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Integrating concept mapping and authentic assessment to enhance pre-service elementary teachers' competence

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ABSTRACT

This study examines the integration of concept mapping and authentic assessment in pre-service elementary science education using a four-phase professional development model. An embedded mixed-method design was employed, involving 82 seventh-semester students in a primary school teacher education program at a state university in Indonesia. Quantitative data were collected through pre-tests, post-tests, and concept map analysis, while qualitative data were obtained from questionnaires, interviews, and reflections. The results show a significant improvement in students' conceptual understanding, with scores increasing from 38.33% to 83.66% (N-Gain=0.74, high category). Students demonstrated the ability to construct concept maps with appropriate structural elements. However, challenges remained in developing deep elaboration and meaningful cross-links, indicating limitations in higher-order thinking and knowledge integration. Qualitative findings indicate that concept maps effectively support visualization and meaningful learning, although students faced difficulties in contextual elaboration, hierarchy construction, and rubric use. This study highlights the potential of concept mapping as both a learning and authentic assessment tool. It also emphasizes the importance of scaffolding, iterative feedback, and improved assessment rubrics to enhance learning outcomes in teacher education.

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1. INTRODUCTION

Concept mapping and authentic assessment are two pedagogical strategies that have received considerable attention in contemporary educational research due to their potential to enhance learning outcomes and promote deeper understanding. Concept mapping, as a visual representation tool, enables learners to organize, structure, and connect knowledge by illustrating relationships among concepts. This approach has been widely recognized for its ability to foster meaningful learning, enhance critical thinking skills, and support the integration of knowledge across disciplines [1], [2].

In the context of pre-service elementary science education, concept mapping plays a significant role in supporting the development of conceptual understanding and pedagogical competence. It has been effectively utilized to help pre-service teachers comprehend complex scientific concepts, design interdisciplinary learning experiences, and strengthen their pedagogical content knowledge [3]–[5]. Furthermore, concept mapping functions as a reflective tool that allows pre-service teachers to identify misconceptions, evaluate their own understanding, and refine their instructional strategies [6], [7].

This reflective aspect is essential in preparing future teachers to become adaptive and critical practitioners in science education. On the other hand, authentic assessment emphasizes the evaluation of learners' abilities to apply knowledge and skills in real-world or meaningful contexts. Unlike traditional assessment approaches that often prioritize memorization, authentic assessment involves performance-based tasks that encourage critical thinking, problem-solving, and decision-making [8], [9]. It has been shown to increase student engagement, align closely with learning objectives, and provide a more comprehensive picture of learners' competencies, thereby better preparing them for future professional challenges [10], [11]. In teacher education, authentic assessment serves as a bridge between theoretical knowledge and classroom practice, enabling pre-service teachers to demonstrate their competencies in realistic teaching scenarios and develop professional readiness [12], [13].

Despite the well-documented benefits of concept mapping and authentic assessment as separate instructional strategies, their implementation in pre-service elementary teacher education remains problematic. In many cases, pre-service teachers still demonstrate limited higher-order thinking skills, particularly in analyzing, synthesizing, and integrating scientific concepts. This limitation is reflected in their difficulty in constructing meaningful conceptual relationships, especially in developing cross-links and deep elaborations within concept maps. In addition, a persistent gap remains between theoretical knowledge acquired in coursework and its application in real classroom practice. Although authentic assessment is intended to bridge this gap, its implementation often remains superficial and task-oriented rather than focusing on meaningful evaluation of conceptual understanding and pedagogical competence [14].

Furthermore, assessment competence among pre-service teachers is often underdeveloped. Many students experience difficulties in designing valid and reliable assessment instruments, particularly in constructing rubrics that can capture higher-order thinking and conceptual integration [15]. These issues indicate that existing teacher education practices have not yet fully supported the development of integrated knowledge structures and assessment literacy.

Although previous studies have explored concept mapping as a tool for knowledge organization and authentic assessment as a means of evaluating real-world application, the integration of these two approaches remains limited and largely descriptive [14]. Specifically, prior research has not sufficiently addressed how concept mapping can be systematically positioned as an instrument of authentic assessment, particularly in evaluating pre-service teachers' ability to apply conceptual understanding in real teaching contexts [16], [17]. Moreover, there is still a lack of structured pedagogical models that explicitly integrate both approaches into a coherent framework, as well as limited empirical evidence within the context of pre-service elementary teacher education [18].

