AI-driven Interactive Hierarchical Concept Maps for Digital Learning Environments and Intelligent Textbooks[*]

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Abstract

This paper explores the design and implementation of AI-driven interactive concept maps as components of intelligent textbooks and digital learning environments, focusing on hierarchical drill-down navigation and human-in-the-loop content refinement. We present a working system architecture and user interface that enable scalable, domain-specific knowledge exploration, supported by AI-assisted map generation and educator oversight. Positive student feedback and questionnaire results demonstrate the perceived effectiveness of the approach in enhancing comprehension, engagement, and structured learning.

Keywords

concept map, knowledge graph, hierarchical navigation, digital concept map, LLM, AI

1. Introduction

In recent years, concept maps have emerged as powerful tools for representing and organizing knowledge within educational systems [1, 2]. Traditional concept maps [3] offer a static visual structure that helps learners make connections between concepts, but they often lack interactivity and scalability. As learning environments become increasingly digital and data-rich, there is growing interest in enhancing these maps with AI capabilities and interactive features [4]. This paper addresses this need by exploring the development of AI-powered interactive concept maps that support drill-down navigation, hierarchical structuring of information, and interactive user experience. These features are particularly relevant in the context of intelligent textbooks and e-learning platforms, where students benefit from structured, layered access to domain knowledge. Such systems represent a core functionality of emerging intelligent textbooks, enabling students to interactively explore structured knowledge rather than passively consuming static text.

The proposed system leverages artificial intelligence to generate initial concept maps, which are then refined through human-in-the-loop input to ensure pedagogical accuracy and relevance. A custom-designed interface enables learners to explore concepts at varying levels of depth, promoting active engagement and quick navigation to the relevant learning content. This paper presents the underlying system architecture, describes the user interface design, and reports on student feedback collected through questionnaires. Results indicate that interactive, AI-assisted concept maps are perceived as effective tools for comprehension, organization of knowledge, and overall learning satisfaction. By integrating automation with human expertise, this approach aims to bridge the gap between intelligent content generation and a meaningful educational user experience.

2. Related work

Numerous studies have highlighted the pivotal role of visualization in enhancing the comprehension and retention of educational content. Early work by Naps et al. [5] emphasized how visual engagement, particularly in computer science education, significantly contributes to

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student understanding and motivation, underscoring the value of interactive and animated representations of abstract topics. The CoMPASS project proposed by Puntambekar et al. [6] introduced navigable concept maps within educational hypermedia systems to improve structural understanding and navigation efficiency, while Andres et al. [7] demonstrated in the ActiveMath platform how adaptive visual structures support the comprehension of theoretical computer science. These approaches converge with proposals by Hollingsworth and Narayanan [8], who argue that interactive features such as concept maps should be standard components of digital textbooks to facilitate domain-specific learning pathways. In a similar vein, Barria-Pineda et al. [9] developed visualization tools that support self-regulated learning via concept-level mapping. Shimada et al. [10] explored meaningful discovery learning in e-book environments. In ontology-oriented learning systems, concept maps serve as structured, navigable representations of knowledge that align content delivery with cognitive processes [4]. One notable system, TM4L (Topic Maps for Learning), introduced by Dicheva and Dichev [11], supports semantic navigation of educational content by linking learning materials to conceptually indexed topic maps. Collectively, these works reinforce the role of concept mapping and knowledge visualization as essential, rather than supplementary, components in the design of effective digital learning environments. In more recent works [4, 12], the author proposed incorporating interactive concept maps into educational web systems to facilitate improved access to structured knowledge.

Many studies have shown that concept maps improve learning outcomes, particularly for complex material. A large-scale meta-analysis by Schroeder et al. [1] reviewed 142 studies and found that studying with concept maps was significantly more effective than reading texts (g = .39) or reviewing outlines and lists (g = .28), supporting their value in enhancing comprehension. Similarly, Bolatli and Bolatli [13] reported higher post-test scores and lower cognitive load in anatomy students who used predefined concept maps, indicating improved learning efficiency.

Interactive and adaptive implementations of concept maps further strengthen their educational impact. Elgendi and Shaffer [14] demonstrated that interactive glossary maps embedded in a computer science e-textbook led to increased student engagement and repeated glossary use, suggesting enhanced motivation and deeper interaction with learning material. Schwab et al. [15] introduced booc.io, a system featuring drill-down hierarchical concept maps that support adaptive navigation, enabling learners to uncover subtopics based on their interests and receive targeted feedback. While Bull [16] and Winne [17] did not focus solely on concept maps, they recognized them as valuable visualizations in Open Learner Models – useful for representing knowledge structure, supporting learner reflection, and enabling learner-system interaction.

