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AI-Driven Digital Concept Maps in Learning Environments: Empirical Insights from Student Use[1][2]

Mapas conceptuales digitales impulsados por inteligencia artificial en entornos de aprendizaje: aportes empíricos a partir del uso estudiantil[3]

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

[2] Editor's Note: Given the monographic nature of this issue and the thematic relevance of the contribution, an article written in English was accepted for publication on an exceptional basis. In accordance with the journal's editorial policies, the title and abstract are provided in Spanish to ensure accessibility for the Spanish-speaking academic community. This decision reflects the plural and open spirit of the issue and does not constitute a permanent modification of our publication guidelines.

[3] *Nota del editor: dado el carácter monográfico de este número y la pertinencia temática del artículo, se aceptó excepcionalmente la publicación de un manuscrito redactado en inglés. En coherencia con las políticas editoriales de la revista, se presentan en español el título y el resumen correspondientes, a fin de facilitar su accesibilidad para la comunidad hispanohablante. Esta decisión responde a la vocación plural y abierta del número, y no constituye una modificación permanente de nuestras normas de publicación.*

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ABSTRACT

This study explores the integration of AI-powered, ontology-based interactive concept maps into a university programming course to support student learning and includes a comparison of these maps with AI-generated instructional text materials. As part of the "SDT 100: Principles of Programming with Java" course at American University Kyiv, foundational instructional materials were generated using GPT-4o and formalized into an ontology via the Semantic Portal platform. The platform then automatically generated interactive concept maps, with each node linked to structured concept descriptions. These maps were used alongside AI-powered text lectures, providing students with an alternative to linear instructional content. To assess pedagogical relevance, students were asked to provide qualitative feedback on the perceived usefulness of the concept maps. The findings suggest that such maps are particularly effective for content review and understanding conceptual relationships, serving as a valuable complement to traditional text-based materials. The study provides empirical evidence on the instructional potential of AI-powered, ontology-based concept maps and outlines future directions for enhancing their automated generation using large language models.

Keywords: artificial intelligence, higher education, teaching methods, educational technology, visual communication, concept maps, interactive learning tools.

RESUMEN

Este estudio explora la integración de mapas conceptuales interactivos, impulsados por inteligencia artificial y basados en ontologías, en un curso universitario de programación, con el fin de apoyar el aprendizaje estudiantil. Asimismo, incluye una comparación entre dichos mapas y materiales instruccionales generados mediante inteligencia artificial. En el marco del curso «SDT 100: Principios de Programación con Java» de la American University Kyiv, se elaboraron materiales instruccionales fundamentales utilizando GPT-4o,

los cuales fueron formalizados en una ontología a través de la plataforma Semantic Portal. Esta plataforma generó de manera automática mapas conceptuales interactivos, en los que cada nodo estaba vinculado a descripciones estructuradas de conceptos. Los mapas se utilizaron junto con conferencias en texto producidas por IA, ofreciendo a los estudiantes una alternativa al contenido instruccional lineal. Para evaluar su pertinencia pedagógica, se solicitó a los participantes que proporcionaran retroalimentación cualitativa sobre la utilidad percibida de los mapas conceptuales. Los hallazgos sugieren que este tipo de mapas resulta especialmente eficaz para la revisión de contenidos y la comprensión de las relaciones conceptuales, constituyendo un complemento valioso a los materiales basados en texto tradicional. El estudio aporta evidencia empírica sobre el potencial educativo de los mapas conceptuales basados en ontologías y generados mediante IA, y propone líneas futuras para optimizar su creación automatizada a través de modelos de lenguaje de gran escala.