From a theoretical perspective, this study is grounded in the principles of meaningful learning, which emphasize the integration of new knowledge into existing cognitive structures, and metacognition, which involves learners' awareness and regulation of their own thinking processes. Concept mapping supports meaningful learning by enabling the visualization and hierarchical organization of knowledge, while authentic assessment facilitates metacognitive reflection through performance-based evaluation [19]. However, the integration of these theoretical perspectives into a unified instructional and assessment framework has not been sufficiently explored in previous studies.

In response to these gaps, the present study offers a novel contribution by integrating concept mapping with authentic assessment in pre-service elementary science education through a structured four-phase model. This study contributes to the field in three main ways. First, it develops an integrated pedagogical model that connects learning processes and assessment practices within a coherent framework. Second, it positions concept maps not only as learning tools but also as instruments of authentic assessment, enabling a more comprehensive evaluation of knowledge structures, critical thinking, and application skills. Third, it applies this integrated model within the context of pre-service elementary teacher education, providing empirical evidence of its effectiveness in improving conceptual understanding and teaching readiness [20].

Furthermore, this study addresses key implementation challenges by exploring strategies to support pre-service teachers in developing concept mapping skills and designing effective authentic assessment tasks, including the use of scaffolding, iterative feedback, and rubric development [18]. By doing so, it contributes to the development of innovative and evidence-based practices in pre-service elementary science education. The significance of this study lies in both its theoretical and practical implications. Theoretically, it advances the framework of integrated learning and assessment by combining concept mapping and authentic assessment within a single model. Practically, it provides concrete strategies that can be adopted by teacher education programs to improve pre-service teachers' readiness, promote meaningful learning, and enhance the quality of assessment practices. Ultimately, this study supports the preparation of competent, reflective, and professionally ready future teachers who are capable of bridging the gap between theory and classroom practice.

2. METHOD

This study employed an embedded mixed-method design, integrating quantitative and qualitative approaches in a complementary manner [21]. The quantitative approach aimed to measure the effectiveness of the four-phase model in improving students' competence in constructing concept maps, while the qualitative approach was used to explore students' experiences, perceptions, and challenges in applying concept maps through authentic assessment. In this design, qualitative findings were embedded within the quantitative results to provide deeper explanations regarding how and why changes in conceptual understanding occurred. Quantitative data, such as pre-test, post-test, and N-Gain scores, were used to identify the extent of learning improvement. The test items were developed through a focus group discussion (FGD) involving the research team. The resulting questions were then administered to 10 senior-level students to ensure the readability and comprehensibility of the items presented. Follow-up interviews were conducted with the respondents to identify any unclear wording or expressions. Based on the feedback obtained, several minor revisions were made to the wording and sentence structure to improve clarity and ensure that the questions could be fully understood by the respondents.

To measure students' conceptual understanding before and after the implementation of the four-phase professional development model, a four-item conceptual understanding test was developed and administered as a pre-test and post-test. The test items were designed to assess students' ability to explain the benefits of concept mapping, identify the essential components of a concept map, explain how to develop a concept map for a specific science concept, and apply concept mapping to thematic science learning integrated with other subjects. Each item was accompanied by a five-level scoring rubric ranging from 0 to 4, with higher scores indicating clearer, more relevant, and more elaborated conceptual responses. Table 1 presents the blueprint of the conceptual understanding questions, including the assessment indicators, questions, and scoring criteria used for the pre-test and post-test.

Table 1. Blueprint of conceptual understanding questions (pretest–posttest)

Number	Indicator	Question	Scoring rubric
1	Explaining the benefits of developing concept maps before the science learning process.	What are the benefits of developing concept maps before the science learning process?	Excellent (4): provides an answer with a clear explanation relevant to the question and includes appropriate reasons to support the answer. Good (3): provides an answer with a clear explanation relevant to the question, but the supporting reasons are still not fully appropriate. Poor (2): provides an unclear answer that is only partially relevant to the question. Very poor (1): provides an unclear answer that is unrelated to the question. No response (0): no answer is provided or the answer is completely incorrect.
2	Explaining the components that should be included in a concept map.	In your opinion, what components should be included so that it can be considered a concept map?	
3	Explaining how to develop a concept map in discussing a particular science concept.	How would you develop a concept map to discuss a particular science concept?	
4	Explaining how to develop a mind map for thematic science learning integrated with other subjects.	How would you develop a mind map to support thematic science learning integrated with other subjects?	

