e-ISSN nº 2447-4266
Palmas, v. 12, n. 1, 2026
http://dx.doi.org/10.20873/uft.2447-4266.2026v12n1a00en

MEANINGFUL LEARNING IN VIRTUAL ENVIRONMENTS: effects of concept map on student metacognition

APRENDIZAGEM SIGNIFICATIVA EM AMBIENTES VIRTUAIS: efeitos do mapa conceitual na metacognição discente
APRENDIZAJE SIGNIFICATIVO EN ENTORNOS VIRTUALES: efectos del mapeo conceptual en la metacognición estudiantil

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Received on:10.24.2025
Accepted on:04.14.2026
Published on: 06.22.2026.

ABSTRACT
Introduction: Concept mapping (CM) combines Ausubel's meaningful learning theory with metacognitive practices. Objective: To assess whether the sequential application of CM promotes meaningful learning and strengthens metacognitive skills in nursing students. Methods: Quasi-experimental study with 76 nursing students from a private institution. Three CM cycles (CM1–CM2) were integrated into the "Women's Health Nursing" course. Results: There was an increase in the number of semantically valid propositions ($p < .001$), and the proportion of network maps rose to 31%. Regarding perceptions, 78% of students rated CM as highly useful for reorganizing prior knowledge. Conclusion: CM proved effective in promoting metacognition and conceptual integration, making knowledge gaps visible.

KEYWORDS: Educational Technology; Learning; Competency-Based Education.

Introduction

Concept mapping (CM) is an effective educational technique that offers two central benefits for quality teaching: (a) identifying students' pre-existing knowledge and (b) organizing it in relation to concepts already understood. Introduced by Joseph Novak in science classrooms, the technique has expanded to various disciplines and educational contexts, in addition to being incorporated into scientific research practices (Novak *et al.*, 1984).

A concept map connects two concepts via a linking word; the nodes represent the concepts, and links indicate their relationships. These elements can be arranged hierarchically, cyclically, or in a hybrid manner, always encompassing the essential concepts. The graphical representation facilitates the activation of prior knowledge, supports problem-solving, improves comprehension, and aids in content review (Van Rensburg *et al.*, 2023).

The technique also enhances strategies for solving clinical cases, as it requires advanced cognitive skills and metacognition. Grounded in Ausubel's theory of meaningful learning, which emphasizes the role of prior knowledge in the acquisition of new knowledge, conceptual mapping allows students to construct propositions and integrate concepts in a structured, y manner (Ausubel, 1968). By making the relationships between concepts explicit, it fosters reflection on cognitive progress and empowers students to take greater control of their learning (Novak *et al.*, 1974).

Empirical evidence indicates that CM stimulates self-reflection, reduces cognitive load, and improves problem-solving performance at different educational levels (Joshi *et al.*, 2022; Torre *et al.*, 2023). Effectiveness, however, depends on proper application; the classroom context, the timing of introduction, and student readiness are decisive factors.

In addition to enriching pedagogical practice, MC allows for a comprehensive assessment that encompasses declarative, procedural, and structural knowledge. As a

e-ISSN nº 2447-4266
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diagnostic tool, it helps teachers map students' prior knowledge and establish a baseline for subsequent activities. In the formative process, it assesses changes in structural knowledge, allowing for adjustments to instruction. In summative assessment, it verifies the final structure of acquired knowledge and provides evidence regarding the effectiveness of formative feedback. Thus, conceptual mapping is a versatile tool that addresses diverse learning needs, supports metacognition, and offers multiple assessment possibilities throughout the entire educational process.

Concept mapping for the development of metacognition and problem solving

In addition to its role in traditional assessments, CM stands out as a metacognitive tool that supports the formative assessment of students' structural knowledge. CM makes it possible to identify differences between beginners and experts in both quantitative aspects, such as the number of concepts and connections, and qualitative aspects, such as the precision of connecting phrases and the depth of relationships. This comprehensive feedback reveals misconceptions and gaps, providing a basis for continuous improvement: for students, it guides the self-regulation of learning; for teachers, it offers data to adjust the pedagogical approach (Barbosa, 2025).

