

Article

An Integrated Framework for Timeline Mapping Using Local Chronicles: A Case Study of Educational Equity in Dengfeng, China

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Abstract

Reconstructing long-term spatiotemporal processes from unstructured historical records presents a fundamental challenge in historical Geographic Information Systems (GIS). Local chronicles contain rich information regarding the timing, location, and context of historical events. However, their narrative form hinders systematic spatiotemporal interpretation and timeline mapping. To address this challenge, this paper proposes an integrated framework for timeline mapping using local chronicles, which includes (1) a dimension-importance evaluation method to identify the most relevant analytical dimension for visualization, (2) a large language model (LLM)-based workflow for extracting, matching, and clustering historical events from unstructured texts with respect to the identified analytical dimension, and (3) a multi-perspective timeline mapping approach to reconstruct and visualize spatiotemporal narratives. The framework is demonstrated through a case study in Dengfeng, China, where historical educational records from local chronicles are employed to reconstruct the long-term spatiotemporal evolution of educational equity. The case study demonstrates that (a) structural balance is identified as the most relevant analytical dimension, guiding subsequent event mining; (b) the LLM-based workflow extracts and structures 721 historical events, with 415 events matched to the identified dimension and clustered into three thematic groups of institutional plurality, school system reform, and spatial reorganization; and (c) the multi-perspective timeline maps generated from these clusters effectively reveal a long-term, coherent process of structural reconfiguration, illustrating the framework's capacity to transform narrative historical records into interpretable spatiotemporal narratives. The proposed framework provides a transferable historical GIS workflow for timeline mapping using local chronicles and offers a practical approach for reconstructing spatiotemporal processes from unstructured historical texts in various geographical contexts.

Keywords: historical GIS; narrative cartography; timeline mapping; large language models; historical text mining; spatiotemporal interpretation

1. Introduction

Reconstructing long-term spatiotemporal processes from narrative historical records is fundamental to historical Geographic Information Systems (GIS) [1,2]. Chinese local



Academic Editors: Andriani Skopeliti, Ioannis Giannopoulos, Vassilios Krassanakis, Guillaume Touya and Wolfgang Kainz

Received: 9 July 2026

Revised: 11 September 2026

Accepted: 21 September 2026

Published: 25 September 2026

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chronicles serve as a crucial data source in this context, providing continuous documentary records of historical events within specific administrative regions while preserving essential information regarding their timing, location, and social context [2,3]. However, these texts are structured as narrative prose, with events dispersed across chapters and recorded without standardized spatial or temporal fields. This lack of structure complicates the direct utilization of these records for spatiotemporal interpretation. Consequently, a methodological approach is necessary to systematically organize and present the spatial and temporal information embedded in local chronicles, thereby facilitating the exploration of long-term historical processes [4].

Narrative cartography serves as an effective approach to address the limitations of traditional mapping by integrating temporal sequencing into spatial representation [5,6]. Among its various forms, timeline mapping is particularly well-suited for organizing historical events according to their temporal progression and spatial context [7]. However, constructing an effective timeline map necessitates more than merely visualizing all available events. Historical records typically encompass multiple analytical dimensions, and displaying all events simultaneously often obscures meaningful spatiotemporal patterns [8]. This underscores the need to identify the single most critical analytical focus for a given study area as a prerequisite for effective timeline mapping. Most existing studies, however, rely on predefined analytical focuses without systematically evaluating which dimension is most relevant in a specific context [9,10]. Furthermore, the most relevant dimension is likely to vary across regions, necessitating a context-sensitive method to determine the appropriate focus for timeline mapping. While historical chronicles are rich in event records, they do not provide systematic multi-dimensional data for such identification. In contrast, contemporary statistical data offer a comprehensive and comparable basis for multi-dimensional assessment [11,12]. The underlying premise is that the fundamental structure of the study domain in a region often exhibits historical continuity, making the dimension identified from contemporary data a suitable lens for timeline mapping using narrative historical records.

With the key dimension identified from contemporary data, constructing timeline maps requires the systematic identification and organization of relevant historical events from local chronicles. However, the extensive volume of textual material spanning long historical periods makes manual extraction impractical [13]. More fundamentally, historical Chinese texts exhibit inherent semantic ambiguity, where identical terms may have different meanings across dynasties, contexts, or administrative scales. This necessitates contextual interpretation that transcends rule-based or keyword-based methods [14,15]. Recent advances in large language models (LLMs) offer new opportunities for contextual disambiguation and thematic clustering from unstructured corpora [16–19]. LLMs can extract historical events and evaluate their relevance to a specified analytical dimension. These events can subsequently be clustered into semantically coherent thematic groups based on their content, thereby providing structured inputs for timeline construction. Crucially, different thematic groups often follow distinct temporal trajectories, each representing a different facet of the same historical process. A single timeline that conflates all events would obscure these distinct trajectories. In contrast, visualizing each thematic group on a separate timeline through a multi-perspective timeline mapping approach can elucidate the heterogeneous evolution of the study domain in a more interpretable manner [20–23]. Given that the quality of event extraction and thematic clustering depends on the underlying model, multiple LLMs are comparatively evaluated to identify the most suitable model for historical event extraction and thematic organization [24].

The goal of this study is to propose an integrated framework for timeline mapping using local chronicles to reconstruct long-term spatiotemporal processes from narrative his-

torical records. Specifically, this study attempts to address three key questions: (1) which dimension of educational equity is most relevant for timeline mapping and how robust this identification is; (2) how effectively LLM-assisted methods can extract and organize historical events from unstructured chronicle texts; and (3) how users evaluate the readability, interpretability, and usefulness of the resulting timeline maps. To achieve these objectives, an evaluation of dimension importance is initially carried out using contemporary data and an objective weighting method to identify the most relevant analytical dimension for timeline mapping. Additional assessments are conducted to examine the robustness of the weighting approach and the identified analytical focus. Subsequently, LLMs are employed to extract, match, and organize historical events from un-structured chronicle texts into multiple thematic groups based on the identified focus. The extracted events and thematic organization are further assessed through manual review and comparative analysis. Following this, timeline maps for each thematic group are generated to visualize distinct temporal trajectories within a unified spatiotemporal reference system, and their interpretability is examined through questionnaire-based evaluation. To provide an empirical illustration of the proposed framework, a case study is conducted in Dengfeng, China, where historical educational records from local chronicles are employed to reconstruct the long-term spatiotemporal evolution of educational equity.

2. Materials and Methods

2.1. Study Area

Dengfeng ($34^{\circ}15'–34^{\circ}35' \text{ N}$, $112^{\circ}49'–113^{\circ}19' \text{ E}$) is a historical city, located in the central region of Henan Province, China (Figure 1). The city covers an area of approximately 1217 km^2 and had a permanent population of 726,800 as of 2024, with 63.02% of residents living in urban areas. According to the 2024 Zhengzhou Statistical Yearbook [25], there were 234 educational institutions in the city in 2023, comprising 103 kindergartens, 66 primary schools, 49 junior high schools, 5 senior high schools, 10 vocational schools, and 1 special education school. The reasons for selecting this case study are as follows: First, the dual-track educational system, which accommodates both general and wushu schools (specialized institutions that integrate martial arts education into formal education) [26], provides a rigorous test for the framework's capacity to manage heterogeneous event streams. Second, the multidimensional nature of educational equity provides a suitable context for evaluating the dimension-importance evaluation component.

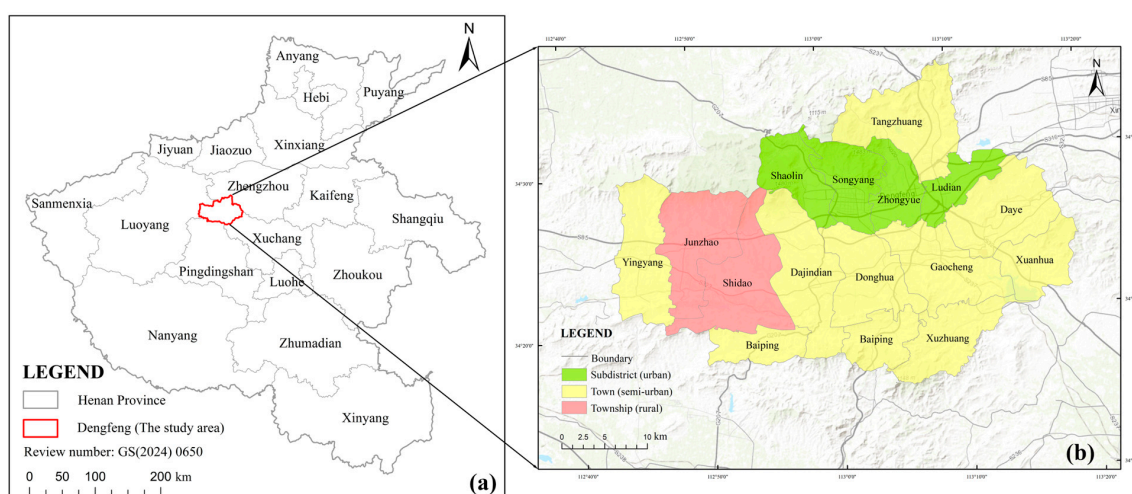


Figure 1. Study area: (a) the location of Dengfeng in Henan Province; (b) the administrative division map of Dengfeng. Both maps are presented in the WGS 1984 World Mercator projected coordinate system.

2.2. Collected Data

School Point of Interest (POI) data, school statistics, resident population data and historical event records were collected in this study. The POI data were obtained from AutoNavi Map, a widely used online mapping service, <https://www.amap.com/> (accessed on 15 December 2025). The school statistics encompass enrollment, staffing, and expenditure data across different educational stages and school types, sourced from the official government information disclosure portals of Dengfeng City, <https://public.dengfeng.gov.cn/> (accessed on 6 December 2025) and <https://df.jiceng.zhengzhou.gov.cn/> (accessed on 6 December 2025). Historical event records, i.e., local chronicle texts, were retrieved from the Knowledge Service Platform of the Chinese Academy of Sciences, <https://www.las.ac.cn/> (accessed on 10 November 2025). Detailed information can be found in Table 1. The resident population data were derived from the Seventh National Population Census conducted in 2020, which represents the most recent official census dataset available at the required subdistrict scale during the study period.