Whereas qualitative data from reflections, questionnaires, and interviews were utilized to explain emerging patterns related to visualization, conceptual elaboration, rubric use, and difficulties encountered during concept map construction. The participants consisted of 82 seventh-semester students enrolled in the primary school teacher education program, who were taking the course "science learning development in elementary school". The participants were divided into two class groups during the odd semester of the 2024/2025 academic year, and the study was conducted at Universitas Pendidikan Indonesia. The research procedure was based on the four-phase professional development model, which focuses on developing concept map construction skills. In the first phase (introduction and design), students were introduced to the fundamental concepts of concept mapping through a pre-test, theoretical instruction based on Novak and Gowin's framework [22], and individual and group activities involving the design and revision of concept maps. The second phase (elaboration and assessment) focused on developing conceptual elaboration and designing assessment rubrics, where students practiced evaluating concept maps and reflected on rubric reliability as a tool for authentic assessment. The third phase (field implementation) involved the application of concept maps in an elementary school classroom over a one-week period, followed by product revision based on classroom feedback. The fourth phase (reflection) included collecting feedback through questionnaires and interviews, as well as group discussions to formulate recommendations for improvement.

To assess the quality of the concept maps constructed by the students, this study employed an assessment instrument developed based on Novak and Gowin's criteria [22], including the number of concepts, propositions, hierarchy levels, cross-links, and examples. In addition, the instrument incorporated aspects of conceptual elaboration assessed using a 1–4 scale rubric. The concept map assessment blueprint was designed to ensure alignment between the assessment indicators, the measured aspects, and the performance descriptors used in the evaluation process. The detailed blueprint of the concept map assessment instrument is presented in Table 2. To ensure instrument validity, all research instruments were evaluated through expert judgment involving three specialists in science education and educational assessment. The concept map rubric was reviewed in terms of content validity, construct alignment, and clarity of performance descriptors. Several revisions were made to improve the alignment between rubric indicators and higher-order thinking skills, particularly in assessing conceptual integration, cross-links, and elaborative explanations. In addition, the questionnaire and interview guidelines were reviewed to ensure their relevance to the research objectives and the clarity of the items.

Instrument reliability was also established prior to data collection. Reliability of the concept map scoring rubric was examined through inter-rater reliability analysis. Two independent raters evaluated a subset of students' concept maps, and the consistency of scoring was calculated using Cohen's Kappa coefficient, which indicated a substantial level of agreement between raters. Meanwhile, the questionnaire instrument was tested using Cronbach's alpha analysis, yielding a coefficient above 0.70, indicating acceptable internal consistency and reliability.

Quantitative data were collected from pre-tests, post-tests, and concept map product scores, and were analyzed using descriptive statistics and N-Gain analysis to determine the level of learning improvement. Qualitative data were obtained from open-ended questionnaires, in-depth interviews, and group reflection documentation, and were analyzed using thematic analysis techniques. The integration of quantitative and qualitative findings was conducted during the interpretation stage by connecting statistical trends with recurring qualitative themes. For example, improvements in concept map scores were interpreted alongside students' reflections regarding increased conceptual visualization, enhanced understanding of interdisciplinary relationships, and challenges in constructing meaningful cross-links and elaborations. To ensure the trustworthiness and validity of the findings, triangulation across data sources and methods was employed.

Table 2. Blueprint of the concept map assessment instrument

Number	Aspect	Description
1	Structure of concept maps	The organization and relationship among concepts in a concept map, including the accuracy of propositions, hierarchy, cross-links, and examples in representing meaningful and logical connections between concepts.
2	Quality of concept map descriptions	Students' ability to explain and develop the content of the concept map accurately, clearly, and contextually based on the relationships among the concepts presented.
3	Cross-disciplinary thematic connections	The ability to connect science learning with other subject areas in a meaningful and coherent manner to support the development of integrated thematic instruction.

3. RESULTS AND DISCUSSION

3.1. Phase I and II (introduction and design, elaboration and assessment)

The results of the tests administered to students before and after the implementation of the professional development model focused on enhancing concept map construction are summarized in Table 3. These data provide a comprehensive quantitative overview of the effectiveness of the four-phase professional development model in improving concept mapping competence among pre-service elementary science teachers. All results were derived from the second series of program workshops (Phases I and II) and are directly linked to source documentation.

Table 3. Conceptual understanding: pre-test vs post-test

Test item	Pre-test (%)	Post-test (%)
1	43.67	89.46
2	33.43	85.84
3	39.76	84.04
4	36.45	75.30
Average	38.33	83.66

The participants (N=82) completed the same four-item test before and after Phases I–II. The average pre-test score of 38.33% (classified as "very low") increased to 83.66% ("high"), yielding an N-Gain of 0.74, which is considered high. The increase in students' scores from 38.33% to 83.66% is not merely a statistical improvement but indicates a substantial shift in conceptual understanding and knowledge organization.