From a problem-solving perspective, mind mapping surpasses traditional expository approaches by externalizing mental models. Joshi *et al.* (2022) observed that biomedical engineering students find mind maps useful for understanding, identifying, and connecting different concepts. Similarly, Howell *et al.* (2021) reported a significant impact of mind mapping on understanding the factors contributing to healthy aging. Although Carmack *et al.* (2024) found no direct empirical evidence, the authors suggest that the technique may support prevention programs aimed at reducing the incidence of sexually transmitted infections among young heterosexual adults in African American communities.

As a strategy that organizes cognitive structures into increasingly integrated patterns, CM is grounded in the theory of meaningful learning. From this perspective, learning occurs when the learner recognizes the demands of a new problem, selects previously acquired skills, and monitors their application during problem-solving. Thus, conceptual mapping facilitates the transfer of knowledge to novel contexts and supports metacognitive development throughout the entire learning process.

In an innovative setting, concept mapping was used as a metacognitive tool in a nursing course during remote classes, with the aim of promoting meaningful learning and developing metacognitive skills. First, students created concept maps; then, they discussed them in pairs and answered reflective questions, which allowed them to rethink complex concepts. The activity was adapted for online learning environments, using the cognitive dimensions of the revised Bloom's taxonomy to facilitate meaningful learning (Nascimento *et al.*, 2021).

Students' academic performance and self-reported perceptions were assessed, revealing learning gaps and enabling constructive feedback. These results reinforce the utility of CM both for supporting metacognition and for guiding adjustments in pedagogical practice. This study aimed to assess whether the sequential application of MC promotes meaningful learning and the strengthening of metacognitive skills.

Materials and methods

This is a quasi-experimental study with a quantitative approach, using a pre- and post-intervention design. The study was conducted at a private institution in the São Paulo Metropolitan Region between August and December 2021. Seventy-six students regularly enrolled in the required course "Nursing in Women's Health" participated. All regularly enrolled students were invited, constituting a convenience sample; due to the COVID-19 situation, all classes were conducted in a hybrid format.

Participants

The sample consisted of 76 nursing students, aged 18 to 39 years (mean = 25.4; SD = 4.1). For the comparative analysis between the two time points, only students who submitted complete maps in both stages were included (n = 26). The majority were female (n = 74; 97%). Among the participants, 73% (n = 55) identified as Black or Brown, and 61% (n = 46) reported being married. Only 2.6% (n = 2) had a prior university degree. Half of the sample (50%, n = 38) reported a family income of up to five minimum wages.

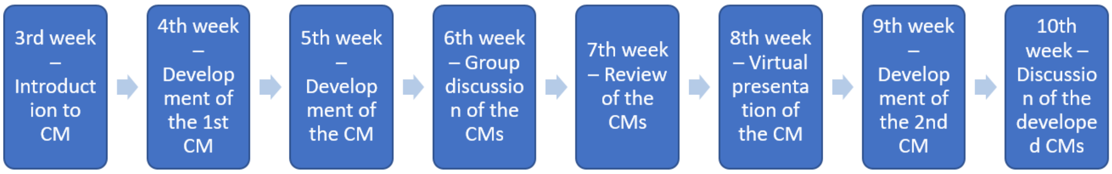
Procedure

Classes were held twice a week, totaling 200 minutes, of which 60 minutes were devoted to problem-solving. The course encouraged pre-reading, active learning, and collaboration through: weekly forum posts (10%), textbook-based quizzes (10%), reinforcement exercises (40%), and two formal assessments (40%). The conceptual mapping intervention unfolded in three phases.

The complete schedule of activities is illustrated in Figure 1.

revista Observatório
e-ISSN nº 2447-4266
Palmas, v. 12, n. 1, 2026
http://dx.doi.org/10.20873/uft.2447-4266.2026v12n1a00en

Figure 1
Evolution of CM activities during the course



Source: Prepared by the author.