Palabras clave: *inteligencia artificial, educación superior, métodos de enseñanza, tecnología educativa, comunicación visual, mapas conceptuales, herramientas de aprendizaje interactivo.*

Introduction

Concept mapping is a powerful cognitive tool that helps visually organize knowledge through interconnected nodes and labeled relationships. Numerous studies have shown that concept maps can improve knowledge retention, conceptual clarity, and learning outcomes. For example, a meta-analysis by Nesbit and Adesope (2006) found concept maps to be more effective than traditional materials such as outlines and passages. This was further supported by Schroeder et al. (2018), who demonstrated the advantages of using concept maps across a range of learning contexts. İzci and Akkoç (2023) confirmed the positive impact of concept mapping on academic performance. With the evolution of technologies, traditional concept maps have transitioned into dynamic, interactive, and often AI-supported formats. These digital concept maps offer multimedia integration, hyperlinking, real-time collaboration, and adaptive feedback (Tergan et al., 2006; Tytenko, 2020), expanding their functionality across instructional design, navigation, assessment, and exploratory learning.

There are multiple approaches for creating digital concept maps. Manual approaches rely entirely on human effort for extracting key concepts, defining relationships, and organizing information within a visual structure. As an example of such an approach, Shaw (2010) created concept maps from browse-based e-learning materials. During the construction process key concepts were extracted from the headers of sections in learning materials, relationships and their attributes were defined, and nodes were linked to relevant webpages. Meanwhile, Aydogdu and Güyer (2019) investigated digital concept maps and the question of student disorientation while navigating learning materials. Their study introduced a manually designed platform that provided two distinct navigation methods: a concept map and a content tree. Ho et al. (2019) used digital concept maps manually constructed by teachers using editable nodes and multiple-choice dropdowns as a tool for assessing medical students' knowledge and delivering automated feedback. The manual approach shows its efficiency in making customized maps and investigating their impact on students' learning.

The shift toward semi-automated methods introduces algorithmic support to build visuals while having expert input for creating the content of the map. An example is the platform booc.io (Schwab et al., 2017), where educators manually construct a hierarchical structure of key concepts and their interrelationships, organizing course material into modular units that are used to construct the map. Li (2015) presented a Web-based e-book platform that enables students to read digital texts while constructing concept maps in the same interface. Lightfoot (2014) introduced a semi-automated web-based knowledge management tool that presents academic programs as interactive concept maps, enabling students to visually navigate degree requirements and access pertinent advising resources.

To improve the efficiency of concept map generation by minimizing human involvement in the process, automated and AI-powered approaches have been developed and continue to evolve. Early methods focus on rule-based Natural Language Processing (NLP) techniques for extracting concepts

and linking phrases from text (Valerio et al., 2012). Later approaches, such as doc2graph (Yang et al., 2020) and fine-tuned LLM-based systems (Perin et al., 2023), have started using deep learning and large language models to generate more structured and interpretable concept maps. One of the most recent approaches, presented by Ma and Chen (2025), introduced a framework for constructing concept maps from e-books using GPT-4o, which demonstrated strong performance in accurately identifying instructor-defined key concepts and in adding other relevant, previously unlisted concepts that enriched the maps.

Production-ready platforms, like MyMap.AI (2023), ConceptMap.AI (2024), and Think Machine (2024), make it easy to turn a document or prompt into a concept map. However, some practical flaws remain. Their concept-creation logic is hidden, so instructors cannot verify why specific terms become nodes. The generated diagrams are static structures: deleting a single edge or re-parenting a branch requires regenerating the whole map. These systems are not designed to work alongside educational materials and lack deeper concept explanations.

A more advanced method uses LLMs to create concept maps by code. In this workflow, the LLM can output compact diagram scripts in markup languages such as Mermaid.js (2014). It can also generate runnable code using libraries like Graphviz (Ellson et al., 2004), NetworkX (Hagberg et al., 2008), or Matplotlib (Hunter, 2007), which you then execute in a supported code editor. The quality and clarity of user input play a pivotal role in ensuring that generative AI produces accurate, relevant, and pedagogically useful outputs in educational settings (Kakun and Tytenko, 2023). While this approach allows material editing, it requires advanced technical knowledge and would be harder for educators to use.

