Bridging Humanities and STEM: Leveraging GraphRAG to Teach Programming through Historical Text Analysis

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Abstract

This study explores the integration of GraphRAG (Graph Retrieval-Augmented Generation), an AI-powered tool, into analyzing historical texts, focusing on its role in bridging humanities and STEM education. Using the case study of the Witchcraft Trials during the Han Dynasty, this research demonstrates how programming and computational tools can empower non-technology and non-engineering students to engage with data-driven historical analysis. By introducing programming skills for text analysis, data visualization, and knowledge graph construction, students gain proficiency in digital tools and develop critical thinking and problem-solving abilities.

The methodology involves guiding students to utilize GraphRAG to uncover complex relationships within historical narratives. This interdisciplinary approach transforms the study of history into an opportunity to cultivate computational thinking and digital literacy, making STEM principles accessible to traditionally non-STEM students. The findings highlight how such integration fosters lifelong learning, enabling students to apply analytical skills across diverse domains.

Furthermore, the study showcases AI's broader educational potential in enhancing curriculum development and teacher training. GraphRAG provides a practical example of how AI can facilitate innovative learning environments, allowing educators to bridge the gap between technical and non-technical disciplines. This approach enriches humanities education and reinforces the importance of interdisciplinary collaboration in addressing contemporary challenges.

The implications of this research extend to higher education, STEM/STEAM education, and professional development, offering a sustainable model for integrating AI into educational practices. By aligning technology with humanities, this study demonstrates the transformative potential of AI-powered tools in fostering critical analysis, digital literacy, and lifelong learning.

Keywords: GraphRAG, STEM Education, Historical Text Analysis, Interdisciplinary Learning, AI in Education

1. Introduction

Historical education has long relied on text-based learning, emphasizing extensive reading and memorization. While this approach provides foundational knowledge, it often lacks interactivity and visual engagement, making it challenging for learners to grasp complex historical narratives involving multiple figures, events, and interrelated causes (Moretti, 2013; Ramsay, 2011). Additionally, history education traditionally focuses on descriptive analysis, often neglecting quantitative and computational methodologies that could enhance historical interpretation (Jockers, 2013). This study addresses these limitations by incorporating STEM-based analytical techniques, particularly GraphRAG, into historical education.

Traditional historical learning methods present several challenges. The dependence on reading and memorization requires students to process large volumes of text without dynamic visualization tools, often leading to cognitive overload (Blevins, 2018). Many historical events involve intricate relationships between political figures, social movements, and economic forces, which are difficult to conceptualize purely through text (Moretti, 2013). Furthermore, history education traditionally lacks computational tools that could help analyze patterns, relationships, and causality in historical data (Jänicke et al., 2015). This study proposes integrating STEM principles into historical education to overcome these challenges, mainly through data-driven analysis, programming-based processing, visualization techniques, and critical thinking frameworks.

Data analysis can employ network-based methods to structure historical events into interconnected nodes, giving more profound insights into causality and character interactions (Jockers, 2013). Programming and natural language processing (NLP) techniques, such as Python-based text processing, can extract key figures, events, and themes from historical texts (Jurafsky & Martin, 2021). Visualization through GraphRAG-based knowledge graphs enhances learners' ability to comprehend relationships and contextualize historical developments (Jänicke et al., 2015). Critical thinking is encouraged as students question historical narratives, analyze biases, and compare multiple scholarly interpretations through interactive historical models (Shanahan, 2015).

GraphRAG is an AI-powered retrieval-augmented generation framework that structures textual information into knowledge graphs, making it an ideal tool for history learners. The methodology involves inputting historical texts such as Han Shu and Shiji into structured datasets for computational processing (Loewe, 2004). Keyword extraction using NLP-based named entity recognition (NER) detects key figures, places, and historical events (Jurafsky & Martin, 2021). Graph construction through NetworkX and D3.js facilitates the creation of interactive historical relationship maps, allowing for exploratory analysis (Jänicke et al., 2015). Interactive exploration enables users to adjust parameters, refine entity relationships, and analyze historical causality dynamically (Shanahan, 2015).