In a recent study, Ma and Chen [18] proposed a comprehensive framework for automated concept map construction from e-books using large language models (LLMs), including section segmentation, key concept extraction, and relationship identification [18]. Their evaluation of GPT-4o in the context of Python programming lectures demonstrated strong performance, effectively extracting key concepts and accurately identifying both hierarchical structures and cross-topic connections [18]. They found that LLMs could generate concept maps that differ from textbook structure, reflecting more logical and content-based organization [18].

In applied systems, Kluga et al. integrated causal concept maps into an intelligent textbook for anatomy, enabling personalized navigation, quiz adaptation, and content feedback to enhance comprehension [19].

A domain-specific contribution by Wehnert et al. [20] presents a dynamic visualization system for exploring concept hierarchies extracted from legal textbooks. Designed primarily for legal education, their system supports top-down, middle-out, and bottom-up navigation modes, allowing users to traverse legal content at varying levels of abstraction. Key features address needs specific to the legal domain, such as the ability to identify and compare occurrences of legal references, view contextual usage across chapters, and understand relationships between legal concepts and case law. While their approach relies on rule-based NLP techniques and predefined textbook structure, it offers a refined user experience for analyzing legally dense material.

These findings collectively highlight the growing importance of interactive concept mapping tools in modern educational platforms. Building on this foundation, the present work highlights the need for LLM-generated digital concept maps that enable nested exploration and immediate access to concept information, while also incorporating student feedback to evaluate their effectiveness in real-world learning contexts.

3. Interactive drill-down interface for hierarchical concept maps

This project explores the implementation and evaluation of an interactive, hierarchical concept map platform designed to enhance digital learning experiences. While the general idea of navigable concept maps is not new, our interface introduces a layered, LLM-augmented design that supports on-demand concept generation, infinite drill-down navigation, and in-context information display. These features are tailored for integration within intelligent textbooks and reflect a tighter coupling between visualization, content retrieval, and human oversight.

Similar to Ma and Chen [18], our system employs LLMs to generate concept maps. Their framework effectively demonstrates how LLMs can automate the extraction of concepts and relationships from structured e-book content and includes an evaluation of the accuracy of the generated maps. However, it does not address the use of such maps in real educational contexts, lacks production-ready interactive UI/UX design, and overlooks the cognitive overload caused by large, flat maps – challenges our approach addresses through hierarchical drill-down navigation, embedded pedagogical content, and validation based on real student feedback. While their use of full course materials improves content alignment, we plan to incorporate this in future iterations using retrieval-augmented generation (RAG) to maintain both scalability and affordability.

The tool proposed in this work enables students to visually explore interconnected course topics through an intuitive drill-down interface, allowing them to click on high-level concepts and progressively navigate into more detailed subtopics.

The system was applied in two university-level courses – Object-Oriented Programming and Data Structures, and UI Design and AI-Assisted Frontend Development – where students used the interactive concept maps as tools for end-of-course review and reflection [21, 22].

3.1. Main map of the course and information panel

The Main Map of the Course functioned as a central, interactive overview of the entire curriculum, visually organizing key topics and their relationships in a hierarchical structure. Each concept was represented as a node within the map, with the ability to expand and explore subtopics through drill-down interaction (Figure 1). This design enabled students to see the "big picture" of the course while also accessing detailed content on demand. By combining structure with interactivity, the main map supported both guided review and self-directed exploration, helping learners reinforce understanding and make connections between different parts of the course.

The Information Panel provided contextual details for each concept selected within the map (Figure 2). When a student clicked on a node, the window displayed a concise explanation, relevant examples, or supporting materials related to that concept. This feature allowed learners to engage with the content without leaving the map interface, maintaining flow and minimizing distractions. By offering just-in-time information aligned with the visual structure, the Information Window enhanced clarity, supported deeper understanding, and encouraged active exploration of the course material.