The platform used in this study, known as the Semantic Portal (2024), enables the automated generation of digital concept maps grounded in a structured ontological framework (Tytenko, 2021). This ontology goes beyond representing concept hierarchies and serves as a multifunctional backbone for several educational tasks. It supports the creation of a domain-specific thesaurus, manages cross-references and explanatory information for each concept, and facilitates both quiz generation and the construction of interactive concept maps (Tytenko, 2019).

As generative AI becomes more prevalent in educational content development, it is essential to investigate the pedagogical relevance and student perception of AI-driven concept maps. While many tools offer AI-based generation of maps, little is known about how learners engage with them in real instructional settings. This study addresses that gap by evaluating the use of AI-generated, ontology-based interactive concept maps within a programming course, focusing on their perceived usefulness and role in supporting student learning. This study examines the students' perceptions of the usefulness of AI-driven concept maps in comparison with AI-generated instructional text materials. Such a comparison of two AI-driven instructional formats highlights an important aspect

in studying the role of contemporary generative AI tools in interactive digital learning environments. Additionally, it is important to identify which learning tasks AI-driven concept maps best support – whether reviewing content, understanding relationships, or deepening conceptual understanding.

To implement this approach, foundational instructional content for a Java programming course was first generated using AI and then systematically formalized into an ontology via the Semantic Portal. Based on this ontological structure, interactive concept maps were created to visually organize and present the material. A study was conducted to assess student perceptions of these AI-driven concept maps as learning tools, with particular focus on their usefulness and perceived effectiveness in supporting the learning process.

Method

Integration of AI-Generated Content and Interactive Concept Maps

The study was conducted within the context of the "SDT 100: Principles of Programming with Java" course at American University Kyiv, involving first-year Bachelor students from the Software Engineering and Data Science programs. In this study, the Semantic Portal (2024) learning platform was used to develop and present the AI-driven course materials investigated. Specifically, both AI-generated text-based lectures and digital preconstructed interactive concept maps were created and integrated into the course content on the platform. These concept maps were designed to visually represent the logical structure of programming topics, enabling students to explore relationships between key ideas (Figure 1). Students had no prior experience with Semantic Portal interactive digital concept maps. However, we did not conduct additional surveys to determine whether they had prior exposure to other types of concept maps. The novelty of working with this specific format, together with the lack of information about students' previous experience with other concept map approaches, may have influenced their engagement and represent potential limitations of this study. Semantic Portal was introduced to students during the fifth week of the SDT 100 course, which lasts 7.5 weeks. Students were provided with access to the platform, and questionnaires were designed to collect their feedback through the university's LMS Canvas. Open-ended questions were delivered through the LMS Canvas quiz tool, and the corresponding answers were collected for analysis. No additional interviews or focus groups were organized. Before engaging with concept maps on the Semantic Portal, students received guidance from the instructor on how to use both the lectures and concept maps effectively. They were given a short demonstration during the class, which ensured that students understood the functionalities of the platform and how to access the materials.

To construct the concept maps on the platform, the following process was implemented. At first the lecture materials were generated using the GPT-4o model of ChatGPT. The generated text was uploaded to the system in HTML format through the admin panel. These materials were then