This improvement suggests that students moved from fragmented knowledge structures toward more integrated and meaningful learning, which is essential for effective science teaching. However, the limited development of cross-links and deep elaboration highlights that higher-order thinking skills, particularly analysis and synthesis, are still not fully achieved. This finding reinforces the importance of scaffolding and iterative feedback in supporting metacognitive development [23]. From a theoretical perspective, these findings support the principles of meaningful learning, where knowledge is actively constructed and hierarchically organized [24]. Additionally, the reflective use of concept maps aligns with metacognitive theory, as students become more aware of their own understanding and learning processes [25]. The average structure of the concept maps developed by the students is presented in Table 4. On average, each concept map created by the students contained 26 concepts, 14 propositions, 12 levels of hierarchy, 2 cross-links, and 4 illustrative examples—in accordance with the structural criteria of Novak and Gowin [22]. Meanwhile, the quality of concept map descriptions for each keyword is presented in Table 5.

Students provided written explanations of their concept maps, which were assessed on a scale from 1 (minimal) to 4 (in-depth elaboration). Although 53.66% reached Level 3 (map+context), only 12.20% achieved Level 4 (map+context+deep scientific elaboration), indicating a need for deeper domain integration. Students connected science concepts with an average of two non-science subjects and provided two justifications per connection, reflecting initial thematic integration aligned with the national curriculum. Table 6 presents the results of students' cross-disciplinary thematic connections developed through mind maps. The table summarizes the average number of non-science subjects integrated into the thematic framework and the average number of justifications provided for each connection, reflecting students' ability to establish meaningful interdisciplinary relationships in science learning.

Table 4. Average structure of concept maps

Element	Average quantity
Concepts	26
Propositions	14
Hierarchical levels	12
Cross-links	2
Illustrations	4

Table 5. Quality of concept map descriptions

Level	Description	*n*	%
4	Map+context+deep scientific elaboration	10	12.20
3	Map+context (without deep elaboration)	44	53.66
2	Map only (without context)	28	34.14
1	Inappropriate map or concept list only	0	0.00

Table 6. Cross-disciplinary thematic connections (mind maps)

Metric	Average
Non-science subjects connected	2
Justifications per connection	2

The improvement across all concept indicators indicates that the instructional model was effective in enhancing students' concept-mapping skills, consistent with research showing that concept mapping promotes meaningful learning through the organization and integration of knowledge [26], while also fostering critical thinking, problem-solving skills, and the ability to connect theory and practice [27], which are further strengthened through repeated practice and feedback [28]; however, although students were able to include the core elements of concept maps based on Novak and Gowin's principles [29], [30], the limited use of cross-links and lack of deep elaboration indicate that their ability to construct more complex maps still needs improvement [1], [14], suggesting that higher-order thinking skills such as analysis and synthesis are not yet fully developed [31], [32], thus requiring instructional strategies such as scaffolding to support deeper elaboration [33].

The depth of description shows that most students reached contextual description (Level 3), while only a few achieved full scientific elaboration (Level 4), indicating limited domain-specific reasoning skills. This is consistent with findings that structured support such as scaffolding, modeling, and iterative feedback is essential to help students move from basic description to deeper scientific reasoning [34]. Furthermore, the layered model of academic writing development suggests that effective scientific elaboration develops progressively from description to analysis and critique, highlighting the need for a spiral learning approach [35].

Meanwhile, cross-disciplinary integration, reflected in an average of two connections and justifications per task, indicates an early stage of thematic integration. Such integration is crucial for addressing complex real-world problems, as it enhances critical thinking, creativity, and collaboration [36]. However, achieving deeper integration remains challenging, requiring structured frameworks, support for linking knowledge across disciplines, and alignment between learning objectives and practical applications [37].

3.2. Phase III (field implementation)

Students' experiences and perceptions in applying concept maps through authentic assessment in the field. Table 7 presents students' perceptions regarding the application of concept maps through authentic assessment during field implementation. The ease of concept visualization (85%) indicates that concept maps are effective in helping students understand knowledge structures through visual representations that show hierarchical relationships among concepts [38]. This allows students to better comprehend complex ideas and see connections between concepts, supporting meaningful learning and improving retention [3], [39]. Additionally, concept maps are considered practical and easy to integrate into instructional processes [40]. However, challenges in contextual elaboration (62%) suggest that students still struggle to add detailed information to concept maps, particularly due to time constraints and high cognitive load. While the basic structure of concept maps is relatively easy to understand, developing deeper connections between concepts requires time and practice [41]. With continued practice and feedback, students' ability to elaborate and organize information tends to improve.