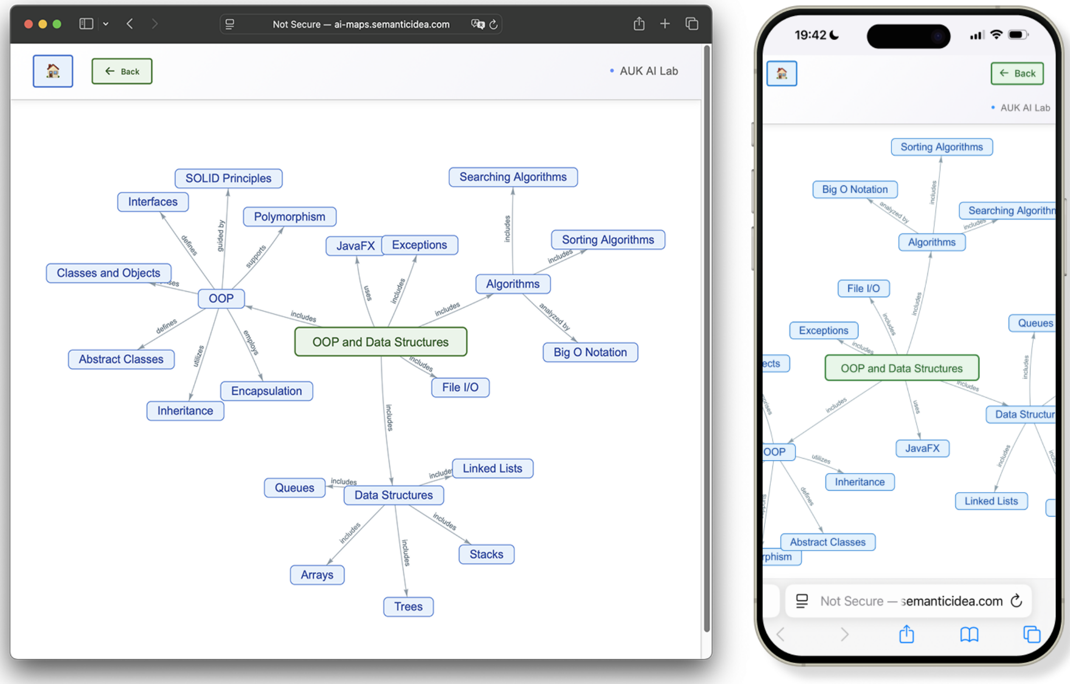

Figure 1: Main map of the course "Object-oriented Programming and Data Structures" – desktop and mobile versions [21].

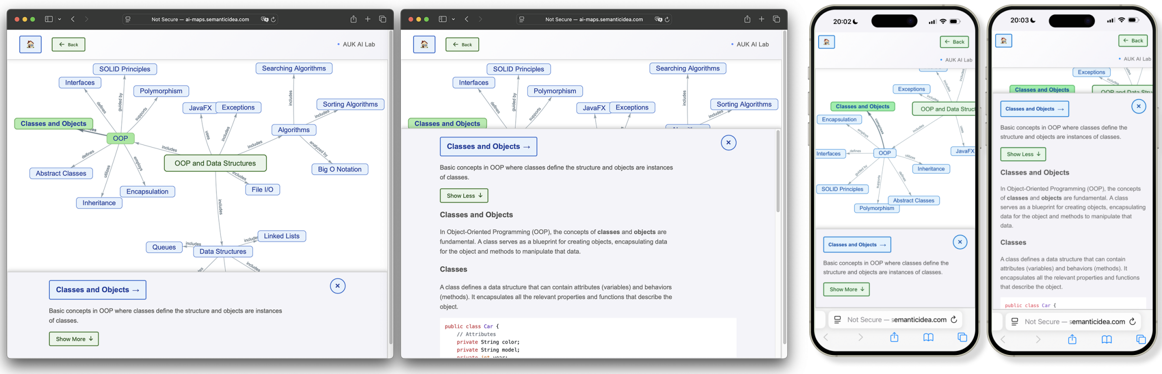

Figure 2: Information window for "Classes and Objects" node – desktop and mobile versions [21].

Child concept map

A Child Concept Map is a secondary, more focused map that expands upon a specific node from the main concept map (Figure 3). When a learner clicks on a parent concept, the system opens a dedicated map showing its subtopics, examples, or related ideas in greater detail. This layered structure supports hierarchical learning by allowing users to progressively explore concepts at increasing levels of depth. Child maps maintain the same interactive features, such as zooming, dragging, and clickable nodes, ensuring continuity in the user experience. They play a key role in enabling drill-down navigation, promoting deeper understanding without overwhelming the learner with too much information at once.