Table 1. Data sources.

Data	Source	Year	Spatial Scale	Coverage/Content Used	Access and Notes
School POI data	AutoNavi Map (AutoNavi)	2024	Point	School locations	Online service; accessed December 2025; academic use under public terms
School statistics	Dengfeng City Government	2024	Subdistrict	Schools, staffing, enrollment, and expenditure	Government disclosure data; accessed December 2025
Resident population data	Seventh National Population Census	2020	Subdistrict	Resident population	Official census data (National Bureau of Statistics of China)
Historical event records	Dengfeng City Chronicle (Dengfeng Local Compilation Committee)	2008	City	Education records (pp. 1221–1305)	PDF accessed via CAS platform (December 2025); ISBN: 978-7-5348-2977-2
Historical event records	Dengfeng County Education Chronicle (Dengfeng County Education Chronicle Compilation Committee)	1988	City	Entire volume (16 chapters, 385p)	PDF accessed via CAS platform (December 2025); ISBN: 7-215-00409-0

2.3. Methodology

The process of this proposed framework can be described as follows: (1) The key dimension is quantitatively identified using a dimension-importance evaluation approach to determine the most relevant analytical focus; (2) Multi-perspective information on historical events is mined from local chronicles by employing large language models (LLMs) to extract, match, and cluster event records based on the identified analytical dimension; and (3) Timeline maps of multiple thematic clusters are generated to reconstruct and visualize spatiotemporal narratives. The flowchart of the proposed framework is illustrated in Figure 2.

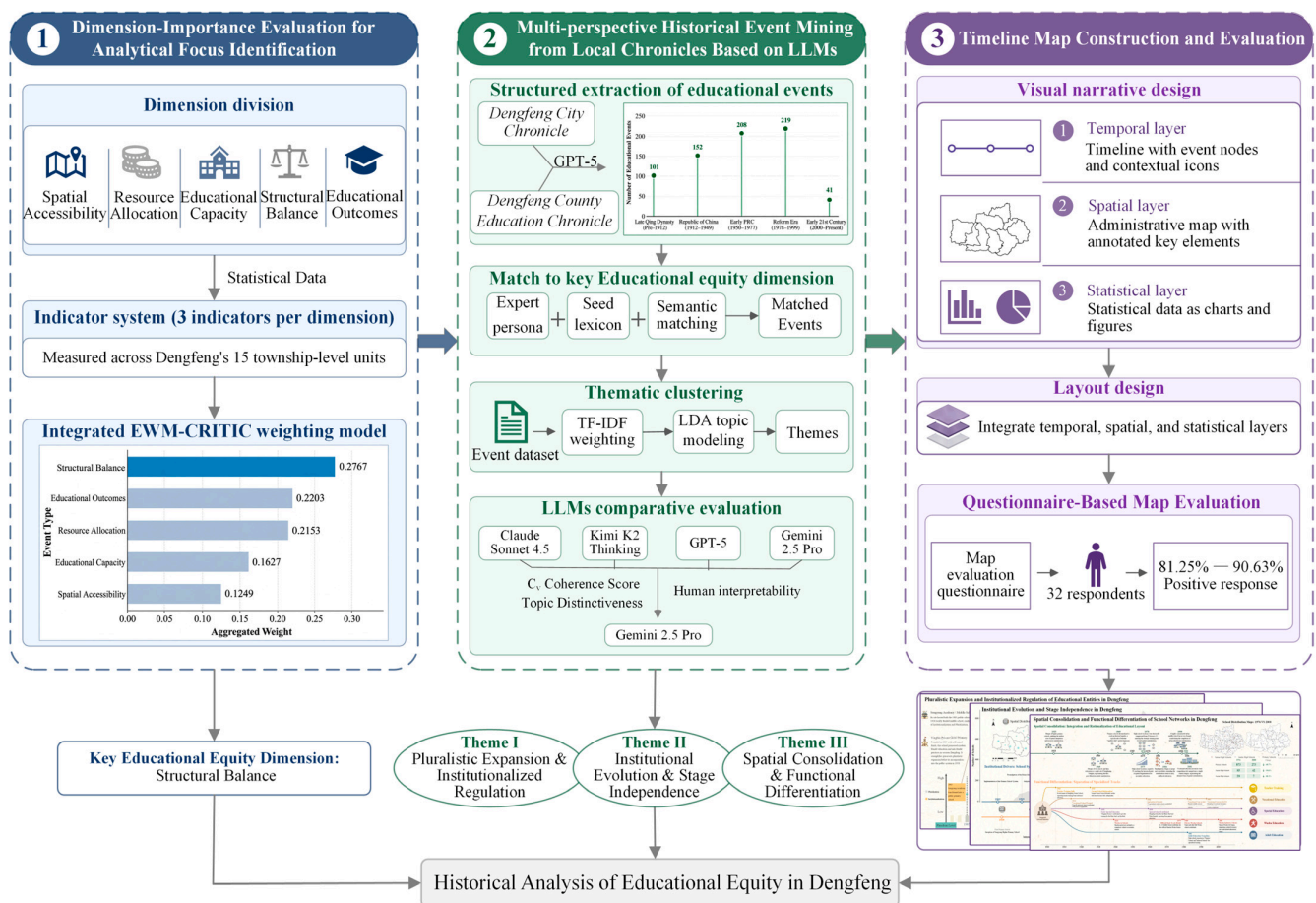


Figure 2. An integrated framework of timeline mapping that combines key dimension identification and LLM-based multi-perspective historical event mining from local chronicles.

2.3.1. Dimension-Importance Evaluation for Analytical Focus Identification

Contemporary statistical data provide a comprehensive and comparable foundation for multi-dimensional assessment. The dimension identified from these data provides an analytical perspective for subsequent timeline mapping using narrative historical records. The process of the key dimension identification using contemporary data is as follows.

(1) Dimension division

Educational equity is categorized into five dimensions of spatial accessibility, resource allocation, educational capacity, structural balance, and educational outcomes. This classification is informed by research on equality of educational opportunity and conceptualizations of educational equity [27,28]. Spatial accessibility measures the geographic distribution of educational facilities and students' physical access to schools, reflecting the extent to which spatial conditions influence unequal participation in education [29,30]. Resource allocation evaluates the distribution of educational funding and student subsidies among schools, capturing disparities in the financial conditions of education [31–33]. Educational capacity assesses a region's ability to accommodate enrollments without overcrowding, reflecting the spatiotemporal balance between educational supply and demographic demand [34]. Structural balance examines the completeness of conventional educational stages and the degree of specialization in education [35]. Educational outcomes capture the downstream results of schooling, including the likelihood of progression to higher educational stages, student retention rates, and the adequacy of teaching resources [36,37].

(2) Dimension-importance evaluation

To identify the key dimension, a combined weighting method that integrates the Entropy Weight Method and Criteria Importance Through Intercriteria Correlation (EWM-CRITIC) [38,39] was adopted, as follows:

First, an indicator system comprising 15 measurable indicators was developed to represent the five dimensions of educational equity. This system was informed by established frameworks for assessing educational equity [40–42] while also incorporating educational characteristics specific to Dengfeng. Detailed information regarding the constructed indicator system is presented in Table 2.

Table 2. Indicator system for key educational equity dimension evaluation.

Dimension	Indicator	Property ¹
Spatial Accessibility	Theoretical Service Radius	—
	Spatial Clustering Index	+
	Kernel Density Mean	+
Resource Allocation	Educational Expenditure	+
	Per-School Expenditure	+
	Subsidized Students	+
Educational Capacity	Compulsory Education Scale	+
	School Network Coverage	+
	Educational Pressure Coefficient	—
Structural Balance	Preschool Education Provision	+
	Martial-Civilian Education Ratio	—
	Educational Stage Completeness	+
Educational Outcomes	High School Spatial Accessibility	+
	Junior High Retention Rate	+
	Teacher-Student Ratio	+

¹ “+” (“—”) denotes a positive (negative) indicator, where higher (lower) values signify greater educational equity.

Second, the EWM-CRITIC model was employed to evaluate the importance of the five dimensions. This model integrates the EWM’s capability to capture information diversity with the CRITIC’s consideration of both contrast intensity and inter-indicator correlations, thereby providing a comprehensive and objective weighting scheme. The formulas for this model are as follows:

$$W_d = \sum_{j \in A_d} w_j \quad (1)$$

$$w_j = \frac{w_j^{\text{EWM}} + w_j^{\text{CRITIC}}}{2} \quad (2)$$

where W_d denotes the overall importance of dimension d , A_d denotes the set of indicators belonging to dimension d , and w_j denotes the combined weight of indicator j . w_j^{EWM} and w_j^{CRITIC} are the weights of indicator j calculated by EWM and CRITIC, respectively. Note that, a higher W_d indicates a greater contribution of the corresponding dimension. Thus, the dimension with the highest W_d was identified as the key dimension. w_j^{EWM} was defined as follows:

$$w_j^{\text{EWM}} = \frac{1 - E_j}{\sum_{k=1}^m (1 - E_k)} \quad (3)$$

$$E_j = -\frac{1}{\ln n} \sum_{i=1}^n p_{ij} \ln(p_{ij}) \quad (4)$$

$$p_{ij} = \frac{x_{ij}^* + \epsilon}{\sum_{k=1}^n (x_{kj}^* + \epsilon)} \quad (5)$$

where E_j denotes the entropy of indicator j , p_{ij} denotes the normalized proportion of administrative unit i for indicator j , x_{ij} denotes the raw value of indicator j for administrative unit i , and x_{ij}^* denotes its standardized value. m and n denote the total numbers of indicators and administrative units, respectively, with $m = 15$ and $n = 15$ in this study. ϵ is a small positive constant, set to 1×10^{-10} in this study, to avoid undefined logarithmic values when $p_{ij} = 0$. w_j^{CRITIC} was defined as follows:

$$w_j^{\text{CRITIC}} = \frac{C_j}{\sum_{k=1}^m C_k} \quad (6)$$

$$C_j = \sigma_j \sum_{k=1}^m (1 - r_{jk}) \quad (7)$$

$$r_{jk} = \frac{\sum_{i=1}^n (x_{ij}^* - \bar{x}_j^*)(x_{ik}^* - \bar{x}_k^*)}{\sqrt{\sum_{i=1}^n (x_{ij}^* - \bar{x}_j^*)^2} \sqrt{\sum_{i=1}^n (x_{ik}^* - \bar{x}_k^*)^2}} \quad (8)$$

where C_j represents the information content of indicator j , σ_j represents the standard deviation of indicator j , reflecting its contrast intensity, and r_{jk} denotes the correlation coefficient between indicators j and k , representing the degree of redundancy among indicators. $\bar{x}_j^*$ and $\bar{x}_k^*$ denote the mean standardized values of indicators j and k , respectively. Before calculating the weights, Min–Max standardization was applied to eliminate scale differences among indicators.