Activity Development

Students were informed, as early as the first week of the remote semester, that they would participate in conceptual mapping (CM) exercises.

Week 3 – Group demonstration: The instructor dedicated approximately 30 minutes of an online class to illustrate, using PowerPoint slides, examples of appropriate and inappropriate concept maps. Next, they led the group creation of a CM1 on obstetric emergencies and clinical management, with active participation from the class.

Week 4 – Mandatory individual CM2: After the demonstration, students were randomly assigned to Google Meet rooms (with four to five students per room) and given 30 minutes to begin their individual maps. During this period, the instructor circulated among the rooms, acting as a facilitator. Students had one week to review their maps before publishing them on CmapTools® (IHMC, 2022) in response to the task: "Create a concept map on Specific Hypertensive Syndromes of Pregnancy (SHEG)." All 76 students completed the activity.

Weeks 9 and 10 – Extension MC with peer reflection: Students received a second challenge, worth extra points:

a) Create a new MC that addresses the following clinical problem: a pregnant woman with preeclampsia progressing to eclampsia.

b) Explain their own map to peers and listen to others' explanations in the next class (after the break).

c) Provide and receive feedback on unclear terms or conceptual relationships.

d) After the discussion, visually highlight the concepts that are difficult to explain.

e) Failure to complete the activity would not affect the final grade.

Each stage of the intervention was related to the dimensions of the cognitive process in Bloom's revised taxonomy (Table 1). The instructor used this correspondence to guide formative feedback and promote meaningful learning.

Table 1
Concept Mapping Intervention for metacognitive development, according to the dimensions of the cognitive Process in Bloom's revised taxonomy

Metacognitive Activity	Description of the activity in the intervention	Evidence	Cognitive Process Dimension
Performing various cognitive activities during the creation of the CM, such as hierarchical structure and links, etc.	Creation of a mind map using knowledge acquired in class.	Submission of the mind maps	Recall, understand, and apply
Assess whether the concepts presented in the MCs are understood by peers and whether the concepts used are appropriate	Peer discussion about MCs	Student responses to the MCs submitted by peers, recorded in posts on the discussion forum; Responses to prompts (self reflection activity)	Recall, apply, analyze
Reflect on the presentation of one's own concept map in a group and identify learning gaps	Identify points with unclear semantics through group discussions	Responses to the self-reflection prompt	Analyze

Source: Prepared by the author.

Ethical principles

This study was approved by the Research Ethics Committee, in accordance with the ethical principles established by Resolution No. 466/2012 of the National Health Council. All participants were properly informed about the objectives and procedures of the research and signed the Informed Consent Form (ICF), ensuring their voluntary and informed participation.

Data Analysis

The data were analyzed using SPSS 21.0 software. Descriptive statistics were employed to present measures such as mean, frequency, and standard deviation. To compare performance in solving clinical cases and the structural parameters of the maps constructed at different times, the paired t-test, Wilcoxon test, and McNemar test were used. Effect size was estimated using Cohen's d. A p-value < 0.05 was considered to indicate significant effects in all tests performed.

revista Observatório
e-ISSN nº 2447-4266
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http://dx.doi.org/10.20873/uft.2447-4266.2026v12n1a00en

Results

The concept maps created by the students on Pregnancy-Specific Hypertensive Syndromes (PSHS) were evaluated for the number of concepts, semantic clarity, linking phrases, cross-relationships, topological taxonomy, and total score. A significant increase in the number of concepts was observed between MC1 and MC2, with means of 36.4 ± 22.6 and 46.4 ± 19.6, respectively (p = 0.003). Semantic clarity also showed a significant improvement, rising from 24.7 ± 18.0 to 43.9 ± 15.0 (p = 0.004).

In contrast, there was a reduction in the number of linking phrases, from 52.0 ± 18.7 to 39.1 ± 20.0 (p = 0.045), as well as in cross references, from 42.6 ± 17.2 to 7.3 ± 3.7 (p = 0.027). Topological taxonomy had a mean of 8.9 ± 4.3 in MC1 and 4.6 ± 0.8 in MC2 (p = 0.037). Despite these structural variations, the total score increased significantly from 5.83 ± 1.10 to 7.60 ± 1.14 (p < 0.001), suggesting an overall improvement in the quality of the concept maps.