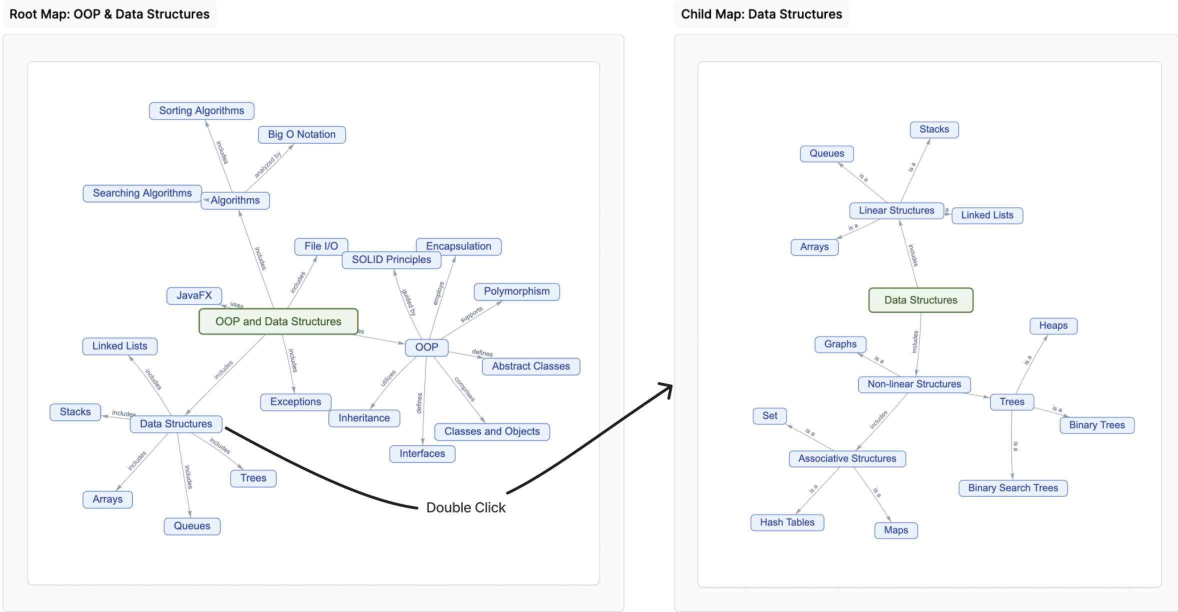

Figure 3: Interactive drill-down interface for hierarchical concept maps.

3.2. Infinite drill-down AI-based domain exploration

The Infinite Drill-Down AI-Based Domain Exploration feature enables learners to move beyond predefined content by generating new sub-maps dynamically using AI (Figure 4). When a student reaches a terminal node and seeks further explanation or deeper knowledge, the system can generate an extended concept map based on the semantic description of the topic. This allows for on-demand expansion of the knowledge graph, tailored to the learner's interests or gaps in understanding. By combining structured curriculum design with AI-driven content generation, this feature transforms the concept map into an adaptive learning environment capable of supporting personalized, self-directed exploration across limitless depth within a subject domain. These features support the vision of intelligent textbooks that adaptively respond to learner queries, offering context-aware depth and structure beyond traditional static materials. This functionality also enables students to explore beyond the boundaries of the predefined course content, encouraging interdisciplinary connections and self-directed inquiry. However, this openness introduces certain risks, which are discussed in detail in the Limitations section.

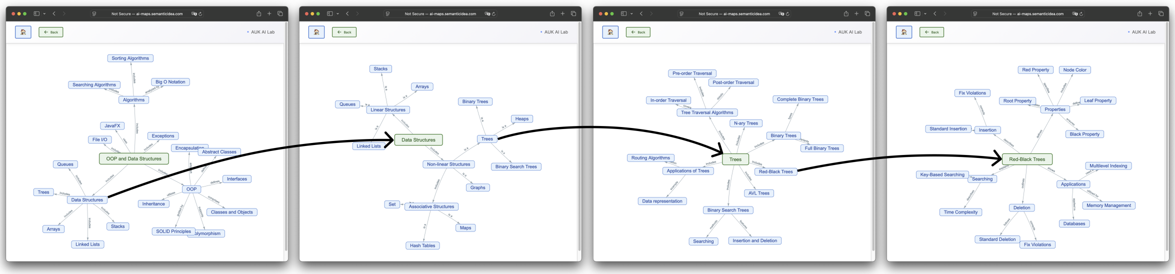

Figure 4: Infinite drill-down AI-based domain exploration.

4. AI-Driven concept map generation with human-in-the-loop refinement

The system generates interactive concept maps by directly querying a large language model (LLM), such as GPT-4o-mini, based on the provided course metadata – namely, a course description and prompt-tuning commands that guide the scope and structure of the output. While the initial map generation does not rely on pre-uploaded materials like syllabi or lecture notes, such documents may be incorporated later during the refinement stage.

Given only a high-level course theme or topic, the LLM produces a structured set of concepts and relationships, forming the foundation of the initial concept map. This AI-generated structure reflects domain-relevant knowledge, organized hierarchically to support logical learning progression. The end-to-end concept map development process includes the following steps:

1. Course creation and course metadata configuration – The instructor defines a new course by providing a course title along with textual metadata, including a free-form course description and optional prompt-tuning instructions. These text inputs help shape the thematic scope and language used during map generation. Instructors may use longer, structured textual inputs, such as excerpts from the syllabus or detailed course outlines, directly in the course description field to further guide the LLM in producing content that aligns with the intended pedagogical flow and terminology.
2. Initial concept map generation – The system queries the LLM to produce a draft map of key concepts and their relationships.
3. Full map regeneration by deleting the previous version, if needed – If the initial map is unsatisfactory, instructors can clear it and regenerate a new one from scratch.
4. Map refinement using a standalone LLM (e.g., ChatGPT) – Users can ask a secondary LLM to rephrase or restructure parts of the map for better clarity or alignment.
5. Concept information generation via the information panel – Clicking a concept opens an interactive panel that fetches descriptive content via the LLM.
6. Concept information regeneration by deleting the previous version, if needed – Instructors can discard and regenerate concept information.
7. Concept information refinement using a standalone LLM (e.g., ChatGPT) – Generated descriptions can be edited or enhanced using a separate LLM interface.
8. Generation of nested (child) concept maps – Instructors can expand on individual concepts by generating subordinate maps, enabling drill-down exploration.