For positive indicators:

$$x_{ij}^* = \frac{x_{ij} - \min_i(x_{ij})}{\max_i(x_{ij}) - \min_i(x_{ij})} \quad (9)$$

For negative indicators:

$$x_{ij}^* = \frac{\max_i(x_{ij}) - x_{ij}}{\max_i(x_{ij}) - \min_i(x_{ij})} \quad (10)$$

where $i = 1, \dots, n$ denotes the administrative units, $j = 1, \dots, m$ denotes the indicators and $x_{ij}^* \in [0, 1]$.

2.3.2. Multi-Perspective Historical Event Mining from Local Chronicles Based on LLMs

After identifying the key dimension, historical event records in the local chronicles were screened for relevance to this dimension. However, the extensive and unstructured prose of these chronicles presents challenges for systematic information mining. Recent advances in LLMs, which exhibit strong natural language understanding and contextual reasoning capabilities, offer an effective solution to this challenge. Consequently, this study employs LLMs for historical event mining through event extraction, matching, and clustering, as detailed below.

(1) Structured extraction of historical educational events from local chronicles

The ‘5W1H’ principle encompasses the six fundamental dimensions of an event: Who, What, When, Where, Why, and How [43]. In adapting this principle to the context of his-

torical educational events, ten structured fields have been defined: Event ID, Event Name, Start Time, End Time, Subject, Object, Location, Event Description, Event Type, and Impact. This structured framework enables the automated extraction of events.

Subsequently, GPT-5 [44] was employed to extract events in batches using structured prompts. The prompt was structured around four components: task instruction, field definitions, output-format requirements, and extraction constraints. It guided the model in identifying educational events from the provided chronicle text and mapping the relevant information to the predefined fields, while specifying field requirements and maintaining a consistent output format. Additional constraints were included to preserve the factual meaning of the source text, avoid introducing unsupported information, and ensure the accuracy of names, dates, locations, and numerical information. The main components of the prompt used for structured extraction are presented in Table 3.

Table 3. Main components of the prompt used for GPT-5-based structured extraction of historical educational events.

Prompt Component	Prompt Content
Task instruction	Identify historical educational events from the provided local chronicle text and map the relevant information to the predefined structured fields.
Field definitions	Extract Event Name, Start Time, End Time, Subject, Object, Location, Event Description, Event Type, and Impact according to their predefined meanings. Event ID is assigned sequentially after extraction.
Output format	Return each event as a structured JSON record using consistent field names and order. Record unavailable information as “Not available”.
Extraction constraints	Preserve the factual meaning of the source text, avoid unsupported information, and maintain the accuracy of names, dates, locations, and numerical information.

To assess the quality of the structured extraction, 80 events were randomly sampled from the complete set of extracted events using a computer-generated random sampling procedure. These events were independently reviewed by two authors against the original chronicle records. The review focused on the accuracy of key factual fields, including time, location, involved entities, and event descriptions. An event was considered correctly extracted only when all reviewed fields were consistent with the original chronicle records. The event-level extraction accuracy was calculated based on the proportion of correctly extracted events. Additionally, the agreement between the two reviewers was assessed. Any disagreements between the two reviewers were resolved through discussion and re-examination of the source text.

(2) Event matching and thematic clustering for key dimension

Although historical events have been extracted from local chronicles and key dimension identified, the relationship between them remains ambiguous. To address this ambiguity, event matching was conducted to identify historical events closely associated with the target dimension through semantic analysis. However, the matched events remained discrete and unconnected, which provided limited insight into broader patterns of educational development. To uncover their underlying thematic structure and improve interpretability, thematic clustering was further performed to group semantically related events into coherent themes. The resulting thematic event groups provided a structured founda-

tion for subsequent timeline mapping and spatiotemporal narrative interpretation. The detailed process is outlined as follows.

First, event matching was performed to identify historical events pertinent to the key dimension of educational equity. The three constituent indicators of this dimension, along with their corresponding seed lexicons, were integrated into the prompts as semantic references to guide the LLMs in identifying their underlying characteristics. The seed lexicons were manually developed based on the conceptual definitions of the three indicators and relevant domain-specific terminology related to educational development. Their purpose was to provide representative semantic cues for each indicator rather than to exhaustively cover all possible expressions. Based on the event titles and descriptions extracted from local chronicles, the LLMs evaluated the relevance of each event to the target dimension through contextual semantic analysis. As illustrated in Figure 3, an event was considered relevant when its substantive content was closely associated with at least one of the three constituent indicators, while the seed terms served as semantic cues rather than strict keyword-matching criteria. Relevant events were retained to construct a dimension-specific event corpus.

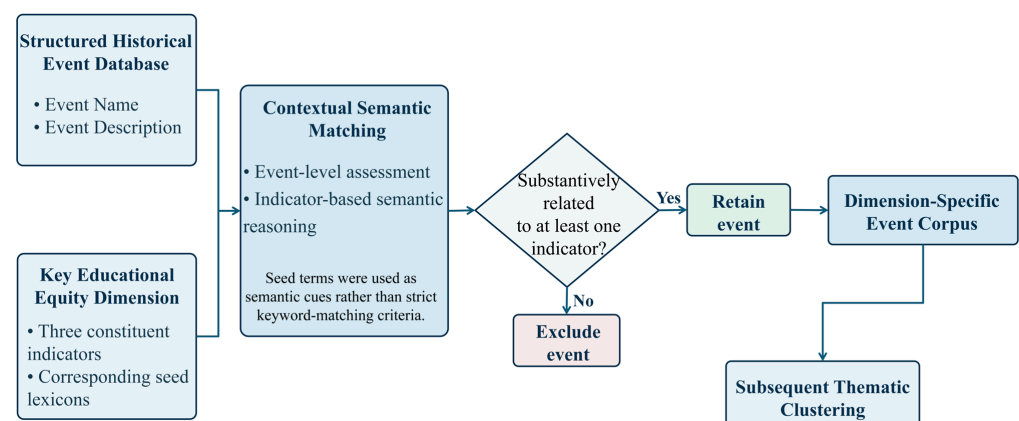


Figure 3. Semantic matching workflow for historical events related to the key educational equity dimension.

Second, thematic clustering was conducted using the code interpreter functionality available through the LLM web interfaces. The LLMs facilitated the implementation and execution of the analytical workflow, while the underlying numerical calculations were performed using Python code. LDA topic modeling [45] was used to uncover latent thematic structures within the corpus. TF-IDF weighting was applied to construct a weighted document–term matrix, which served as the input for the LDA topic modeling, calculated as:

$$TF - IDF(t, d, D) = TF(t, d) \times \log \frac{|D|}{|\{d \in D : t \in d\}|} \quad (11)$$

where t denotes a term, d denotes an event document, D denotes the complete event corpus, $TF(t, d)$ denotes the term frequency of term t in document d , $|D|$ is the total number of event documents, and $|\{d \in D : t \in d\}|$ is the number of documents containing term t . The number of topics was set to $K = 3$. Each event was then assigned to its dominant topic based on the highest posterior probability. For each topic, the top 10 terms with the highest topic–word probabilities were retained and subsequently interpreted by the LLMs to generate thematic labels.

Third, Claude Sonnet 4.5 [46], Kimi K2 Thinking [47], GPT-5 [44], and Gemini 2.5 Pro [48] were applied using the same corpus and prompt framework specifying the same analytical tasks and output requirements. The model names refer to the labels displayed in

the respective web-based interfaces at the time of analysis. The analyses were conducted through the web-based interfaces of the corresponding platforms using the default settings available at the time of analysis. In this paper, the comparative LLM analysis was conducted on 20 December 2025, with each model executed once using the finalized prompt and identical input corpus. The resulting LLM-assisted workflows were compared to improve the reliability of model selection. The final workflow was selected based on three criteria: C_v coherence score, topic distinctiveness (TD), and human interpretability evaluation of the generated thematic clusters [49]. The C_v coherence score was used to evaluate semantic coherence among the top-ranked terms within each topic. This score combines word co-occurrence information with normalized pointwise mutual information (NPMI) and an indirect confirmation measure. Higher C_v values indicate a greater degree of semantic coherence within a topic. The TD was computed as follows:

$$TD = 1 - \frac{2}{K(K-1)} \sum_{i < j} \frac{|T_i \cap T_j|}{|T_i \cup T_j|} \quad (12)$$

where K denotes the number of topics ($K = 3$ in this study); T_i and T_j denote the sets of the top 10 terms for topics i and j , respectively. Higher TD values indicate greater distinctiveness between topics. To further assess the interpretability of the generated thematic clusters, a human interpretability evaluation was conducted. The evaluators comprised researchers and scholars specializing in GIS/cartography, education, history, and computational science, thereby providing multidisciplinary perspectives for assessing topic interpretability. The identities of the LLMs used to generate each thematic cluster were concealed during the evaluation process to reduce potential bias. Each generated topic was rated on a five-point Likert scale, with semantic clarity, internal consistency, and suitability for supporting historical narrative interpretation considered the primary evaluation criteria. The final human interpretability score was calculated as the average rating across all evaluated topics and evaluators.

