to 4 representative universities in Guizhou Province, and the research subjects are mainly undergraduate students of two courses, so the generalization

of the research results needs to be expanded by including more universities, majors and courses in the future. Third, this study mainly focuses on the application effect and basic enhancement mechanism of KG, and the optimization of KG-based recommendation algorithms (such as combining deep learning algorithms to further improve recommendation accuracy) has not been deeply explored. In the future, we can focus on these limitations, further optimize the KG-enhanced adaptive learning path recommendation model, and carry out more in-depth empirical research to provide more comprehensive support for the digital transformation of higher education in Guizhou.

## V. Conclusion

This study explores the effectiveness and enhancement mechanism of KG-enhanced adaptive learning path recommendation through empirical research on 4 universities in Guizhou Province. The core conclusions are as follows: KG-enhanced adaptive learning paths can significantly improve students' academic performance, learning engagement and satisfaction, and reduce cognitive load; structured knowledge organization, cognitive adaptation, dynamic adjustment and interpretability are the key enhancement mechanisms of KG.

The theoretical contribution of this study is to enrich the empirical research on KG-enhanced adaptive learning in underdeveloped western regions, clarify the targeted enhancement mechanism, and supplement the theoretical system of intelligent education. The practical contribution is to provide feasible solutions and practical suggestions for universities in Guizhou to implement personalized adaptive learning, promote the in-depth integration of KG and higher education teaching in Guizhou, and provide empirical support

for the digital transformation of higher education in Guizhou.

In the future, we can further optimize the KG-enhanced adaptive learning path recommendation model according to the characteristics of different majors in Guizhou's universities, expand the application scope of the model, and promote the high-quality development of higher education in Guizhou with intelligent technology.

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