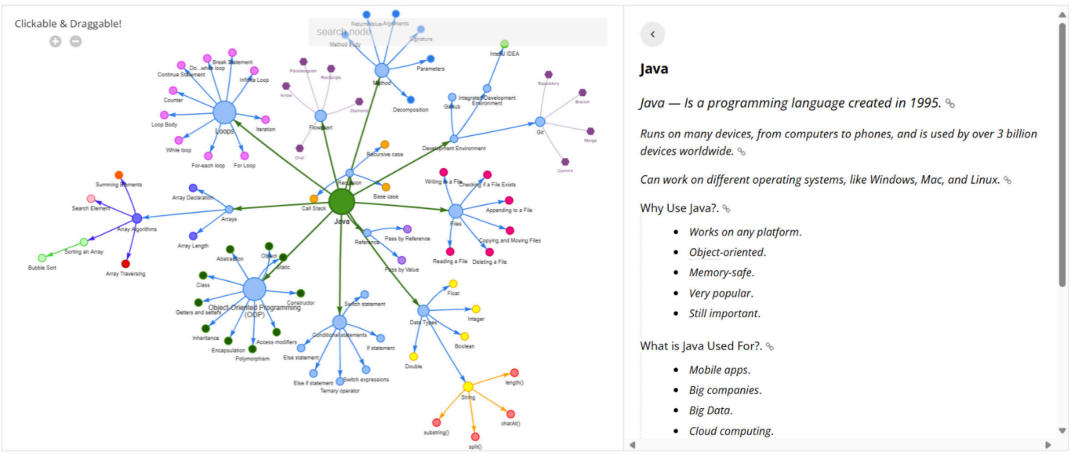
structured into a course designed to fulfill the intended learning outcomes and provide coherent progression across lectures.

The ontological formalization of the text was performed using the platform's interactive admin panel. Key concepts and supporting theses were extracted from the AI-generated lecture materials. Each concept was identified within the text, and the platform automatically highlighted its occurrences throughout the course and linked them to a dedicated concept page. In addition to defining individual concepts, the ontology development process included the creation of structured semantic relationships, such as *part-of* and *aspect-of* links, which organize concepts into hierarchical structures (Tytenko, 2019).

Based on the resulting ontological description of concepts and their relationships, the platform generated an interactive concept map. This map allows users to visually explore the course content and filter the graph by specific topics, reducing cognitive load and enabling more focused study. Nodes in the concept map are clickable, providing access to the concept description in the form of a formatted list of theses. These entries may also include supporting media such as code snippets, diagrams, or images.

Figure 1

Semantic Portal (2024) concept map on the topic "Java"



Note. Screenshot from authors' own platform.

Qualitative Questions on Concept Map Use

After engaging with the learning materials on the platform, the 22 students who participated in the course were asked to provide qualitative feedback on their experiences, particularly regarding the perceived effectiveness of the concept maps in supporting their learning. The questionnaire consisted

of five questions in total. This paper focuses on two that are most relevant to the research goals. The remaining questions addressed other aspects of the use of the learning tools. As these questions were not directly related to the focus of this study, they were not included in the present analysis.

The two open-ended questions selected for analysis in this study are as follows:

- Question 1: *Please share your reflections on the usage of concept maps. What was useful? How does it help?*
- Question 2: *What is more convenient: text format or concept maps? Why?*

The following sections present student responses and analyze their implications for evaluating the perceived effectiveness of AI-driven digital interactive concept maps in learning, as well as their comparison with AI-generated instructional text materials. Out of 22 participants, 18 students responded to the first question, while every participant answered the second.

The purpose of Question 1 was to gather qualitative data on how students used concept maps during their learning process and to identify which aspects of this tool they perceived as most effective or beneficial. Some examples of students' responses to Question 1 are demonstrated below:

- *"The concept map helped summarize all the information and rewind the theory we've already learned. It was also useful as a hint if I forgot a syntax of a certain functionality".*
- *"The concept map was useful for recapping information. I'm not sure that it is effective to learn something from scratch, but it is completely applicable and effective for refreshing what you already know".*
- *"Concept maps helped me to put the whole program into perspective, and to see how the different topics relate to each other".*
- *"I think concept maps are useful. If you don't understand what, for example, boolean means, you can read about it briefly and get the overall idea of it".*

After the feedback collection, responses were categorized into four main categories: Review, Relations, Understanding, and a combined category of Review + Relations. The detailed meaning of these themes is shown in Table 1.