2.3.3. Timeline Map Construction and Evaluation

After thematically organizing the historical events, they were subsequently transformed into timeline maps. This transformation aimed to integrate temporal, spatial, and thematic information into a coherent visual narrative. To ensure that the resulting maps presented historical information systematically while remaining understandable and interpretable for readers, the mapping process incorporated both visual narrative design and a questionnaire-based evaluation. The detailed procedures are described as follows.

(1) Timeline Map Construction and Visual Narrative Design

To translate the thematic clusters identified above into a spatiotemporal visual narrative, the timeline maps were designed based on three guiding principles. First, a horizontal timeline spanning from the late Qing Dynasty to the early twenty-first century serves as the structural backbone, with key events plotted as nodes. Icons reflecting historical and cultural significance have been incorporated to enhance both readability and visual expressiveness [7,50,51]. Second, an administrative map of Dengfeng is embedded within each composition, with important spatial features annotated to reveal the uneven distribution of educational change across the city [5]. Third, statistical data on key dimensions of educational equity are presented alongside each map in the form of charts and figures, bridging quantitative analysis with qualitative historical narratives [6,52]. Each map thus integrates spatial, temporal, and statistical layers into a single comprehensive composition.

Following thematic clustering, the top-ranked keywords and semantic characteristics of each thematic cluster were used to identify candidate events. The authors conducted a

manual review of these candidate events based on their thematic relevance, historical significance, temporal coverage, and contribution to the spatial and narrative interpretation of educational change. Similar or closely related events within the same historical period were selectively retained or aggregated to minimize redundancy and enhance visual readability. The selected events were organized according to the narrative structure of each thematic cluster. To ensure visual consistency, all timeline maps adhered to a uniform layout size of 170×80 mm and incorporated essential components, including a map title, narrative spaces, textual explanations, inset maps, and a legend. The layouts were tailored to the thematic logic of each cluster, featuring a centralized layout for Theme I, a layered layout centered on parallel timelines for Theme II, and a stacked two-section layout for Theme III. Spatial data processing and map preparation were performed using ArcGIS Pro, while timeline composition, textual and graphical arrangement, and final visual refinement were executed in Adobe Photoshop. The overall workflow and layout designs are illustrated in Figure 4.

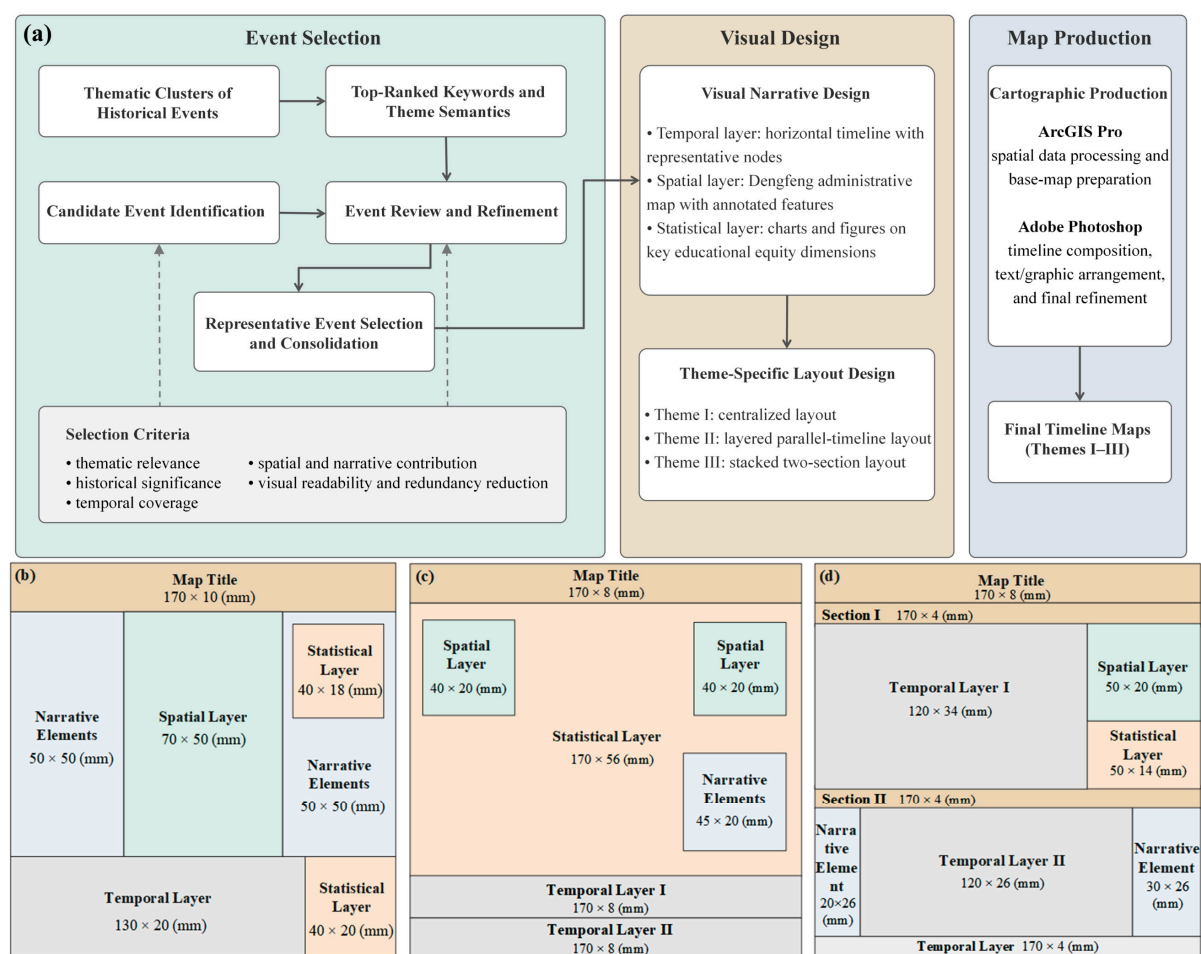


Figure 4. Workflow and layout design of the thematic timeline maps: (a) Workflow of representative-event selection and timeline map construction; (b) Layout design of Theme I; (c) Layout design of Theme II; (d) Layout design of Theme III.

(2) Questionnaire-Based Map Evaluation

To evaluate the perceived interpretability and readability of the timeline maps, a questionnaire-based reader evaluation was conducted after the maps were completed. Previous studies have demonstrated the value of user- and expert-based evaluations in assessing cartographic and geovisualization products [53]. Participants were recruited through convenience sampling, including university teachers/researchers and students

from diverse academic and professional backgrounds, with varying levels of familiarity with maps, GIS, and spatial visualization. After reviewing the three timeline maps, respondents indicated their level of agreement with five statements using a five-point Likert scale, with options ranging from ‘strongly agree’ to ‘strongly disagree.’ The statements addressed aspects such as temporal representation, spatial representation, visual design, narrative coherence, and support for historical interpretation. Additionally, the questionnaire recorded respondents’ academic or professional status, disciplinary background, and familiarity with maps, GIS, or spatial visualization. For descriptive analysis, responses of ‘strongly agree’ and ‘agree’ were combined as positive responses, and their proportions were calculated for each statement. The evaluation statements and corresponding response options are presented in Table 4. Participation was voluntary and anonymous, and no personally identifiable information was collected. According to the relevant institutional regulations, ethical approval was not required for this questionnaire because it involved minimal-risk anonymous participation.

Table 4. Statements and response options used in the timeline map evaluation questionnaire.

Statements	Options
The timeline maps clearly present the temporal sequence and long-term evolution of historical educational events.	A. Strongly agree; B. Agree; C. Neutral; D. Disagree; E. Strongly disagree.
The maps clearly represent the spatial distribution and spatial changes in educational institutions and historical events over time.	
The visual design, including colors, symbols, layout, and graphical elements, effectively distinguishes different thematic groups and key historical events.	
The three timeline maps help reveal a coherent long-term narrative of the evolution of educational equity in Dengfeng.	
The timeline mapping approach facilitates the understanding and interpretation of historical information extracted from local chronicles.	

3. Results

3.1. Key Dimension Identification and Robustness Analysis Results

Figure 5 presents the evaluation results of five dimensions of educational equity, including the indicator weights (Figure 5a) and the dimension scores (Figure 5b). At the indicator level, the Martial-Civilian Education Ratio (0.1156) and Educational Stage Completeness (0.1124) received the highest weights, indicating that these indicators contribute most significantly to the overall evaluation within the indicator system. As illustrated in Figure 5b, Structural Balance achieved the highest dimension score (0.2767), followed by Educational Outcomes (0.2203), Resource Allocation (0.2153), Educational Capacity (0.1627), and Spatial Accessibility (0.1249). Therefore, Structural Balance was identified as the key dimension of educational equity for Dengfeng, aligning with the city’s distinctive educational landscape. Dengfeng has long maintained a dual-track system comprising general schools and wushu (martial arts) schools. The high score of Structural Balance likely reflects the structural disparities between these two tracks, such as differences in school completeness and the relative share of wushu education, which are less pronounced in other dimensions like spatial accessibility. Consequently, subsequent historical analy-

ses and timeline mapping will focus on the evolution of structural balance, utilizing local chronicles to identify events related to the dual-track system.