This study applies GraphRAG to analyze the Witchcraft Trials in the Han Dynasty, a complex historical event involving political manipulation and power struggles. The analysis focuses on mapping key figures such as Emperor Wu, Crown Prince Liu Ju, and Jiang Chong, analyzing causal relationships between the political motivations behind the trials and their historical consequences, and comparing interpretations by different historians and textual sources through a computationally structured framework (Simian, 1950). Beyond history, this interdisciplinary approach has broad applications in education and research.

AI-assisted learning expands GraphRAG's integration into digital humanities curricula, improving student engagement and accessibility (Blevins, 2018). Gamification of historical learning through interactive learning platforms allows students to explore history through simulation-based knowledge graph navigation (Jänicke et al., 2015). The GraphRAG framework

can also be extended to literature, sociology, and political science, fostering a multi-domain analytical methodology (Moretti, 2013).

This study aims to demonstrate that by integrating STEM methodologies into historical education, learners can engage with history more analytically, gaining computational literacy while preserving the interpretative nature of humanities-based inquiry.

2. Method

2.1. Sample

The study focuses on historical events from the Han Dynasty, particularly the "Case of Witchcraft." Primary sources include the Han Shu and secondary analyses from scholars such as Tian Yuqing (Tian, 1980) and Pu Muzhou (Pu, 1995). The dataset was preprocessed using NLP techniques to extract entities, relationships, and themes for knowledge graph construction. The objective is to compare traditional historical research methodologies with AI-assisted approaches such as GraphRAG to determine how knowledge graph retrieval improves historical interpretation.

2.2. Instrument

This study employs GraphRAG, an AI-driven retrieval-augmented generation system that integrates machine learning with knowledge graph visualization. GraphRAG enhances conventional text-based retrieval by structuring relationships within historical texts, allowing for contextual interpretation of historical events. This method facilitates comparative analysis by systematically extracting key themes, figures, and event interactions, enabling a deeper understanding of competing historical interpretations.

2.2.1. Tools

Python-based Neo4j was employed as a graph database to store structured knowledge representations of historical texts. NLP models were utilized to automate text parsing and entity linking, allowing students and researchers to interactively explore historical networks (Jurafsky & Martin, 2021).

2.3. Learning Procedure

To implement GraphRAG for historical text analysis, the study follows a structured multi-step workflow integrating historical research techniques with AI-enhanced analytical tools. Figure 1 represents the five-step process of GraphRAG-enhanced historical analysis, showing how data is processed, structured, analyzed, and interpreted using AI and knowledge graphs.

Step 1: Data Collection and Preprocessing

The first phase involved selecting a historical case study, such as the Case of Witchcraft during the reign of Emperor Wu of Han. Primary sources such as Han Shu and Shiji were digitized, while secondary analyses from historians like Tian Yuqing and Pu Muzhou were incorporated for comparative study.