Table 1

Classification of students' responses

Answer to question 1	Meaning
Review	The concept maps were useful for reviewing the topic
Relations	The concept maps were useful for understanding the relations between concepts
Understanding	The concept maps were useful for understanding the concepts
Review+Relations	The concept maps were useful for both reviewing the topic and understanding the relations between concepts

Note. Prepared by the authors.

To categorize the responses, the following approach was used. Recurring keywords and phrases in students' answers were identified and mapped to the categories. This approach enabled the grouping of similar reflections and the identification of the common patterns in how students used concept maps and what they found most effective. The mapping of the keywords to the categories is presented in Table 2.

Table 2

Mapping of the keywords from Question 1 to the categories

Key word	Category
recap	Review
repeat	Review
rewind	Review
revise	Review
means	Understanding
relationships	Relations
recall	Review
relate	Relations
connections	Relations
review	Review
refresh	Review

Note. Prepared by the authors.

Question 2 focused on students' comparative evaluation of concept maps and text-based lectures, each created with the support of generative AI tools. The responses were categorized into three groups: preference for concept maps, preference for text format, and preference for both. This categorization was done by interpreting the meaning of each response. Some examples of students' responses to Question 2 are demonstrated below:

- *"As for text format, I would change icons (put names of themes instead of parts of code), add some little practical tasks and improve the interface. In turn, concept maps have a great interface, but lack of (there are no) practical tasks too. I liked concept maps more".*
- *"For me, both of them. It depends on the complexity of the material."*
- *"For me, it was more convenient to use the text format."*

After the categorization of the answers to both questions, quantitative analysis was performed using Google Sheets. The number and percentage of responses in each category were calculated, and graphs were created to visualize the distribution.

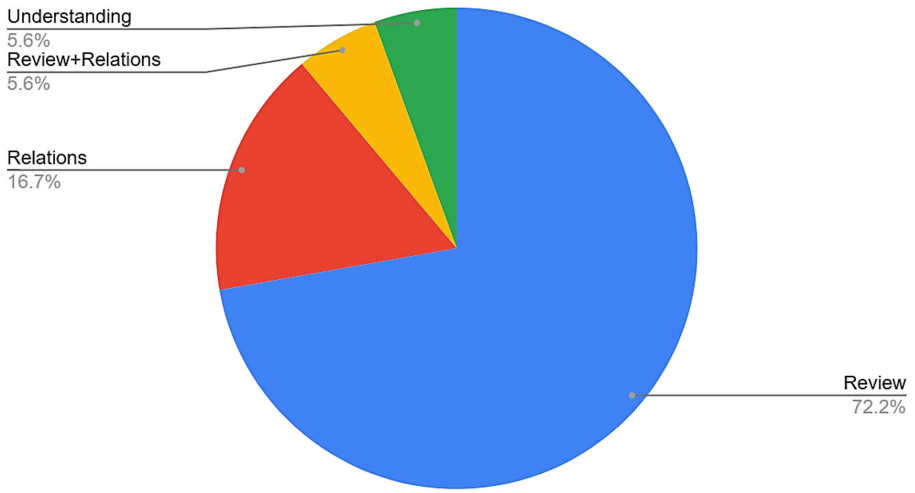
Results

Student Perceptions of Concept Maps' Usefulness

The majority of the students (13 out of 18) reported that concept maps were particularly effective for reviewing the topic. A smaller number of students found the maps helpful for understanding the relations between concepts (3 students), and only one student highlighted their value in supporting conceptual understanding. One student identified both review and relations as beneficial. Most students perceived the concept maps in this system primarily as effective tools for reviewing and reinforcing previously learned material, rather than for developing new conceptual understanding. The results were visualized with the help of the pie chart (see Figure 2).

Figure 2

The pie chart of the student responses to Question 1 grouped into the mentioned themes



Note. Figure created by the authors using data collected through their own study.