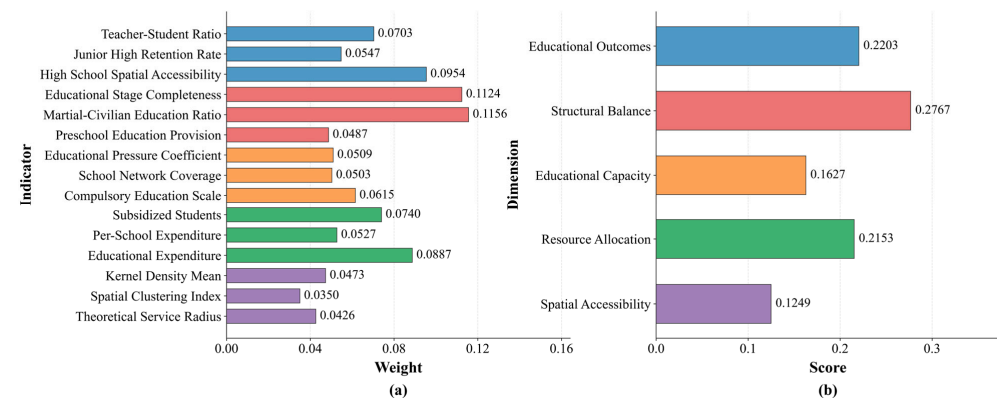


Figure 5. Ranking of indicators and dimensions: (a) the weights of individual indicators; (b) the scores of evaluation dimensions.

To examine whether the contemporary analytical focus aligns with earlier educational structures, a historical consistency analysis was conducted using township-level school distributions from 1985, 2005, and the contemporary period. Spearman's rank correlation showed a significant positive association between junior-high-school distributions in 1985 and 2005 ($\rho = 0.704, p = 0.007$). The distributions from 1985 and 2005 were also significantly positively associated with the contemporary distribution of compulsory-education schools ($\rho = 0.593, p = 0.032$, and $\rho = 0.576, p = 0.039$, respectively). These results indicate a degree of temporal continuity in the spatial structure of educational provision, further supporting the use of Structural Balance as the analytical focus for the subsequent historical analysis.

The robustness of the dimension-ranking result was further assessed by varying the relative contributions of the EWM and CRITIC methods within the combined weighting scheme. The contribution of EWM was varied from 0 to 1 at intervals of 0.05, with the remaining weight assigned to CRITIC. As shown in Figure 6, Structural Balance consistently ranked as the highest dimension in 16 out of the 21 tested configurations and in all configurations where the EWM contribution was at least 0.25. In contrast, when the CRITIC contribution became dominant, Educational Outcomes ranked first. These findings suggest that the identification of Structural Balance as the key dimension was generally robust across most tested weighting configurations, although some sensitivity was observed under conditions of pronounced CRITIC dominance.

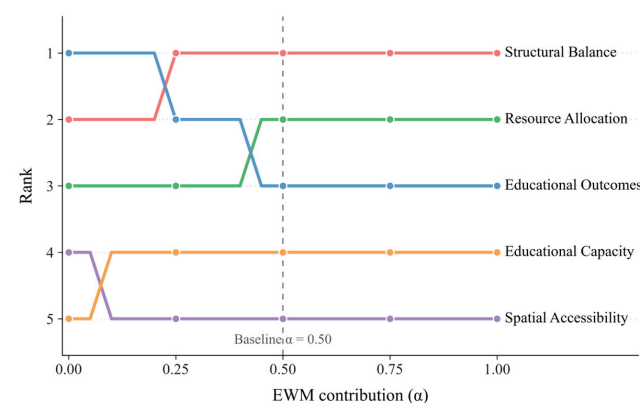


Figure 6. Sensitivity analysis of dimension weights under different EWM–CRITIC weighting configurations.

3.2. LLM-Based Multi-Perspective Historical Event Mining Results

A total of 721 historical educational events were extracted from the Dengfeng City Chronicle and the Dengfeng County Education Chronicle using GPT-5. This initial extraction aimed solely to obtain a structured event corpus, which was subsequently assessed through manual review and used for matching and thematic clustering. Figure 7 presents a representative example linking an original chronicle passage to its corresponding structured event record. This example demonstrates how key factual information was organized into the predefined event fields.



Figure 7. Example of structured historical event extraction from local chronicle text.

To assess the quality of the structured extraction results, 80 events were randomly selected from the extracted event corpus for manual review by two authors. The assessment showed that Reviewer 1 and Reviewer 2 identified 79 and 80 correctly extracted events, resulting in event-level extraction accuracies of 98.75% and 100%, respectively. The initial percentage agreement between the two reviewers was 98.75% (79/80). After discussion and re-examination of the original chronicle records, the disagreement was resolved, and all reviewed events were confirmed to be consistent with the source texts. The identified discrepancy was attributed to variations in historical place-name expressions across local records rather than an incorrect interpretation of the historical event itself.

Subsequently, the matching and clustering tasks were conducted independently by multiple LLMs for comparative analysis. Table 5 presents examples of the seed lexicon used as semantic references for matching events related to the key educational equity dimension of Structural Balance from the extracted 721 events. Table 6 illustrates the performance of four LLMs: GPT-5, Kimi K2 Thinking, Claude Sonnet 4.5, and Gemini 2.5 Pro. GPT-5 achieved the highest C_v coherence score (0.5307), indicating stronger lexical coherence among topic terms. However, Gemini 2.5 Pro and Claude Sonnet 4.5 achieved the highest topic distinctiveness score (1.0000), indicating clearer separation among thematic clusters. In the human interpretability evaluation, Gemini 2.5 Pro obtained the highest score (4.83 ± 0.16), suggesting that its generated topics exhibited stronger semantic richness and interpretability for historical narrative interpretation. Given that this study aims to construct interpretable historical timelines rather than solely maximizing lexical coherence, Gemini 2.5 Pro was selected as the final model for subsequent analysis because it pro-

vided the most appropriate balance between topic distinctiveness and human-perceived interpretability.

Table 5. Examples of the seed lexicon used for structural balance dimension event matching.

Indicator	Seed Lexicon
Preschool Education Provision	幼儿园 [kindergarten], 托儿所 [nursery], 学前班 [preschool class], 入园率 [enrollment rate], 村办园 [village-run kindergarten]
Martial-Civilian Education Ratio	武校 [martial arts school], 文武兼修 [integrated martial-civilian curriculum], 招生秩序 [enrollment regulation], 武术产业 [martial arts industry]
Educational Stage Completeness	九年一贯制 [nine-year integrated schooling], 撤点并校 [school consolidation], 教学点 [teaching outpost], 学段衔接 [inter-stage articulation]

Table 6. Comparative evaluation of LLM outputs.

Model	C_v Coherence Score	Topic Distinctiveness	Human interpretability Score (Mean $\pm$ SD)
GPT-5	0.5307	0.8578	4.70 $\pm$ 0.08
Kimi K2 Thinking	0.4918	0.9881	4.62 $\pm$ 0.09
Claude Sonnet 4.5	0.3225	1.0000	4.73 $\pm$ 0.07
Gemini 2.5 Pro	0.3415	1.0000	4.83 $\pm$ 0.16

Based on the output from Gemini 2.5 Pro, a total of 415 extracted events corresponding to the structural balance dimension were identified. Figure 8 illustrates the temporal distribution of these matched events across different historical periods. For each historical period, the matching rate was calculated as the number of matched structural balance events divided by the total number of extracted events within that period, reflecting the proportion of recorded events associated with the target dimension. The matching rates were relatively low during the Late Qing Dynasty, approximately 42%, which may reflect both historical educational characteristics and variations in documentary coverage. In contrast, the Early PRC period (1949–1978) and the Reform Era (post-1978) exhibited matching rates exceeding 60%. Collectively, these two periods account for over 63% of all matched events, indicating a significant intensification in the evolution of structural balance after the mid-20th century, coinciding with state-led educational restructuring and the formal recognition of wushu schools within the national educational system.

Finally, based on the top-weighted terms identified by the LDA model, the three clusters were interpreted as distinct perspectives on the evolution of structural balance, as illustrated in Figure 9. Figure 9a presents the temporal distribution of the 415 matched chronicle events among the three themes, with Theme I representing the largest share of events. These distributions reflect the events recorded in the available chronicles and retained through the matching procedure, while acknowledging that the chronicles may not provide a comprehensive record of all educational events in each historical period. The keywords presented in Figure 9b denote the highest-probability terms within each topic, providing semantic support for the interpretation of the clustered events. These three thematic clusters form the basis for multi-perspective timeline mapping, as detailed in the subsequent section.

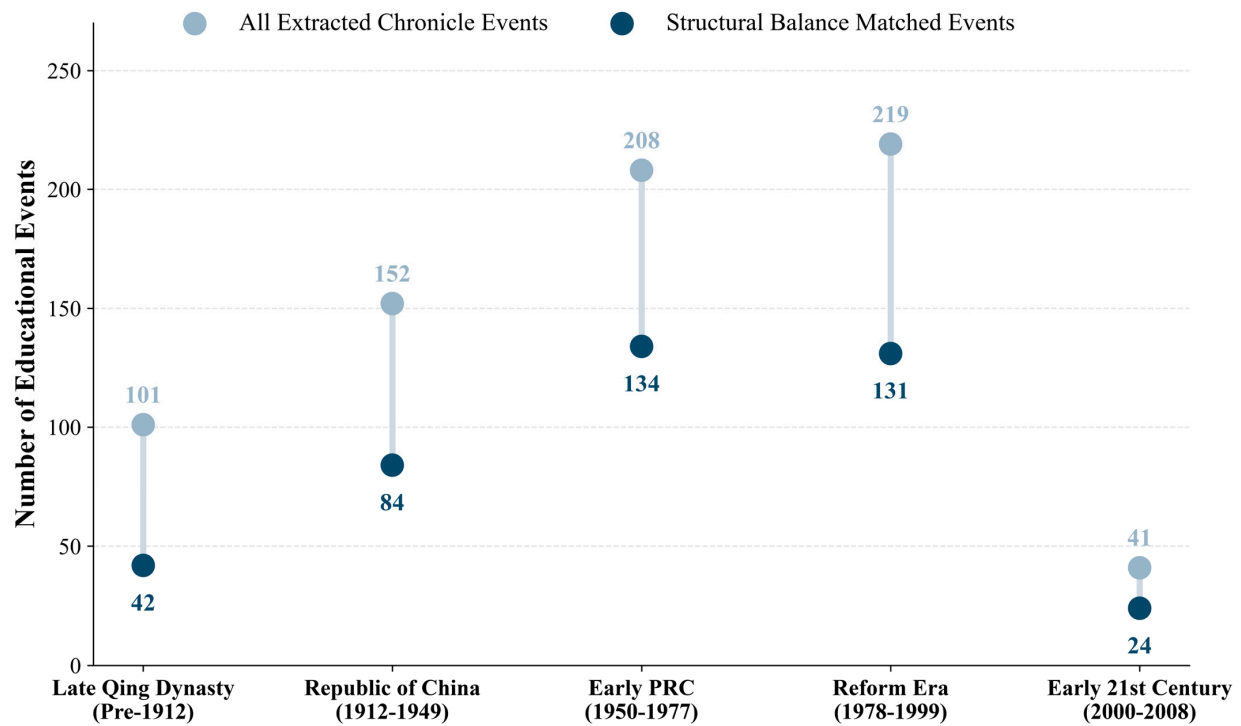


Figure 8. Temporal distribution of total extracted events versus matched structural balance events.