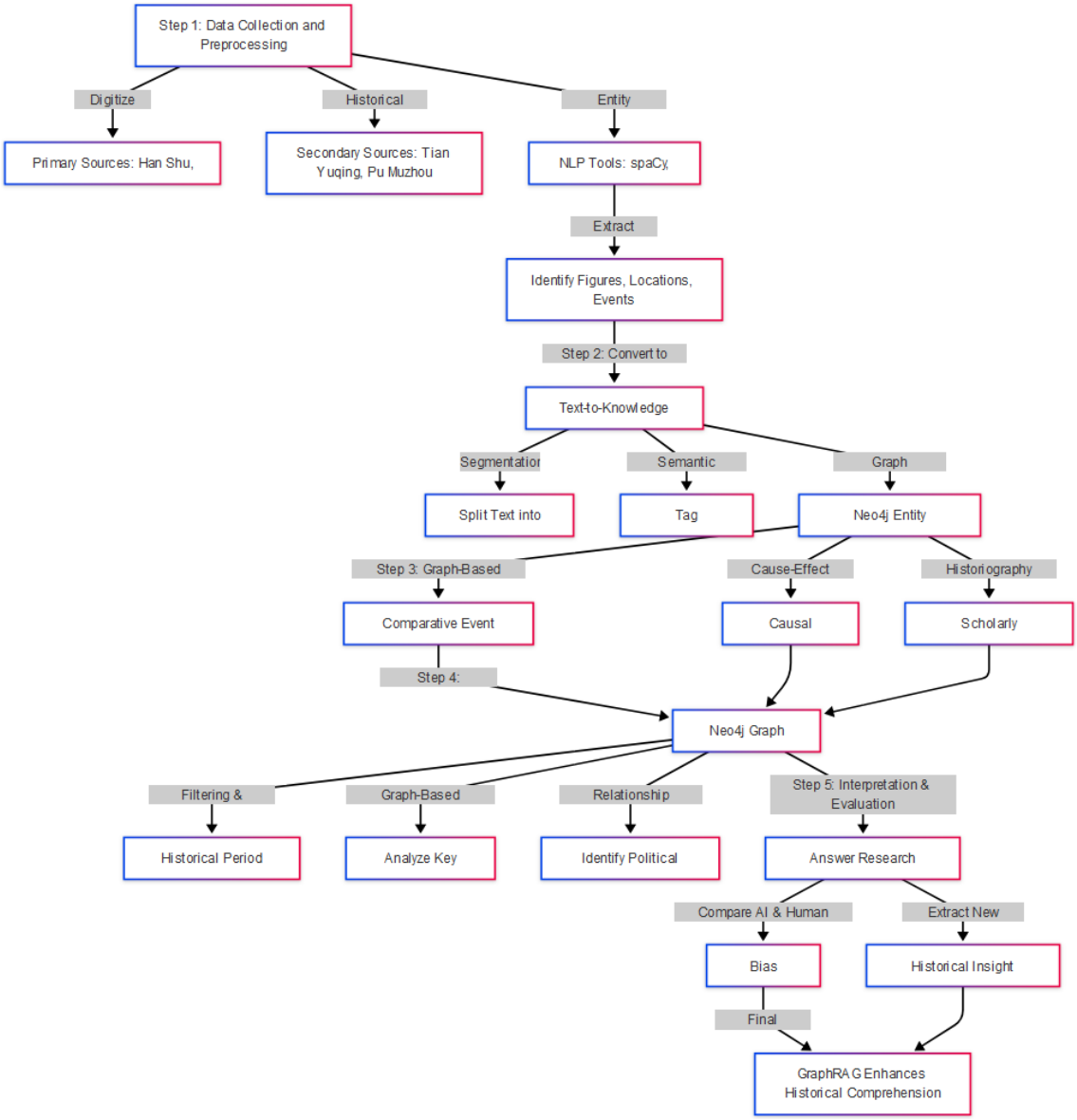
NLP tools such as spaCy and NLTK were applied to name entity recognition (NER) to ensure accurate entity recognition. These tools identified key figures, locations, events, and relationships, forming the foundational dataset for subsequent knowledge graph construction.

Step 2: Text-to-Knowledge Graph Transformation

Historical texts were then converted into graph-based representations to systematically model relationships between events and figures. This involved:

1. Text segmentation: Splitting texts into multiple nodes representing key entities (e.g., Jiang Chong, Liu Ju, Emperor Wu).
2. Semantic annotation: Using NLP techniques to automatically tag relationships between entities (e.g., "victim of," "executed by," "issued edict").
3. Graph construction: Using Neo4j to establish entity relationships, enabling structured event interpretation.

Figure 1 GraphRAG Learning Procedure Workflow



Step 3: Graph-Based Analysis and Comparison

Once the knowledge graph was constructed, analytical techniques were applied to compare traditional human-led historical interpretations with AI-assisted insights. The focus areas included:

1. Comparative Event Linkage: Examining thematic consistency between AI-generated event connections and established historical interpretations.

2. Causal Reasoning: Using graph traversal techniques to infer cause-effect relationships between events (e.g., how the Case of Witchcraft influenced the issuance of the Luntai Edict).
3. Scholarly Disagreement Analysis: Comparing the views of Tian Yuqing and Pu Muzhou using GraphRAG retrieval to observe their interpretative differences regarding Emperor Wu's repentance.