This process supports rapid creation of customized, AI-generated concept maps while preserving expert oversight and instructional relevance through human-in-the-loop refinement at multiple stages.

We acknowledge the importance of ensuring quality and coherence across a large volume of generated concept maps and concept pages. In practice, accurate course-specific maps can be generated relatively quickly using the system's prompt-based workflow. As map creators typically navigate through up to three nested levels during generation, the corresponding submaps are automatically cached in the system. However, the refinement process requires manual review of each map level and corresponding concept description page to validate the pedagogical relevance and accuracy of the AI-generated content. If the content or structure is unsatisfactory, instructors can either regenerate the map or update individual concept descriptions using a separate LLM interface (e.g., ChatGPT) and then commit those revisions to the system.

For highly customized course structures or pedagogy styles, the refinement process can become more time-consuming. Nevertheless, the system's AI-assisted generation significantly reduces the baseline effort required, making the creation and maintenance of hierarchical course maps both feasible and scalable for practical use in intelligent textbooks. Future work on integrating course materials into the system will enhance both the efficiency and usability of the content generation and refinement process.

5. Limitations of Generic LLM-generated Concept Maps

While the proposed system demonstrates the feasibility of rapid, AI-assisted concept map generation, several limitations emerge from relying solely on large language models (LLMs) without incorporating course-specific materials such as textbooks, syllabi, or lecture notes.

Metadata-Based Generation. The initial concept maps are generated based only on a course title and concise metadata, without explicit instructional content. This design allows for quick onboarding and flexibility, particularly for well-defined or traditionally structured subjects. However, it introduces a risk of shallow or misaligned content in specialized, interdisciplinary, or rapidly evolving domains where domain nuance and pedagogical intent are critical. The generated concepts may not fully reflect the instructor's unique framing of the material, leading to gaps or mismatches in terminology, structure, or emphasis. Future work will explore the integration of retrieval-augmented generation (RAG) techniques to enable concept map generation based directly on actual course content, such as textbooks or lecture notes.

Infinite Drill-Down Navigation. Although infinite drill-down capability is one of the system's most innovative features, it also poses challenges:

- Disorientation: As users delve deeper into nested submaps, they may lose awareness of their location within the overall concept structure.
- Topic Drift: In the absence of clear semantic boundaries, LLMs may generate tangential or unrelated subtopics, resulting in conceptual divergence from the core subject matter.

To address these issues, future work will explore introducing limits on the depth of map nesting and developing UX strategies that provide clearer visual cues to help users maintain orientation within the hierarchical navigation flow.

Submap Consistency. Because submaps are generated independently, a concept node that appears on a higher-level map may include child nodes that are not reproduced or expanded upon when that same node is opened in a dedicated submap. This lack of continuity between parent maps and their corresponding submaps can result in structural gaps and confuse the logical progression of concepts. While instructors can address these issues through manual refinement, scalable resolution will require algorithmic support and improved tooling to ensure consistency across the concept hierarchy.

6. Architectural design of an AI-powered interactive concept map system

The system features a lightweight, modular architecture that combines AI-driven content generation with interactive frontend visualization (Figure 5). The backend, built in Python, handles HTTP requests, interacts with the OpenAI GPT-4o-mini API, and stores course content in a file-based structure. Each course includes a meta.json file, a root concept map .txt, individual .txt files for node descriptions, and all previously cached submaps.

The frontend uses Vis.js to render dynamic, clickable concept maps. Selecting a node displays its content in an information panel, and drill-down navigation is enabled through parent-child links in the map data. Users can extend their exploration by navigating to subtopics, triggering the on-demand generation of sub-concepts via a large language model (LLM). All generated content is editable by instructors, allowing human refinement to maintain pedagogical quality.