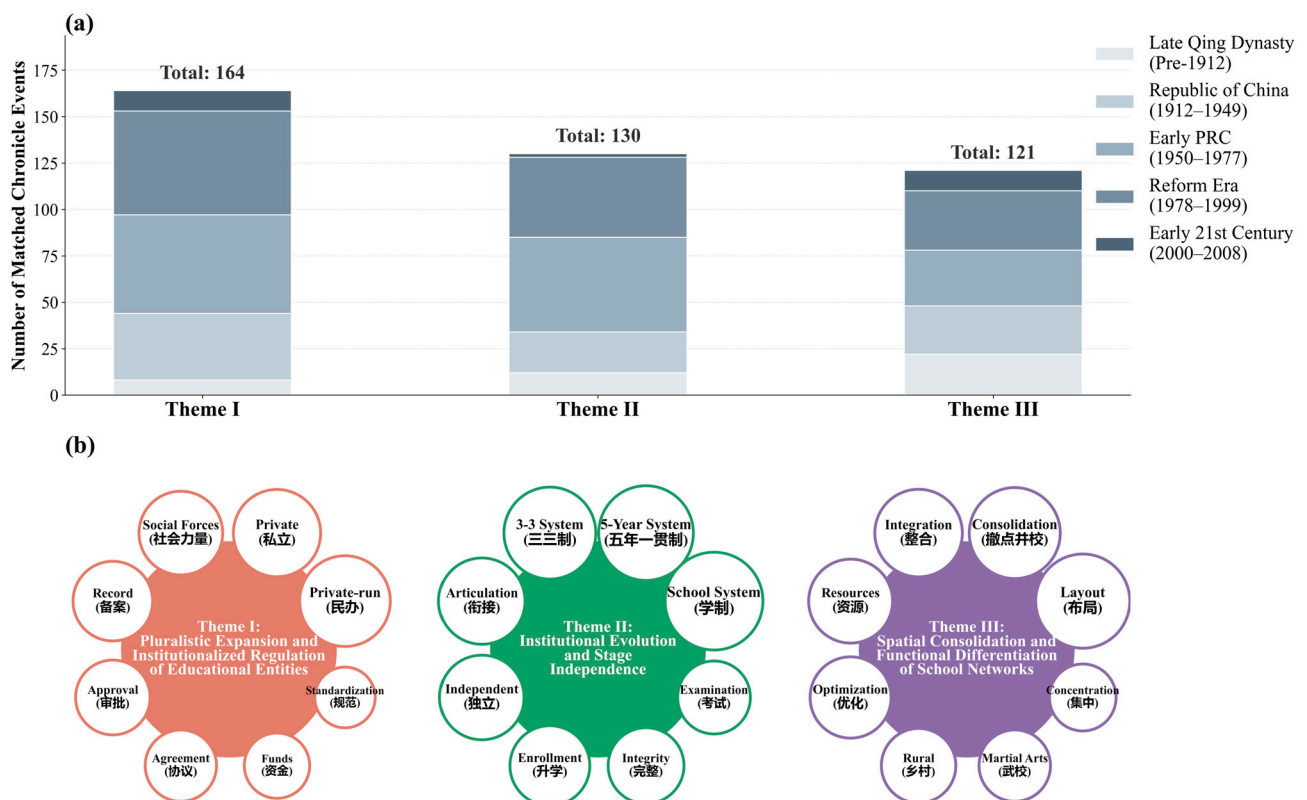


Figure 9. Thematic clustering and temporal distribution of educational events: (a) the temporal distribution of matched chronicle events within themes; (b) the keyword clusters by theme.

3.3. Multi-Perspective Timeline Map Construction Results and Evaluation

3.3.1. Theme I: Pluralistic Expansion and Institutionalized Regulation of Educational Entities

Figure 10 presents a timeline map for Theme I, illustrating the cyclical alternation between pluralistic expansion and institutional regulation of educational entities in Dengfeng across three historical phases, each associated with distinct spatial anchors. During the modern transition (1905–1950), state-initiated and community-funded institutions coexisted in a state of tension. The 1905 conversion of Songyang Academy, located in the urban core, marked the formal entry of state authority, while grassroots initiatives, such as the 1925 Yingbin Private Girls' Primary School, sustained pluralism. In the same urban core, the 1926 community-funded Songyang Middle School further exemplified this coexistence. In contrast, the state-run period (1950–1979) imposed a structural rupture with the 1952 nationalization of all private schools. However, the proliferation of Gengdu schools after 1964, primarily emerging in peri-urban areas, revealed the limitations of exclusive public provision, setting the stage for a subsequent shift. The pluralistic return (1979–2005) reactivated social forces, exemplified by the 1983 surge of community-funded school initiatives. Notably, the northwestern suburbs became the spatial origin of re-pluralization, where the Shaolin Wushu School first institutionalized private wushu education outside state channels. This phase culminated in the formalization of the academic-martial dual-track model in 2003, bridging the urban core and suburban wushu hubs. Throughout all phases, the Songyang Academy site in the urban core functioned as the recurring locus of institutionalization, while the Shaolin Wushu School in the northwestern suburbs served as the seed of re-pluralization. The County Education Bureau, located in the administrative center, anchored the regulatory dimension throughout.

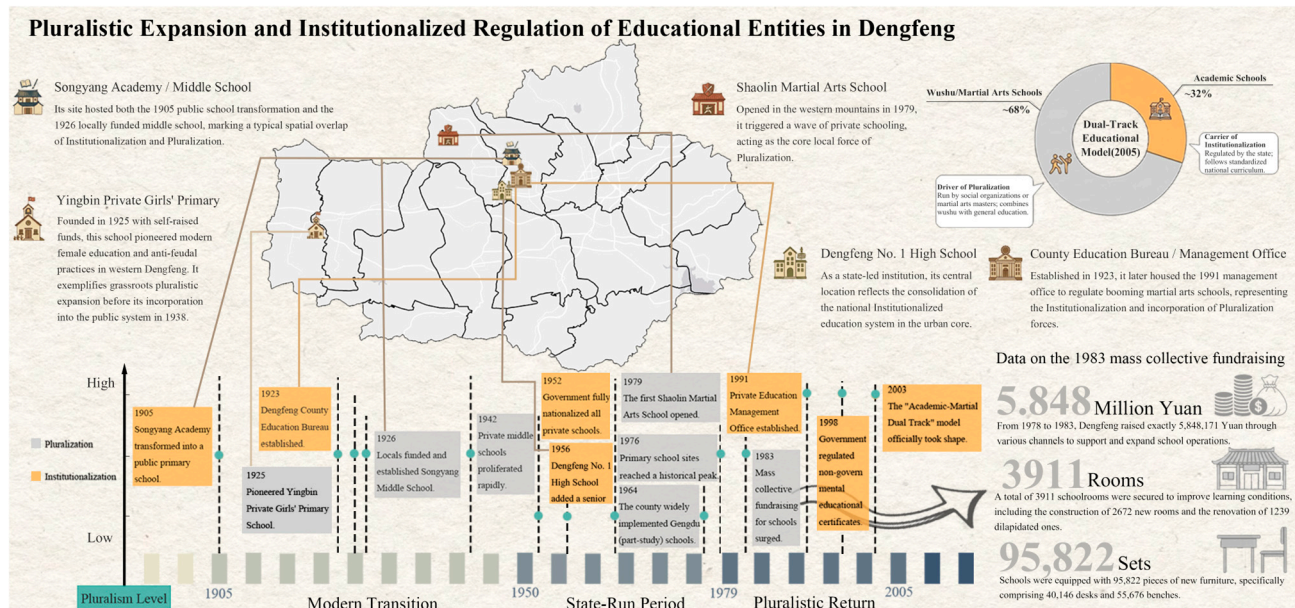


Figure 10. Timeline map of Theme I: Pluralistic Expansion and Institutionalized Regulation of Educational Entities.

3.3.2. Theme II: Institutional Evolution and Stage Independence

Figure 11 presents a timeline map for Theme II that delineates two parallel developments in Dengfeng: the evolution of school system reforms (upper timeline) and the progressive differentiation of educational stages (lower timeline). The upper timeline documents a series of significant transitions in the school system. The adoption of the Renxu System in 1922 established the first nationally standardized 6-3-3 structure. Subsequent

adjustments, including the 1952 pilot of the 5-Year Consistent System, the 1953 restoration of the 4-2 Dual-Segment System, and the 1968 implementation of the 5-2-2 Shortened System, reflect a persistent instability in school system reform that lasted five decades, culminating in the city-wide unification of the 6-3 Compulsory System in 2002. The lower timeline illustrates the progressive institutional independence of each educational stage. Preschool education, initially prompted by the 1922 Renxu System, was mandated as a trial in 1931 and attained formal institutional status with the establishment of the first formal preschool in 1952. Primary education, which served as the structural foundation from 1905, expanded substantially before consolidating in later decades. Notably, despite varying administrative boundary configurations, comparative maps for 1946 and 2000 reveal a widening urban-rural divide. Junior high education was formally established through Songyang Middle School in 1926 and expanded via the Yuhong Classes in 1970. Between 1985 and 2005, the number of schools declined across all areas, with township-level reductions proportionally larger than those in urban areas. Senior high education followed the most tumultuous path, evolving from an experimental pilot in 1946 to full stage completion in 1956, experiencing peak expansion, structural downsizing, and a large-scale re-expansion in 1997.