Step 4: Visualization and Interactive Exploration

With the knowledge graph-structured, interactive visualization tools were employed using Neo4j Graph Builder. This allowed researchers and students to manipulate the dataset by: dynamically

1. Filtering specific historical periods within the event timeline.
2. Focusing on individual historical figures to analyze their network of relationships.
3. Highlighting semantic relationship types (e.g., "allies," "political adversaries").

Additionally, AI-powered summarization was integrated into the GraphRAG interface, allowing users to extract scholarly viewpoints quickly and compare competing narratives.

Step 5: Reflection and Historical Interpretation

The final step involved using GraphRAG-generated insights to answer three central historical research questions:

1. How does AI-assisted historical interpretation differ from human-driven analysis?
2. What key historical insights emerge when applying GraphRAG to the Case of Witchcraft?
3. Does AI reveal new patterns in historical discourse that were previously overlooked?

Results from these analyses were evaluated against traditional historical methodologies, emphasizing interpretative validity, bias detection, and computational efficiency. The findings demonstrated that GraphRAG enhances historical comprehension by structuring complex narratives into an evidence-based analytical framework, improving scholarly discourse efficiency while maintaining historical integrity.

This study confirms that AI-powered historical analysis tools like GraphRAG can serve as valuable supplements to traditional historical research methods, particularly in studying highly debated historical events such as the Case of Witchcraft.

3. Results

3.1. Understanding Historical Figures through GraphRAG - The Case of Jiang

Figure 2 presents a graph focusing on Jiang Chong, a central figure in the Case of Witchcraft. Key event nodes related to Jiang Chong are identified by embedding historical texts into a knowledge graph.

These include his role in investigating the Witchcraft trials, his involvement in the execution of Prince Zhao Liu Dan, and his eventual downfall. These events are extracted from multiple historical sources, highlighting how GraphRAG enables cross-referencing between academic interpretations.

This approach allows learners to grasp Jiang Chong's role in the broader political landscape of the Han Dynasty without requiring them to sift through extensive textual records. The ability to map relationships and interactions visually enables history students to develop a structured understanding of how Jiang Chong's actions influenced the larger historical narrative.

Figure 2 Knowledge Graph Representation of the Witchcraft Trials During the Han Dynasty