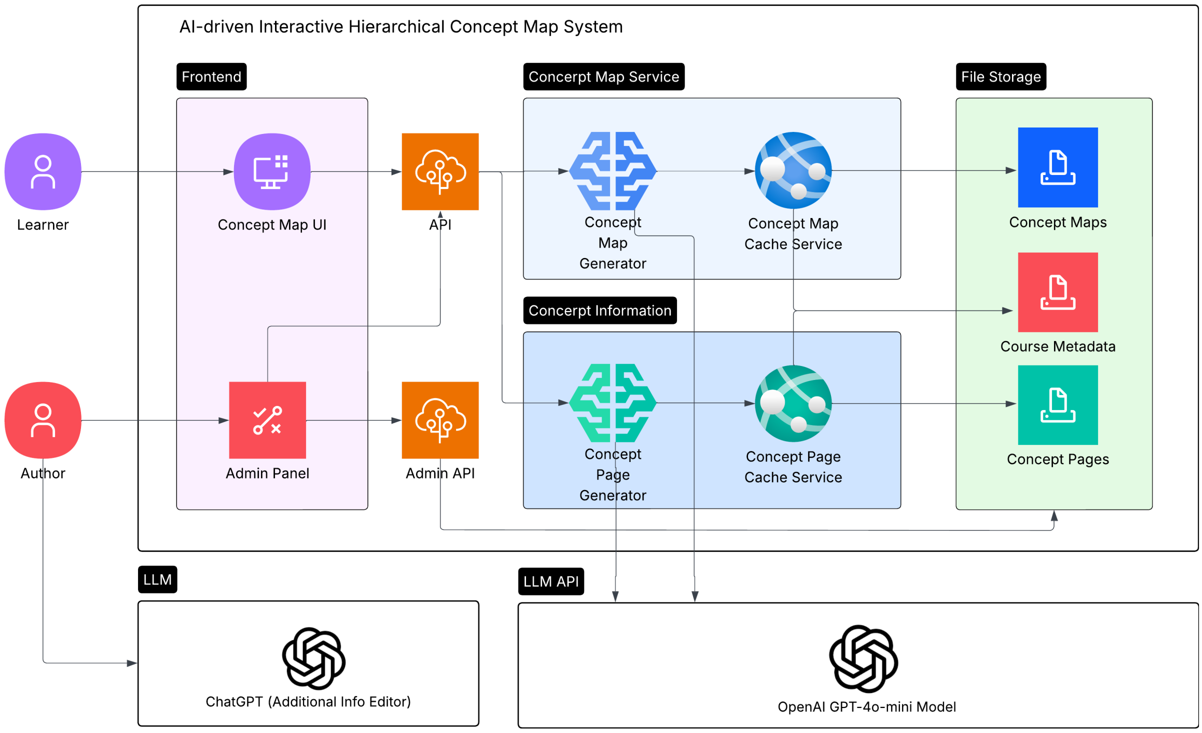

Figure 5: Architectural design of an AI-powered interactive concept map system.

6.1. Prompt-Engineered Generation of Concept Maps

The system generates concept maps by dynamically constructing and sending prompts to a large language model (LLM), such as GPT-4o-mini. This process is driven by input provided through the frontend during map navigation – namely, a topic, a description, and a course code. These inputs are combined with metadata retrieved from the system, including the course description and any prompt-tuning instructions for the course. These elements are merged into a structured prompt that defines the content scope and the desired output format.

The prompt is engineered to guide the LLM toward producing well-structured, domain-relevant concept maps. Specifically, it instructs the model to:

1. Generate at least 15 nodes.
2. Define a single root concept.
3. Create a tree-like hierarchical structure with no cycles or dangling nodes.
4. Format the output as JavaScript code compatible with the Vis.js visualization library.
5. Label all edges with clear semantic relationships.
6. Ensure domain-specific accuracy, particularly for technical subjects like programming.
7. Include a concrete example demonstrating the expected output format using Vis.js syntax.

The constructed prompt is sent from the backend to the OpenAI GPT-4o-mini API. The received response is cached as a plain text file within the system's structured file storage. As a result, subsequent requests for the same concept map are served directly from the local file system, avoiding redundant calls to the OpenAI API. If needed, the current concept map stored in the system can be removed and regenerated through the instructor interface to reflect updated metadata or improved structure.

This lightweight yet powerful prompt-engineering strategy allows the system to rapidly generate high-quality, domain-aware concept maps without pre-uploaded materials, while still offering flexibility for later refinement.

6.2. Prompt-Engineered Generation of Concept Pages

The system generates individual concept pages as HTML fragments through targeted prompt engineering. When a user selects a concept node, the system constructs a prompt based on the concept name, description, course metadata, and any prompt-tuning instructions of the course. The goal is to generate a well-structured, one-page educational summary suitable for embedding directly into a web interface.

The prompt explicitly instructs the model to:

1. Generate a valid HTML fragment, not a full document.
2. Use semantic HTML tags such as <h2>, <p>, <ul>, <li>, <code>, and <pre>.
3. Format code snippets (for programming courses) using <pre><code> tags.
4. Format mathematical content using LaTeX and MathJax, with \(...\) for inline and \[...\] for block formulas.
5. Escape HTML characters in code examples to prevent rendering issues.
6. Return only the raw HTML, with no comments, markdown, or extra text.

Like maps, generated pages are cached for performance and can be regenerated if needed. This method ensures consistent formatting and domain-specific detail across all concept nodes of the course.

6.3. Content Management Panel for AI-driven concept map generation

The Content Management Panel is a core component of the instructor-facing tools that enables efficient oversight of all AI-generated concept map content (Figure 6). Instructors can create and manage multiple courses, each represented as a folder containing its metadata, root map structure, nested maps, and individual concept information files. Through the panel, educators can initiate the regeneration of concept maps, refine existing maps by editing their content, and run regeneration or customization of individual concept pages.