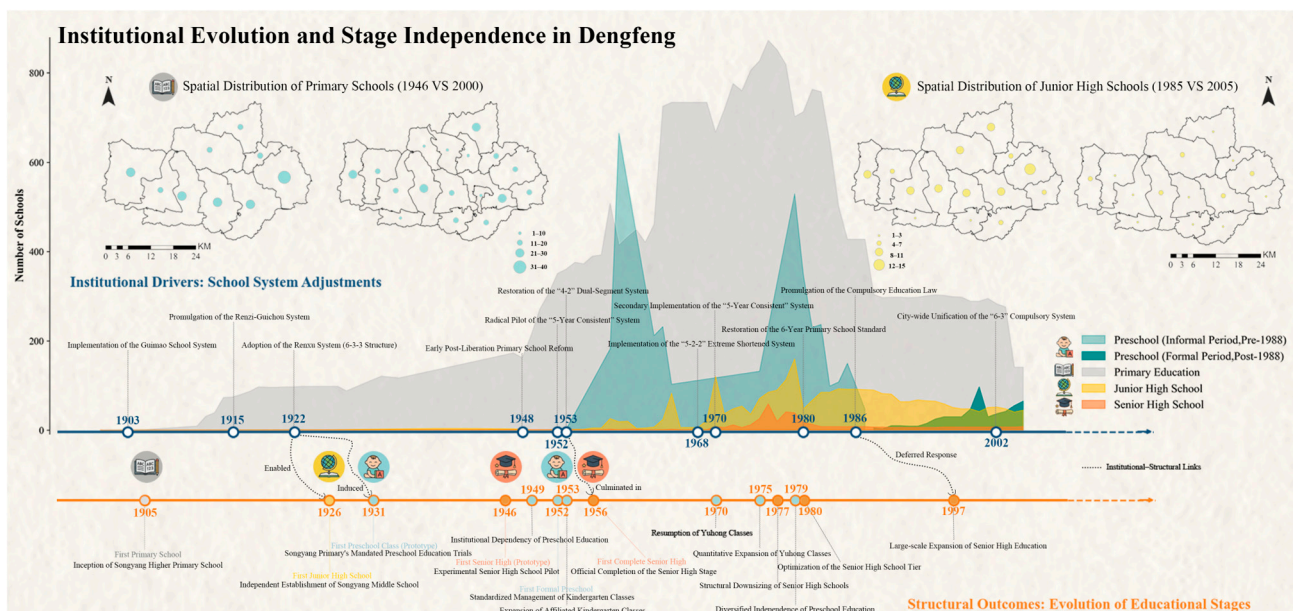


Figure 11. Timeline map of Theme II: Institutional Evolution and Stage Independence.

3.3.3. Theme III: Spatial Consolidation and Functional Differentiation of School Networks

Figure 12 presents a timeline map for Theme III that traces the structural reorganization of Dengfeng's school network through two parallel narratives: the spatial consolidation of the educational layout (upper timeline) and the progressive functional differentiation of specialized educational tracks (lower timeline). The upper timeline documents the process of spatial consolidation in education. The merger of higher primary schools in 1923 marked the initiation of this spatial consolidation, while the relocation of two schools to Chenghuang Temple in 1949 represented the first deliberate centralization following liberation. This trend experienced a reversal during the Cultural Revolution, as primary schools were decentralized to rural production brigades in 1969, resulting in historical peaks for senior high schools and primary schools in 1975 and 1976, respectively. A significant contraction in senior high school locations occurred by 1978, followed by the 1984 merger of kindergartens, the 1998 urban middle school concentration, and the 2001 consolidation of

vocational resources into a single campus. Comparative maps illustrate this contraction, revealing marked declines in the number of all three school types between 1976 and 2000. The lower timeline outlines the progressive functional differentiation of five specialized educational tracks from integrated general education. Teacher training was the first to attain full independence by 1925. Vocational education emerged in 1914, expanded rapidly to include 77 agricultural middle schools by 1958, and achieved institutional maturity with the founding of Dengfeng Vocational Secondary School in 1993. Special education evolved from the Pingmin Factory established in 1931 to a dedicated school by 1959. Wushu education was introduced as a compulsory subject in schools in 1939 and later consolidated into a specialized cluster with the formation of Shaolin Wushu City in 2000. Adult education completed its transition in 1982, evolving from night schools into Farmers' Cultural and Technical Schools.

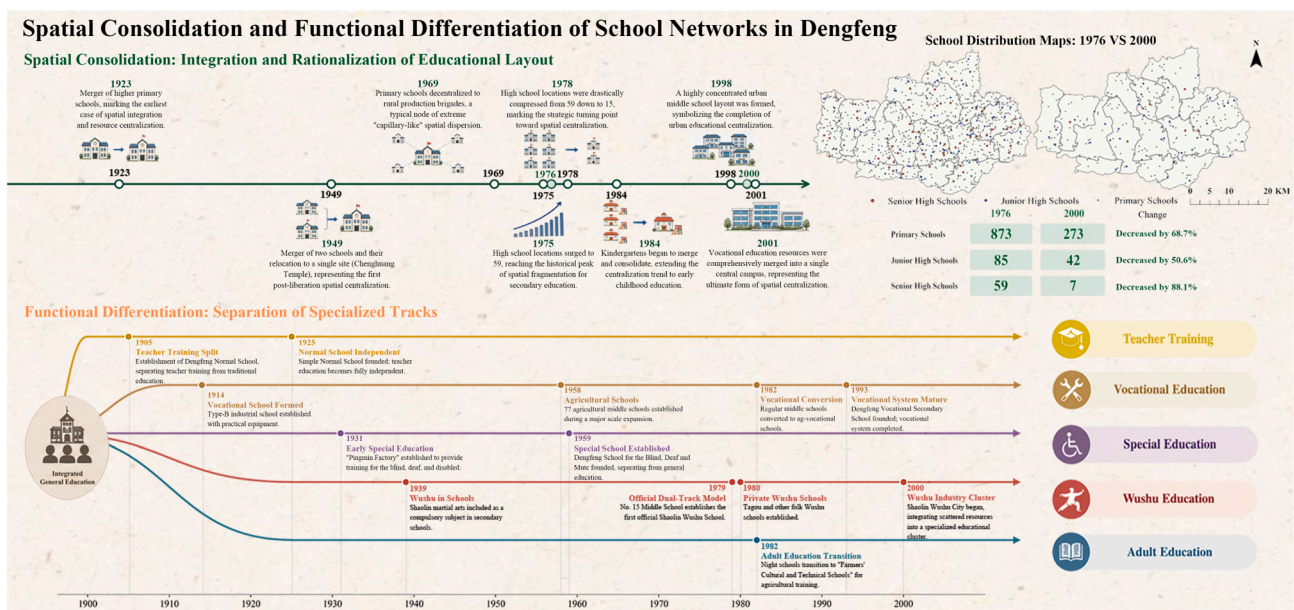


Figure 12. Timeline map of Theme III: Spatial Consolidation and Functional Differentiation of School Networks.

3.3.4. Timeline Map Evaluation Results

A total of 32 valid responses were obtained from respondents with diverse academic and professional backgrounds. Among these, 17 respondents (53.13%) were university or college teachers or researchers, while 18 respondents (56.25%) had backgrounds in GIS, cartography, or geography. In terms of familiarity with maps, GIS, or spatial visualization, 16 respondents (50.00%) reported being familiar or very familiar, whereas 10 respondents (31.25%) indicated moderate familiarity. This suggests that the evaluation included a considerable proportion of participants with relevant geospatial knowledge and experience. Figure 13 presents the results of the questionnaire-based evaluation of the three timeline maps. The evaluation results were generally positive across all five statements. Positive responses, defined as “strongly agree” or “agree,” accounted for 84.38% for temporal representation, 81.25% for spatial representation, 87.50% for visual design, and 81.25% for narrative coherence. The highest positive response rate, 90.63%, was observed for the statement that the timeline mapping approach facilitates the understanding and interpretation of historical information extracted from local chronicles. Overall, the positive response rates ranged from 81.25% to 90.63%, indicating that the timeline maps were generally perceived as effective and interpretable for presenting the temporal, spatial, thematic, and narrative dimensions of historical educational information.

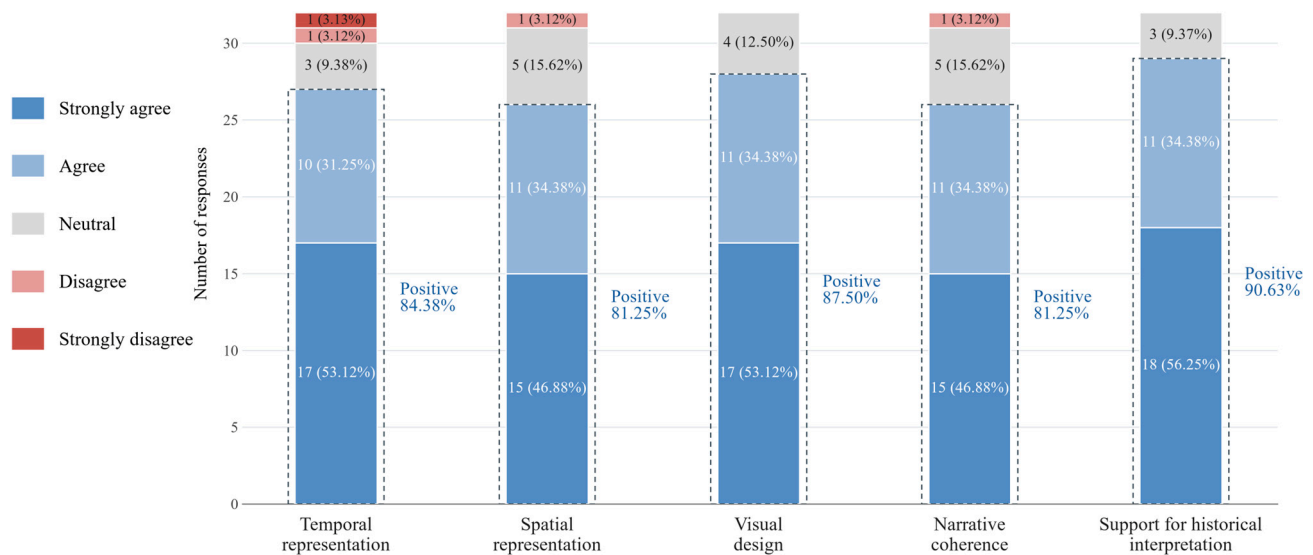


Figure 13. Distribution of responses to the five evaluation statements for the timeline maps.