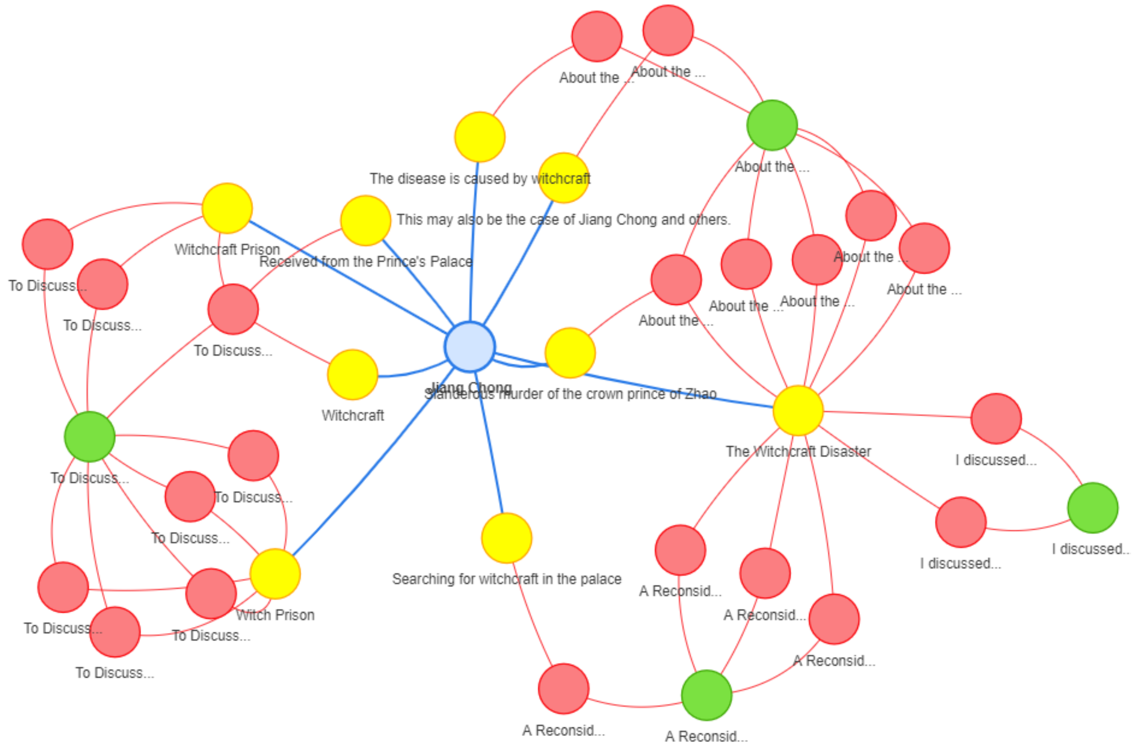
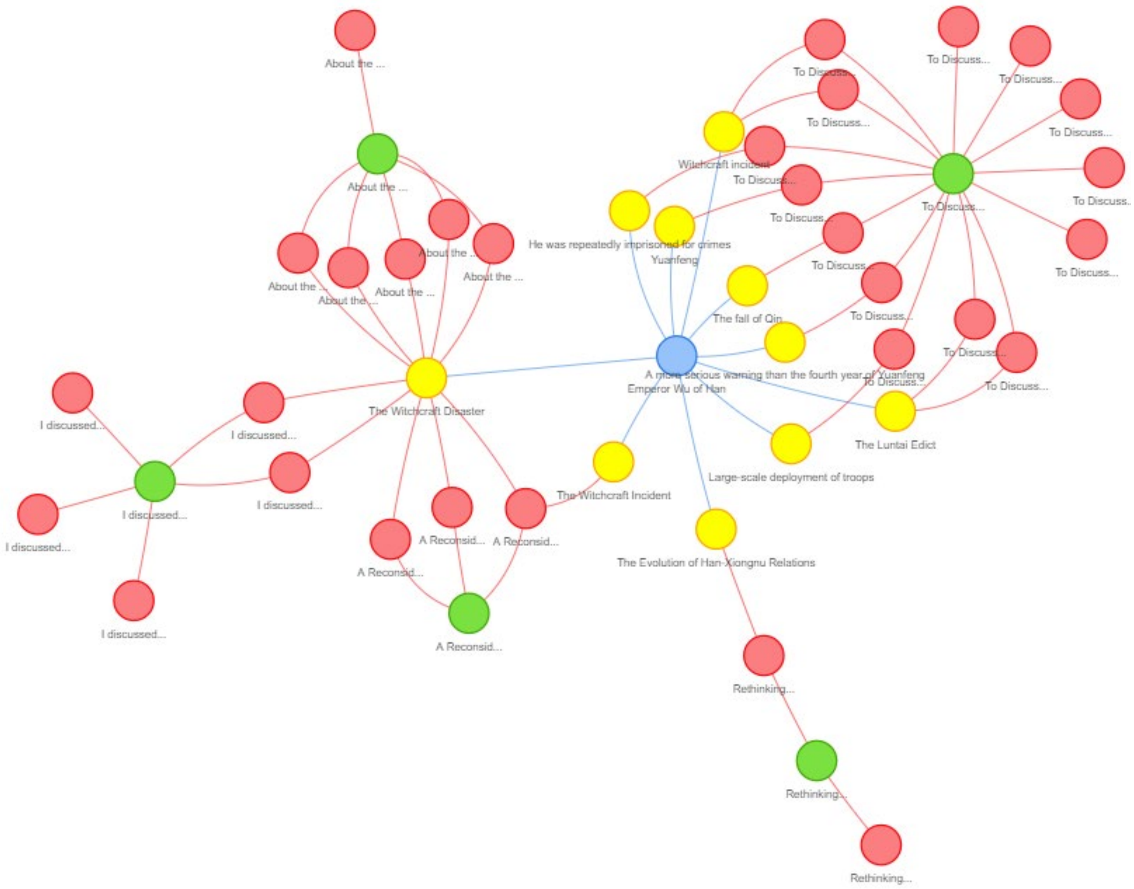