Table 2

Descriptive analysis of the analytical structure of the Concept Maps

Structure	CMs	Mean	Median	DP	Q1	Q3	N	IC	p- value
Concepts	CM1	36,4	23,5	22,6	22	45,8	26	11,8	0,003
	CM2	46,4	41,5	19,6	37	48,0	26	10,3	
Semantic Clarity	CM1	24,7	48,5	18,0	35	51,5	26	7,9	0,004
	CM2	43,9	48,5	15,0	35	51,5	26	7,9	
Transition phrases	CM1	52,0	52,5	18,7	46,3	64,3	26	9,8	0,045
	CM2	39,1	36,5	20,0	25,5	50,5	26	10,5	
Cross relationships	CM1	42,6	48,5	17,2	28	53,5	26	9,0	0,027
	CM2	7,3	6,5	3,7	5	10,3	26	1,9	
Topological taxonomy (Levels)	CM1	8,9	9	4,3	5,5	10,8	26	2,3	0,037
	CM2	4,6	4	0,8	4	5,0	26	0,4	
Total points	CM1	5,83	6,0	1,10	5,1	6,9	26	0,63	<0,001
	CM2	7,60	7,5	1,14	7,1	8,4	26	0,61	

Notes: CMs: conceptual maps; SD: standard deviation; Q1: 1st quartile; Q3: 3rd quartile; N: number of individuals; CI: confidence interval; *p< 0.05 for all variables analyzed).
Source: Prepared by the author.

In the topological taxonomy analysis, approximately half of the maps were classified at level 4 (n = 36; 47%), indicating an advanced conceptual hierarchy. A difference was observed in the hierarchical levels of the maps between CM1 and CM2, with means of 8.9 and 4.6, respectively (p = 0.037), indicating structural reorganization of the maps throughout the intervention. Furthermore, Table 3 presents the descriptive results, comparing the hierarchical organization adopted at each stage of CM construction.

Table 3
Distribution of conceptual maps according to hierarchical organization at different stages

Structure/Resources	CMs		CM1		CM2		p- value
			N	%	N	%	
Hierarchical organization	CMs	Linear	61	81	52	69	0,043
		Network	14	19	24	31	

Notes: CMs: conceptual maps; N: number of individuals; %: percentage; *p<0,05.
Source: Prepared by the author.

Regarding the hierarchical organization of the concept maps, a statistically significant difference was observed between CM1 and CM2 (p = 0.043). There was a reduction in the proportion of linear maps, from 81% (n = 61) to 69% (n = 52), and an increase in the proportion of network maps, from 19% (n = 14) to 31% (n = 24), as shown in Table 3. This result suggests greater conceptual integration following the pedagogical intervention.

Discussion

In MC1, 46% of the students established connections that achieved ≥ 75% of the maximum score for valid propositions. All maps included the Specific Descriptors (SDs), a fundamental step for the subsequent phases of the process (Iannicelli *et al.*, 2019). At this stage, students had to understand the clinical progression of the disease, assess systemic repercussions, and formulate actual and risk diagnoses, which requires active information seeking, critical thinking, and clinical reasoning (NANDA-I, NIC, and NOC, 2019).

Performance on MC2 exceeded that of the previous map, suggesting that the approach promoted integration between theory and case data, creating meaningful connections (Leoni-Scheiber *et al.*, 2019). Nevertheless, some maps exhibited low semantic clarity and numerous invalid propositions—concepts connected without logical coherence. Three factors may explain this result: (1) insufficient theoretical knowledge of SHEG; (2) limited familiarity with the nursing process; (3) initial learning of the CmapTools® software.

e-ISSN nº 2447-4266
Palmas, v. 12, n. 1, 2026
http://dx.doi.org/10.20873/uft.2447-4266.2026v12n1a00en

MC2 addressed a clinical case involving Pregnancy-Specific Hypertensive Syndromes (SHEG), a multisystemic condition that can progress to severe outcomes (Ukah *et al.*, 2019). Failures in the early recognition and timely management of gestational hypertensive disorders remain associated with severe maternal morbidity, long-term disabilities, and maternal and perinatal mortality.