4. Discussion

4.1. Evaluation of the Proposed Framework

A central challenge in historical GIS is the transformation of narrative historical records into interpretable spatiotemporal representations that facilitate the analysis of long-term processes [54,55]. While conventional approaches have predominantly relied on structured historical datasets or cross-sectional geographic data, such methods often provide limited insight into the temporal dynamics underlying the emergence of spatial patterns. The integrated framework proposed in this study, which includes dimension-importance evaluation, LLM-based historical event mining, and multi-perspective timeline mapping, addresses this challenge by offering a workflow for the extraction, organization, and visualization of historical events from unstructured local chronicles. The Dengfeng case serves as an empirical testbed for evaluating this framework. The dimension-importance evaluation identifies structural balance as the most relevant analytical dimension for organizing historical events within this context. This finding diverges from conventional emphases on resource allocation or spatial accessibility [30,31], yet aligns with the city's historically entrenched dual-track educational system. The LLM-based workflow successfully extracts and structures 721 historical events, of which 415 are matched to the identified dimension and clustered into three thematic groups: institutional plurality, school system reform, and spatial reorganization. The resultant multi-perspective timeline maps reveal that these developments, rather than manifesting as isolated events, form coherent temporal trajectories when organized through the proposed framework. This demonstrates the framework's capacity to transform unstructured narrative records into structured, interpretable spatiotemporal narratives, a core objective of historical GIS analysis utilizing local chronicles.

4.2. Integrated Interpretation on Multi-Perspective Timeline Mapping

The interrelationships among the three thematic clusters further illustrate the framework's utility for analyzing historical processes (Figure 14). The timeline maps indicate that changes in educational entities were frequently accompanied by adjustments in governance arrangements and institutional boundaries. Major reforms, ranging from the nationalization of education in 1952 to the subsequent unification of the compulsory education system, consistently redefined the roles of providers and governance structures. Concurrently, the diversification of educational providers prompted functional differentiation.

Notably, the expansion of private wushu schools coincided with the spatial concentration of wushu activities, resulting in a distinctive educational cluster. Periods of institutional reform often coincided with spatial reorganization, reflecting a close historical linkage between institutional change and spatial restructuring. These interactions, captured through multi-perspective timeline maps, reveal a coherent, long-term process of structural reconfiguration [55,56]. Moreover, while the Dengfeng case demonstrates these capabilities in the domain of education, the framework is designed as a transferable historical GIS workflow applicable to other historical corpora and geographical contexts where unstructured narrative records need to be transformed into spatiotemporal narratives.

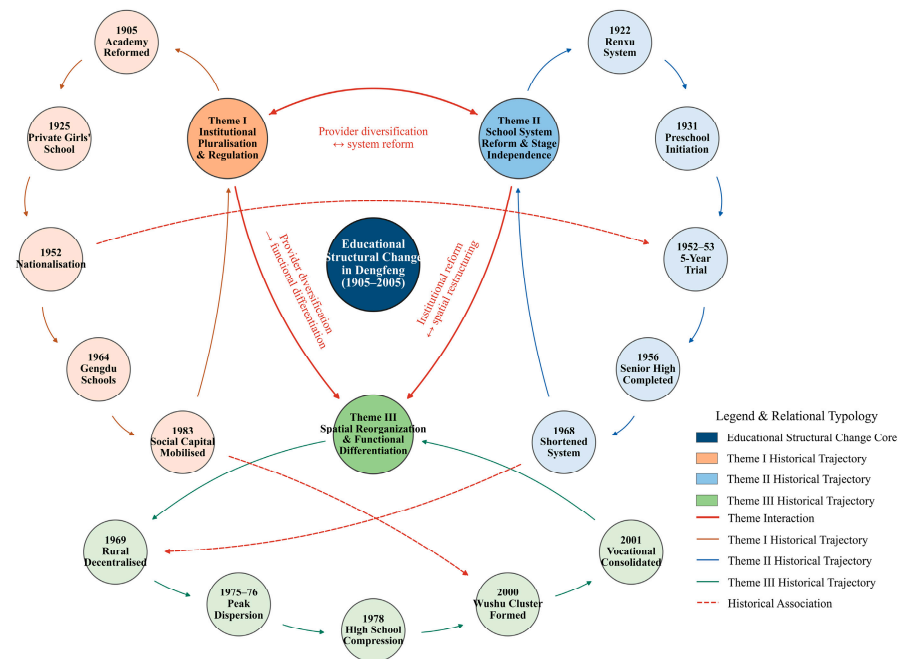


Figure 14. Interrelationships among three themes of educational structural change in Dengfeng.

4.3. Methodological Contributions and Limitations

The main contributions of this study are as follows: First, the proposed framework introduces a quantitative and context-sensitive dimension-importance evaluation method that establishes the semantic focus for timeline mapping without relying on predefined assumptions regarding the most relevant dimensions. Second, this study develops an LLM-based workflow that extracts, matches, and clusters historical events from unstructured local chronicles. This transformation converts narrative historical records into structured thematic event groups, thereby supporting multi-perspective timeline mapping. Third, the study operationalizes multi-perspective timeline mapping as a spatiotemporal narrative tool for representing and interpreting long-term historical processes derived from local chronicles. This approach enhanced historical GIS analysis by transitioning from single-thread narratives to multiple intersecting historical trajectories.

However, this study has several limitations. First, the framework is demonstrated through a single case study in Dengfeng, and its applicability to other regions and historical contexts requires further evaluation. Second, local chronicles may contain incomplete or uneven historical records, and the absence of documented events does not necessarily indicate their non-occurrence. Third, although LLMs provide an efficient approach for historical event processing, issues such as hallucination, prompt sensitivity, and output variability remain and require further systematic evaluation. In addition, convenience sampling may introduce sampling and expertise biases in the questionnaire-based evaluation, and accessibility for users with color vision deficiencies remains to be assessed. Future

research will address these limitations through multi-case applications, integration of additional historical sources, more comprehensive evaluation of LLM-based extraction, and improved visual accessibility using colorblind-friendly palettes and non-color visual cues.

5. Conclusions

This study proposes an integrated framework for timeline mapping using local chronicles, which comprises three methodological components: dimension-importance evaluation for identifying analytical focus, LLM-based historical event mining, and multi-perspective timeline mapping. To demonstrate the applicability of the proposed framework, a case study was conducted in Dengfeng, China, where historical educational records from local chronicles were employed to reconstruct the long-term spatiotemporal evolution of educational equity. The results of the case study indicate that (1) structural balance was identified as the most relevant analytical dimension in Dengfeng, and this identification remained robust under different weighting conditions, reflecting the city's historically entrenched dual-track educational system; (2) the LLM-based historical event mining procedure effectively transformed unstructured chronicle texts into structured event records, resulting in the extraction of 721 historical events from local chronicles, of which 415 were associated with structural balance and clustered into three thematic groups: institutional plurality, school system reform, and spatial reorganization; and (3) the resulting multi-perspective timeline maps revealed that these three themes are closely interrelated, demonstrating that the historical evolution of educational equity in Dengfeng is characterized by long-term, coherent processes of structural reconfiguration rather than isolated or static events. Additionally, a questionnaire-based evaluation further confirmed their readability, interpretability, and usefulness of the findings. Overall, these findings demonstrate the framework's capacity to transform unstructured narrative records into structured, interpretable spatiotemporal narratives. Future research could extend the framework through multi-case applications, multi-source data integration, systematic assessment of LLM robustness, and improved visual accessibility.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/ijgi15100441/s1>: Supplementary File S1: All structured historical event dataset; Supplementary File S2: Indicator dataset and EWM–CRITIC calculation results; Supplementary File S3: LLM prompt templates; Supplementary File S4: Enlarged timeline maps; Supplementary File S5: Manual Quality Assessment of Structured Historical Event Extraction; Supplementary File S6: Human interpretability evaluation of thematic clusters; Supplementary File S7: Summary of event selection for timeline map construction.

Author Contributions: Conceptualization, Chaorui Huo and Yongji Wang; methodology, Chaorui Huo and Yongji Wang; validation, Chaorui Huo, Xinhui Wang and Keke Li; formal analysis, Chaorui Huo and Donglei Si; investigation, Chaorui Huo and Qili Wang; resources, Yongji Wang; data curation, Chaorui Huo and Keke Li; writing—original draft preparation, Chaorui Huo; writing—review and editing, Yongji Wang; visualization, Chaorui Huo; supervision, Yongji Wang; project administration, Yongji Wang; funding acquisition, Yongji Wang and Zhihui Tian. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Key Research and Development Project of Henan Province, grant number 261111212800; the Key Scientific Research Projects of Colleges and Universities in Henan Province, grant number 25A170010; and a grant from State Key Laboratory of Resources and Environmental Information System.

Data Availability Statement: The datasets and supporting materials generated and analyzed during the current study are provided in the Supplementary Materials. The original local chronicle texts used as data sources are not redistributed due to copyright restrictions. However, the structured

information derived from these sources is provided in the Supplementary Materials, including event identifiers, event names, temporal information, locations, subjects, objects, event descriptions, event types, and thematic assignments.

Acknowledgments: The authors would like to acknowledge all the reviewers and editors.

Conflicts of Interest: The authors declare no conflicts of interest.

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