Figure 3 Knowledge Graph Representation of Emperor Wu and the Witchcraft Trials



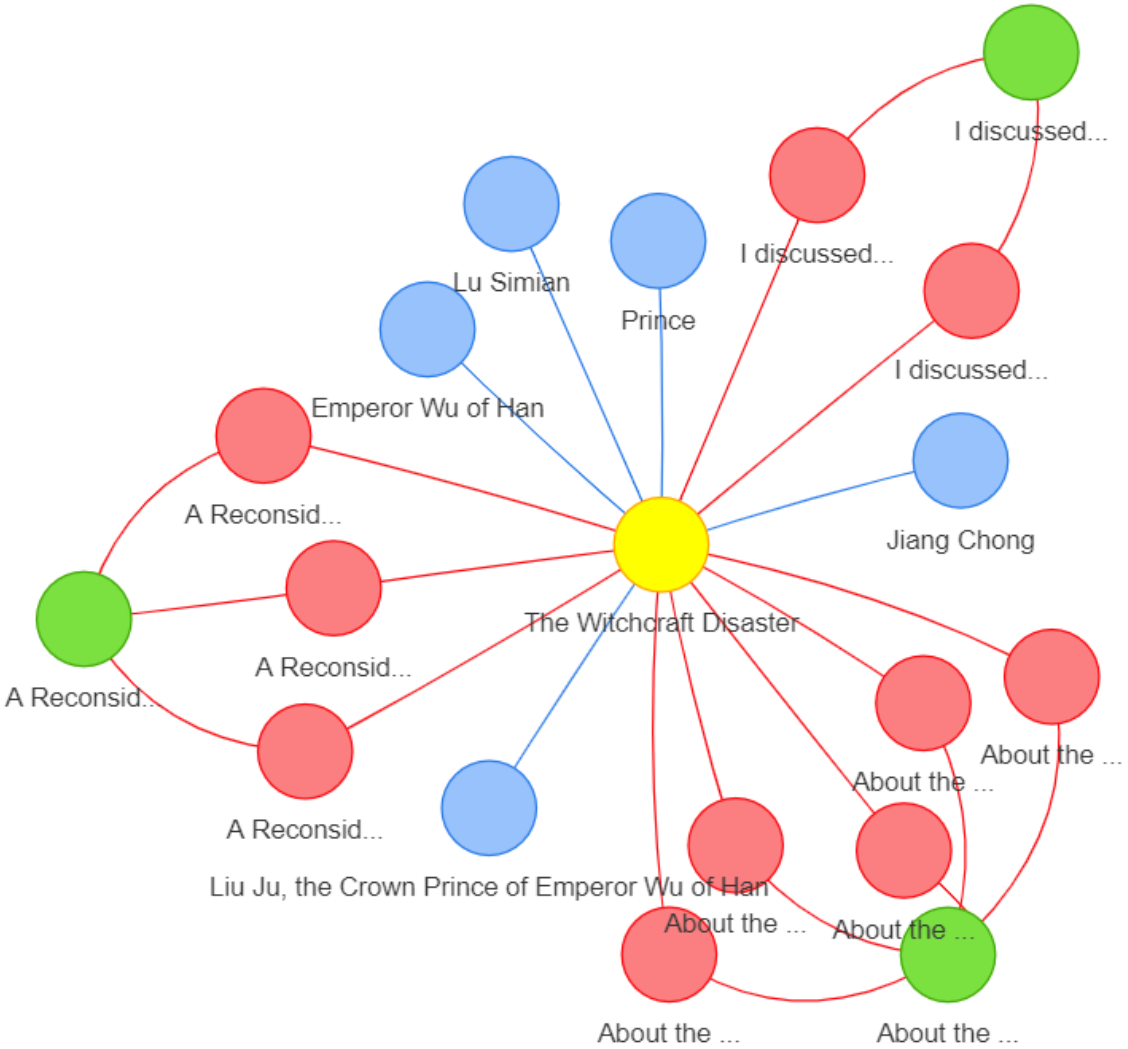
3.2. Analyzing Emperor Wu's Political Shift