Maps containing invalid propositions indicate partial understanding and facilitate the identification of conceptual errors. This finding reinforces the need to improve knowledge of nursing taxonomies and to train students in both the nursing process and the use of the software, so that they can develop precise and semantically correct propositions.

Most maps exhibited a moderate number of cross-relationships. This pattern suggests that students tend to make simplistic associations that, although indicating an attempt to reorganize knowledge, do not yet express the full conceptual complexity involved (Torre *et al.*, 2023). Thus, learning remains incipient and superficial, pointing to the need for additional strategies, such as structured feedback and progressive map refinement exercises, in order to promote higher levels of conceptual integration and metacognition.

From a taxonomic perspective, a predominance of maps with greater structural complexity (levels 4 and 5 of the topological taxonomy) was observed, evidencing hierarchical organization and conceptual branching. There was a heterogeneous distribution among students, and in many cases, the absence of explanatory texts and connecting phrases resulted in excessive branching that hindered comprehension. Nevertheless, students' persistence in challenging activities was associated with quantitative gains in performance.

The study also showed that the quality of the concept map decreases when students disregard the instructions provided in the initial training. As highlighted by Van Rensburg *et al.* (2023), creating effective maps requires time and practice; students exposed to the process for the first time tend to underestimate the effort required.

Peer discussion played a crucial role in promoting metacognition (Barbosa, 2024). During this phase, students reflected on the group's explanations and identified points of difficulty in their own communication of concepts, according to Nascimento *et al.* (2021). This joint reflection fostered an understanding of conceptual interrelationships and contributed significantly to the metacognitive development observed in MC2.

These findings reinforce the need for: (a) ongoing training in the use of CmapTools®, (b) rubrics to guide the construction of clear semantic propositions, and (c) systematic space for peer discussion, aiming to deepen conceptual integration and elevate the maps to higher levels of the taxonomy.

The implementation of conceptual mapping (CM) in this study served as a connecting axis between Ausubel's meaningful learning and the three central components of metacognition—planning, monitoring, and evaluation. Data analysis shows that CM was not merely a graphic resource, but an epistemic tool that allowed students to articulate, reorganize, and critique their own cognitive structures based on empirical evidence.

First, metacognitive planning was evident even during the initial map building phase: when selecting core concepts of Gestational Hypertensive Syndrome (GHS), students had to make decisions regarding relevance, granularity, and conceptual hierarchy. This intellectual framework reveals a shift from the traditional focus on content memorization to an investigative stance, in which one critically evaluates "what" and "why" to include (Novak & Cañas, 2008).

The longitudinal comparison between MC1 and MC2 confirmed this shift by showing improved semantic clarity and a significant increase in the overall structural quality index, indicating that students had internalized, to a greater extent, previously implicit conceptual validation criteria.

Metacognitive monitoring, in turn, emerged more clearly during the mandatory oral presentations. By explaining the relationships between concepts to their peers, the students demonstrated higher-order thinking, as they revisited their linking decisions, assessed semantic coherence, and identified gaps that required restructuring.

This process was amplified by peer feedback: divergent comments served as cognitive triggers, compelling the presenter to justify or modify their propositions in light of clinical evidence and nursing taxonomies (BARBOSA, 2024). The literature on health learning corroborates this dynamic, emphasizing that the social resolution of conceptual discrepancies increases the likelihood of lasting knowledge retention (Clark & Samson, 2019).