Comparative Preference of Concept Maps and Text Lectures

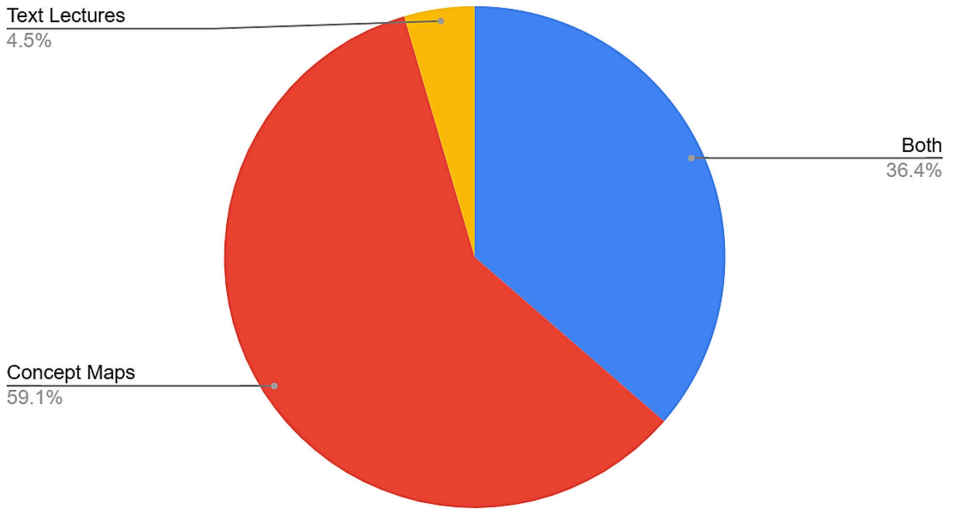
The second question focused on students' comparative evaluation of concept maps and traditional text-based lectures. Among 22 responses:

- *13 students (59.1 %) stated that the concept maps were more convenient.*
- *8 students (36.4 %) preferred a combination of both formats.*
- *1 student (4.5 %) expressed a preference for text lectures alone.*

The results were visualized with the help of the pie chart (see Figure 3).

Figure 3

The pie chart of the student responses to Question 2 grouped into the mentioned themes



Note. Figure created by the authors using data collected through their own study.

Discussion

Relationship Between Perceived Usefulness and Learning Format Preference

To explore whether the perceived function of concept maps influenced students' overall preference for learning formats, the relationship between the two sets of responses was examined.

Notably, only those students who reported using the concept maps primarily for review purposes indicated that they found them more convenient than text-based lectures, without stating that they used both of them. That could mean that when concept maps serve as tools for consolidation and repetition, students are more likely to view them as stand-alone learning aids. However, it is important to note that not all students who mentioned review as the primary way they used the concept maps found them to be more preferred than text-based lectures. Out of 13 such individuals, 10 fall into this category, while the other three either reported the concept maps to be effective in combination with text lectures or found the text lectures to be more convenient.

Our finding that students most frequently used the maps for review (72.2 %) aligns with meta-analytic evidence that concept maps are especially effective for reinforcing knowledge and supporting recall (Nesbit and Adesope, 2006; Schroeder et al., 2018).

Another valuable insight was that the students who cited connections or understanding as key benefits were more likely to fall into the "both formats" category, indicating a preference for a blended learning approach. While they valued the clarity of the concept maps, they also relied on the textual lectures for depth and elaboration. Students' emphasis on relationships between concepts corresponds to the role of digital concept maps in integrating knowledge structures and supporting coherent representations of complex subject matter (Tergan et al., 2006). This also resonates with the advantages of hierarchical, non-linear navigation in digital environments (Schwab et al., 2017), highlighting the organizational clarity maps provide beyond textual explanations.

No consistent pattern emerged indicating that those focused on review preferred concept maps alone, or that students prioritizing deeper understanding rejected visual formats.