Figure 3 presents a graph focusing on Emperor Wu of Han, illustrating key events surrounding his reign and the Case of Witchcraft. The network highlights notable moments such as the fourth year of Yuanfeng, the impact of the Witchcraft trials, and the issuance of the Luntai Edict, widely interpreted as an act of political repentance. The graph structure reveals that most events clustered around Emperor Wu are related to decisions he made post-trials, suggesting that the Witchcraft trials significantly influenced his later governance. The analysis also underscores how event frequency and scholarly attention can bias historical understanding; because our dataset primarily focuses on political shifts following the trials, earlier events in Emperor Wu's reign may be underrepresented. This allows learners to reflect on historiographical gaps and the selective nature of historical documentation.

3.3. Mapping the Complexity of the Case of Witchcraft

Figure 4 presents a graph on the Case of Witchcraft, detailing how different figures were implicated in the trials. The visualization shows key figures such as Emperor Wu, Crown Prince Liu Ju, and Jiang Chong; their relationships are annotated based on historical sources.

Figure 4 Network Representation of Key Figures in the Witchcraft Disaster



The graph also includes annotations from academic interpretations, such as Lu Simian's analysis of the trials. The network structure highlights Prince Liu Ju's designation as a victim of the trials, ultimately leading to his downfall. By connecting figures to their respective roles (e.g., "accused," "investigator," "executed"), learners can better understand the political motivations behind the event and the competing narratives surrounding its causes and consequences. The inclusion of Lu Simian's work emphasizes how different scholars have interpreted the same events differently, reinforcing the importance of multiple perspectives in historical research.

3.4. STEM-Based Approaches to Historical Learning

The integration of GraphRAG into historical research demonstrates a significant shift from traditional text-based analysis to computational methodologies. By structuring historical knowledge into interactive graphs, learners gain a STEM-oriented perspective on history, which includes:

1. Data-driven analysis: Extracting relationships between historical figures and events allows for a structured understanding of complex narratives.
2. Computational modeling: Constructing historical relationship graphs Using Neo4j (https://neo4j.com/docs/python-manual/current/) facilitates a more precise examination of political networks.
3. Visual representation: Interactive graphs give learners a dynamic way to explore historical events rather than passively reading dense historical texts.
4. Critical thinking and interpretation: By interacting with knowledge graphs, students can assess biases in historical documentation and question dominant narratives.

These methodologies represent a transformational approach to history education, making historical inquiry more analytical, exploratory, and computationally rigorous.

3.5. Comparing Traditional vs. AI-Assisted Historical Analysis

Through GraphRAG, we compare traditional RAG-based textual analysis with GraphRAG's structured knowledge extraction. Traditional retrieval-augmented generation (RAG) relies on retrieving textual excerpts from documents based on relevance but lacks structured relationships between entities. GraphRAG enhances retrieval by embedding relationships into a knowledge graph, allowing users to visualize how events and figures interact. This structured approach reveals connections that are not immediately apparent in text-based retrieval.

For example, traditional RAG methods retrieve passages describing Emperor Wu's remorse after the trials in analyzing the Case of Witchcraft. However, GraphRAG contextualizes this remorse within a broader political framework, showing how factional conflicts and court dynamics influenced his actions post-trials. This comparative analysis highlights GraphRAG's advantage in uncovering hidden patterns and causal relationships in historical narratives.