Finally, the dimension of metacognitive evaluation materialized in the iterative review cycles provided by CmapTools®. Students accessed objective metrics, such as the number of cross-links and hierarchical depth, and qualitative criteria, such as semantic clarity and appropriateness of linking words, to judge the robustness of their conceptual representation.

revista Observatório
e-ISSN nº 2447-4266
Palmas, v. 12, n. 1, 2026
http://dx.doi.org/10.20873/uft.2447-4266.2026v12n1a00en

The analysis showed that a significant portion of the participants produced maps with a more elaborate structural organization. Although this pattern indicates more robust interrelationships, the persistence of less integrated maps suggests that conceptual integration skills remained nascent in a portion of the class, highlighting the need for additional instructional interventions, such as more detailed rubrics and exercises comparing prototypical maps with those produced by students.

From an epistemological perspective, the results reaffirm that the MC acts as a meta-representation interface: by making each individual's "conceptual spaces" visible, it enables grounded critique and the active reconstruction of knowledge. However, two limitations deserve mention. First, the absence of a control group makes it impossible to attribute the observed gains exclusively to the MC; other didactic factors, such as guided readings, may have contributed. Second, the learning curve for the digital tool takes time; 24% of students reported technical difficulties that interfered with the depth of their proposals, aligning with the warning by Van Rensburg *et al.* (2023) regarding the underestimation of the effort required.

Limitations

This study was conducted at a single institution, which limits the generalizability of the findings to similar contexts. The sample size reduces statistical representativeness and may introduce self-selection bias. Conducting the intervention in a virtual environment may also have influenced performance, as connectivity conditions, digital proficiency, and reduced nonverbal interaction differ from hybrid teaching. It is recommended to expand the sample size and include multiple institutions, preferably from different regions, to increase representativeness.

Final considerations

Concept mapping has thus proven capable of promoting meaningful learning and developing metacognitive skills, as it encourages the critical selection and anchoring of new concepts, stimulates continuous monitoring through peer dialogue, and provides metrics for rigorous self-assessment. Future research should test combinations of CM with other active teaching strategies, such as high-fidelity clinical simulations, and employ experimental designs that include control groups in order to isolate and quantify the specific effect of CM on the metacognitive and clinical-care performance of nursing students.

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RESUMO
Introdução: O mapeamento conceitual (MC) combina a teoria da aprendizagem significativa de Ausubel com práticas metacognitivas. Objetivo: Avaliar se a aplicação sequencial de MC favorece a aprendizagem significativa e o fortalecimento das habilidades metacognitiva. Métodos: Estudo quase-experimental com 76 estudantes de enfermagem, de uma instituição privada. Três ciclos de MC (MC1–MC2) foram integrados à disciplina "Enfermagem na Saúde da Mulher". Resultados: Houve um aumento no número de proposições semanticamente válidas ($p < 0,001$) e a proporção de mapas em rede elevou-se para 31%. Quanto às percepções, 78% dos estudantes atribuíram alta utilidade ao MC para reorganizar conhecimento prévio. Conclusão: O MC revelou-se eficaz para promover metacognição e integração conceitual, tornando visíveis lacunas de conhecimento.

PALAVRAS-CHAVE: Tecnologia Educacional; Aprendizagem; Educação Baseada em Competências.

RESUMEN
Introducción: El mapeo conceptual (MC) combina la teoría del aprendizaje significativo de Ausubel con prácticas metacognitivas. Objetivo: Evaluar si la aplicación secuencial del MC promueve el aprendizaje significativo y fortalece habilidades metacognitivas en estudiantes de Enfermería. Métodos: Estudio cuasiexperimental con 76 estudiantes de enfermería de una institución privada. Tres ciclos de MC (MC1–MC2) se integraron en la asignatura "Enfermería en la Salud de la Mujer". Resultados: Hubo un aumento en el número de proposiciones semánticamente válidas ($p < 0,001$) y la proporción de mapas en red se elevó al 31%. En cuanto a las percepciones, el 78% de los estudiantes atribuyó alta utilidad al MC para reorganizar el conocimiento previo. Conclusión: El MC se mostró eficaz para promover la metacognición y la integración conceptual, haciendo visibles las brechas de conocimiento.

PALABRAS CLAVE: Tecnología educativa; Aprendizaje; Educación basada en competencias.