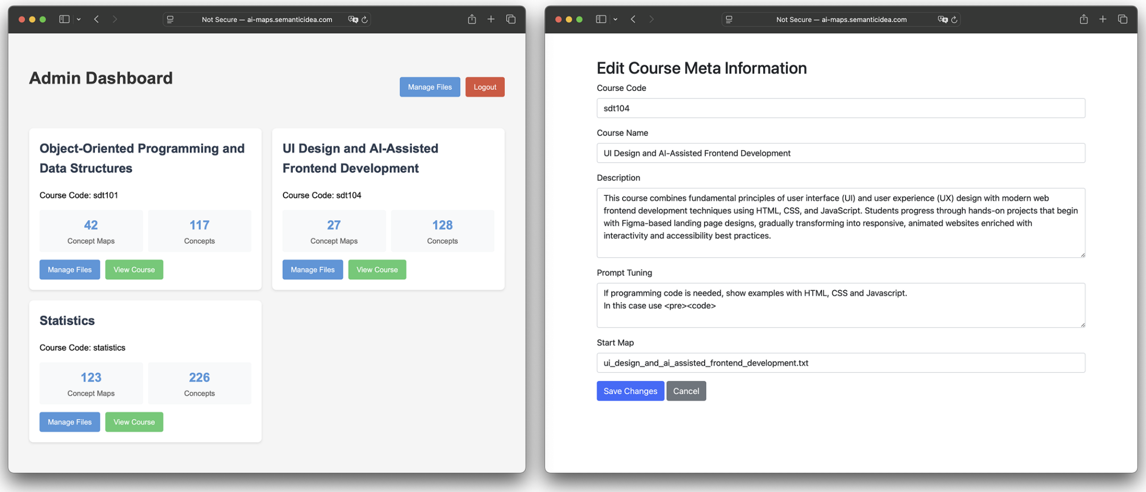

Figure 6: Content Management Panel for AI-driven concept map generation.

Edit access to the source of concept maps and concept pages is provided through a user-friendly interface, allowing instructors to use third-party LLMs to refine content and ensure better alignment with course outcomes and the instructor's perspective.

7. Evaluation: student feedback analysis on AI-powered concept map interfaces

7.1. Survey design

Hierarchical concept maps were developed for several courses at American University Kyiv, with a particular focus on the following two courses:

1. Object-Oriented Programming and Data Structures [21] – delivered to first-year students in the Bachelor of Software Engineering and AI and Bachelor of Data Science programs. A total of 42 concept maps and 117 individual concept pages were generated and integrated into the course. A total of 24 students participated in the survey.
2. UI Design and AI-Assisted Frontend Development [22] – delivered to first-year students in the Bachelor of Software Engineering and AI program. The instructors controlled and refined the generation of 27 concept maps and 128 concept pages for this course. A total of 11 students participated in the survey.

We received a total of 35 surveys from both courses. The survey was proposed at the final part of the course as a means of recalling course content and evaluating the concept map's effectiveness for structured review. The following questions were asked of students as part of the feedback process:

1. "Overall, how satisfied are you with your learning experience using the concept map app?" *(Rated on a Likert scale from 1 to 10)*
2. "Did the app make learning more engaging or enjoyable?"
3. "What do you think is more effective for helping you review and recall the course content?" *(Options: Text-based materials (textbooks, presentations); Interactive Concept Maps; Both equally)*
4. "In your opinion, how effective is the Concept Map tool for learning new content?" *(Rated on a scale from 1 to 10)*
5. "Was the ability to click on a concept name and jump to a related concept map useful to you?"
6. "What features of the app did you find most useful?"
7. "What features do you think should be improved?"

These questions aimed to assess the usability, pedagogical value, and areas for enhancement of the concept map system.

7.2. Survey results and analysis

The analysis shows a high level of student satisfaction, with an average score of 8.91 out of 10. Similarly, students rated the app's usefulness for learning new content at an average of 8.31 out of 10. A large majority (91.4%) agreed that the app made learning more engaging or enjoyable. 100% of students confirmed that the ability to click on concept names and navigate through nested maps was helpful, reinforcing the effectiveness of the interactive hierarchical concept map approach.

Regarding preferred methods for reviewing course material:

- 60% of students found both interactive concept maps and traditional materials equally effective;
- 34.3% preferred interactive maps;
- and only 5.7% preferred text-based materials alone.

These results quantitatively confirm that the interactive and visual structure of the concept maps was well-received and perceived as effective in supporting student learning.