Recent research syntheses have shown that concept maps have a broadly positive effect on academic performance across diverse educational contexts (İzci and Akkoç, 2023). Building on this broader foundation, studies with a focus on generative AI add new perspectives: Perin et al. (2023) and Ma and Chen (2025) explore concept maps generated directly by large language models, while our work examines ontology-based interactive maps constructed from AI-generated text. Taken together, these contributions represent complementary steps toward advancing the role of AI in developing interactive concept maps for education.

Interpretation and Implications

The analysis shows that digital preconstructed interactive concept maps, as implemented via the Semantic Portal (2024) platform, are perceived as effective educational tools. Students valued them mainly for content review and visualization of conceptual relationships, with a majority preferring them over traditional lectures or appreciating their use in combination with textual materials.

The cross-analysis suggests that students who mainly used the maps for review often viewed them as sufficient on their own, although some still preferred to combine them with text lectures. Students who valued conceptual understanding tended to adopt a blended approach, suggesting that combining visual and textual formats addresses a wider range of learning needs.

Overall, the findings point to a nuanced pattern in students' evaluations: while their preferences are shaped by how they engage with concept maps, these are also mediated by individual learning strategies and perceived educational value. Rather than demonstrating a clear preference for one format over the other, students generally recognized the complementary strengths of both concept maps and text lectures. This highlights the value of combining multiple instructional formats, supporting a more integrated and flexible approach to teaching and learning.

Limitations

This study is subject to several limitations. First, it was conducted within a single course (SDT 100: Principles of Programming with Java) at one institution, which may limit the generalizability of the findings to other disciplines, institutions, or educational levels. Second, the sample size was relatively small (22 students), and while the second question was answered by all participants, only 18 provided detailed responses to the first feedback question, which constrains the statistical robustness of the results. Third, the feedback collected was qualitative and self-reported, relying on students' subjective perceptions rather than objective learning outcomes or performance data. Additionally, the study focused exclusively on preconstructed concept maps generated using the Semantic Portal, with concept descriptions based on AI-generated lecture text citations, presented in the format of concise theses. Since this specific format shapes how information is presented and accessed, alternative formats, such as AI-generated explanatory text tailored to each concept, may result in different patterns of student engagement and perception. Finally, the absence of a detailed questionnaire on students' prior experience with different types of concept maps remains a limitation, as such background information could have provided important context for interpreting their engagement and feedback. Preferences may also reflect a novelty effect and the timing of platform introduction, as the Semantic Portal was integrated only in week 5 of a 7.5-week course. Introducing the maps near the end of instruction may have predisposed students to use them primarily for review, whereas earlier exposure might have highlighted their potential for supporting initial concept acquisition.

Conclusions

The integration of AI-driven interactive concept maps into course delivery offers a practical enhancement to traditional learning materials, particularly in supporting content review and conceptual organization. Our case study using the Semantic Portal (2024) demonstrated that preconstructed, interactive concept maps, where each node includes a structured concept description, can serve as effective visual supplements. In this study, these maps were evaluated alongside AI-generated text lectures, allowing for a direct comparison between two AI-based instructional formats. A majority of students (59.1 %) preferred the concept maps over text-based lectures, while 36. 4% preferred a combination of both formats. Notably, 72.2 % of students indicated that they used the concept maps primarily for reviewing content, suggesting that students perceived them as especially useful for reinforcing previously learned material.

These findings indicate that, when thoughtfully integrated, AI-driven interactive maps with embedded concept descriptions can enhance the learning experience by providing visual clarity and supporting cognitive processes involved in review and relational understanding. While they are not a replacement for detailed textual explanations, such maps represent a valuable complement to conventional instructional formats. Nevertheless, these conclusions should be interpreted with caution, as the study

was based on a single course with a relatively small sample and relied on self-reported perceptions rather than objective performance measures. Future work will focus on advancing the level of automation in concept map generation using large language models, with the goal of preserving pedagogical quality while improving the efficiency of the creation process.

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