3.6. The Broader Impact on History Education

Traditional history education heavily relies on reading and memorization, often requiring students to analyze long, complex texts without visual support. By incorporating STEM methodologies, this study illustrates how GraphRAG enhances historical learning by structuring information, fostering interactive exploration, and promoting a deeper engagement with historical analysis. Visualizing event relationships, competing interpretations, and causal links makes history more accessible and allows learners to interact with historical narratives actively. The structured analysis also facilitates comparative historiography, enabling students to assess how different scholars have interpreted the same events.

Ultimately, the use of GraphRAG in historical education aligns with the broader trend of digital humanities, demonstrating that computational methods can complement traditional historiographical approaches. By integrating data science, natural language processing, and graph-based retrieval, this methodology offers an innovative framework for exploring historical complexity while maintaining the interpretative nature of the humanities.

The findings in Figures 2, 3, and 4 illustrate how AI-assisted historical research can provide a structured and interactive way to engage with history. As computational tools advance, integrating AI into historical studies will open new possibilities for analyzing large datasets, identifying hidden patterns, and refining our understanding of historical events.

This research contributes to the ongoing discourse on how AI and machine learning can revolutionize the humanities, advocating for a more interdisciplinary and technologically enhanced approach to history education.

4. Discussion

This study highlights how GraphRAG transforms historical research and education by integrating STEM methodologies with traditional historiography. One key advantage is its ability to structure complex historical narratives, reducing reliance on manual cross-referencing. Unlike traditional methods that depend on linear textual reading, GraphRAG systematically links figures, events, and scholarly interpretations into an interactive format, enhancing research efficiency and enabling dynamic exploration of multiple perspectives.

However, AI-generated analyses remain subject to source biases and NLP model limitations. While GraphRAG uncovers hidden connections, it does not replace human interpretation—historians must verify AI-generated insights for contextual accuracy and potential overgeneralization.

Compared to traditional RAG retrieval, which retrieves relevant text snippets but lacks structured entity relationships, GraphRAG excels in encoding event sequences and scholarly debates (e.g., differing interpretations of Emperor Wu's repentance by Tian Yuqing and Pu Muzhou). However, GraphRAG relies on structured historical data, and poorly documented events may lead to fragmented visualizations. Future improvements in NLP accuracy and historical text structuring could enhance its effectiveness.

GraphRAG fosters data literacy, computational reasoning, and critical analysis in education. It encourages students to question sources, verify biases, and explore historical relationships visually, enhancing their understanding of causality and interpretation. However, adoption remains limited due to the technical expertise required for AI-driven tools. Training educators in graph-based querying, AI-assisted text processing, and developing interactive learning platforms can help bridge this gap.

5. Conclusion

This study demonstrates that GraphRAG represents a transformative tool for historical research and education, bridging traditional historiography with AI-driven knowledge graph analysis. By systematically structuring historical events and debates, GraphRAG enhances historiographical clarity, cross-referencing efficiency, and student engagement in complex historical narratives. Our contributions of GraphRAG to Historical Research are as follows:

1. Enhanced Event Structuring – Converts unstructured historical texts into queryable, interconnected knowledge graphs.

2. Comparative Historiographical Analysis – Highlights interpretative differences among scholars through structured retrieval.
3. Causal Relationship Mapping—This tool enables dynamic exploration of historical causality, such as how the Case of Witchcraft influenced Emperor Wu's policies.
4. AI-Augmented Learning – Promotes data-driven historical reasoning, empowering students to explore history beyond rote memorization interactively.

While GraphRAG provides a novel AI-driven approach to historical research, challenges remain in data accuracy, AI interpretability, and educational accessibility. Future research should focus on:

1. Improving NLP accuracy in historical document processing to reduce misinterpretation of event relationships.
2. Expanding GraphRAG's dataset coverage to include multi-language historical texts for broader historiographical analysis.
3. Develop educational interfaces that simplify GraphRAG-based history exploration, making AI-driven analysis more accessible to students and educators.

By integrating GraphRAG into historical studies, researchers and educators can unlock new insights into past events, improve scholarly discourse efficiency, and encourage an interdisciplinary approach to historiographical inquiry. GraphRAG is a valuable supplement to traditional methods, enabling historians to analyze, compare, and interpret complex historical narratives with unprecedented computational support.

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