The analysis of open-ended survey responses provides deeper insight into which features students valued most and what areas they felt could be improved. Results for the question *“What features of the app did you find most useful?”* revealed two major advantages most frequently mentioned by students:

1. Clickability and depth navigation. Students appreciated being able to click, navigate, and explore deeper levels of topics. 11 students mentioned this, citing features like: “the most useful features are that I can click and read info about a topic or go further and find more details” and “Double-clicking to go to a deeper level of the topic.”.
2. Visual structure and relationships between topics. Responses highlight the clarity and usefulness of the visual concept map structure. 9 students mentioned this, citing features like: “It is interactive, has nice and clear structure”, “I really like that with the help of graphs it is easy to see which concepts are related, this feature helps me to memorize new material” and “All topics you need are available in one place, and it is great for reviewing materials”.

Results for the question *“What features do you think should be improved?”*:

1. 7 students felt the app was already perfect or good enough: *“everything is perfect”*, *“all is good”*, or *“nothing”*.
2. UI improvements recommended by 8 students: *"UI can be improved a little bit, just the visual side"*, *“I would change the design a bit so it would be more pleasant”*, *“Dark theme is needed.”*
3. Improvements in the current interactions were recommended by 6 students: *“Honestly, I think the design is raw, and interactions with the graph (dragging, making it bigger or smaller, moving left or right) are a little bit inconvenient, it feels like it has too much sensation for every movement”*, *“More interactivity”*, *“I find the "show more" button a little bit unnecessary, I think it would be easier to access the information just by scrolling”*.
4. Various individual ideas were suggested regarding additional functionalities, such as online collaboration, shared comments, quizzes, the ability to ask questions, etc.

These findings indicate that while the app is highly appreciated for its interactivity and visual clarity, students also see potential for refinement in interface design and user experience. The suggestions reflect both a strong overall satisfaction and a desire for deeper functionality and smoother interaction.

While this evaluation focuses primarily on student perceptions rather than objective performance metrics, the consistently high ratings across both courses suggest that the AI-generated maps are sufficiently relevant to support learning. The hierarchical drill-down structure offers an effective human-computer interaction (HCI) pattern, enabling students to explore complex domains at their own pace and depth. Notably, the substantial portion of concept map creation handled by the LLM significantly reduces instructor workload, making interactive concept maps a more practical and scalable component of intelligent textbooks. The strong student response supports the validity of this direction in learning tool design and affirms that AI-assisted hierarchical concept mapping holds promise for broader adoption in digital textbooks.

8. Conclusion and future work

This study presented the design and implementation of an AI-driven system for generating interactive hierarchical concept maps for digital learning environments and intelligent textbooks. This positions the system as a practical implementation of the intelligent textbook paradigm, where AI augments both content delivery and navigational structure in support of student-centered learning. The platform combines prompt engineering of large language models with human-in-the-loop refinement to produce content that is educationally relevant and adaptable across diverse instructional contexts. Built on a lightweight architecture with a Python backend and a Vis.js-powered frontend, the system enables learners to explore domain knowledge through structured, drill-down navigation, while instructors retain control over quality and relevance.

The evaluation results, based on 69 AI-generated concept maps and 245 unique concept descriptions created across two undergraduate computer science courses, confirm the educational value of the system. Feedback from 35 student surveys revealed an average satisfaction score of 8.91 out of 10, while the usefulness score for learning new content was 8.31 out of 10. Students expressed strong appreciation for the visual clarity, interactivity, and depth navigation features, highlighted by 100% confirming the usefulness of clickable nested maps. These findings underscore the potential of integrating AI-generated maps into intelligent textbooks and online courses to enhance comprehension, engagement, and structured review.

Future work will address current limitations identified in the system's architecture and usage. One key direction is the integration of retrieval-augmented generation (RAG) techniques to allow the LLM to incorporate course-specific materials, such as syllabi, lecture notes, or textbooks, into the generation process. This will help ensure stronger alignment with the instructor's framing and reduce content mismatch in intelligent textbook contexts.

To improve usability and mitigate disorientation during deep drill-down exploration, future enhancements will include research on depth-limiting mechanisms and UX improvements that provide visual context and navigational cues. To resolve submap inconsistencies, algorithmic methods and instructor-facing tools will be developed to support structural validation and map coherence across different levels of hierarchy.

The refinement process will also be integrated more tightly into the instructor-facing UI, enabling seamless editing and regeneration of maps and concept pages within the same workflow. The admin dashboard will be extended to provide broader control and monitoring of content quality. Additional research will explore the effectiveness of the system in other domains such as mathematics, management, and postgraduate software engineering education. Finally, the implementation of agentic AI workflows, where multiple autonomous agents coordinate multi-step concept map construction and refinement, will be explored to further scale and automate the process.

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Declaration on Generative AI

During the preparation of this work, the author used ChatGPT-4 and Grammarly to check grammar and spelling, improve writing style, paraphrase and reword. After using these tools and services, the author reviewed and edited the content as needed and takes full responsibility for the for the publication's content.

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