Difficulties in determining hierarchy and cross-links, reported by about 50% of participants, indicate that constructing complex concept map structures remains challenging. This is due to the complexity of relationships between concepts, which are not always clearly visible, highlighting the need for structured frameworks, concrete examples, or supporting tools to facilitate hierarchical organization and connections [42]. In addition, the need to improve authentic assessment rubrics was identified, with approximately 46% of participants expressing that the current rubrics lack sufficient detail in evaluating contextual elaboration and inter-concept relationships. Effective rubrics should provide clear criteria, as well as ensure validity and reliability to support consistent and meaningful assessment [43]. Involving students in rubric design and aligning it with real-world contexts are also important to enhance understanding, fairness, and the effectiveness of authentic assessment [44].

Table 7. Frequency of themes in participant reflections

Experience/perception theme	Percentage of respondents (%)
Ease of concept visualization	85
Challenges in contextual elaboration	62
Difficulties in determining hierarchy and cross-links	50
Need for improvement in authentic assessment rubrics	46

3.3. Phase IV (reflection)

During the reflection phase, the researchers provided all 82 students with the opportunity to complete a questionnaire and participate in in-depth interviews regarding the strengths, weaknesses, and challenges of applying concept maps in real classroom settings. Table 8 presents the main themes identified during the reflection phase based on questionnaire responses and in-depth interviews with participants. The themes summarize students' experiences, perceived benefits, and challenges encountered during the implementation of concept maps in authentic classroom settings, particularly related to visualization, contextual elaboration, concept hierarchy, cross-links, and assessment rubric development.

Table 8. Reflection phase: key themes and brief descriptions

Theme	Brief description
Ease of visualization	Most participants reported that concept maps helped them clearly visualize the structure of science content, making conceptual relationships more tangible and intuitive during classroom instruction.
Contextual elaboration challenges	Many students struggled to add real-world contexts—such as examples, applications, or illustrations—to each concept node. Only 12.20% of participants reached the highest level of science content elaboration (Level 4).
Hierarchy and cross-link difficulties	About half of the participants reported confusion in determining concept hierarchies and constructing accurate cross-links; on average, they included only two cross-links per map.
Need for rubric improvement	Participants suggested developing more detailed assessment rubrics with performance descriptors for each criterion and exemplar concept maps to support more consistent and transparent assessments in authentic classroom contexts.

Concept maps are widely recognized as effective tools for visualizing and organizing science content, making conceptual relationships more tangible and intuitive for students during classroom instruction. They allow learners to structure information visually, facilitating comprehension of complex topics and interconnections between concepts [45]. Students often report that concept maps enhance their understanding and retention of material, as they provide a clear, holistic view of course content [46]. For example, in engineering and science education, concept maps have been shown to improve students' ability to connect theoretical knowledge with practical applications, fostering deeper learning [14]. However, students still face challenges in contextual elaboration, particularly in adding real-world examples or applications to each concept. These difficulties are driven by the cognitive demands of selecting and integrating relevant information, resulting in only a small proportion of students reaching the highest level of elaboration.

Difficulties in determining hierarchy and cross-links indicate that students still face challenges in constructing complex knowledge structures, particularly when dealing with abstract or indirectly related concepts. Identifying hierarchical relationships and meaningful connections requires higher-order thinking skills, and limitations in these abilities result in the relatively low use of cross-links. Consequently, the integration and synthesis of knowledge remain underdeveloped, as cross-links play a crucial role in connecting different parts of a concept map [47], [48]. Meanwhile, current assessment rubrics tend to focus primarily on structural aspects, such as the number of concepts or links, and do not fully capture the quality of content or depth of understanding. This highlights the need for more comprehensive rubrics that include detailed performance descriptors for each criterion, enabling clearer and more systematic evaluation [49]. In addition, providing exemplar concept maps can help clarify expectations for students, while the use of technological tools and holistic assessment approaches can enhance objectivity, consistency, and the overall meaningfulness of the assessment process [50].

This study provides several practical implications for teacher education programs. The findings suggest that the integration of concept mapping and authentic assessment can be effectively incorporated into course design to support the development of conceptual understanding, critical thinking, and professional teaching competencies among pre-service teachers. The study also highlights the importance of providing scaffolding through guided examples, structured practice, and iterative feedback to help students construct more meaningful and well-organized concept maps. In addition, the findings emphasize the need for detailed assessment rubrics with clear performance descriptors to support consistent and transparent evaluation processes. Engaging students in rubric co-construction was also identified as a valuable strategy for enhancing assessment literacy and promoting deeper understanding of assessment criteria and learning expectations [51]. From a policy perspective, the integrated model developed in this study aligns with national teacher competency standards, particularly in strengthening pedagogical, professional, and assessment competencies. Therefore, this model has the potential to be adopted as a framework for curriculum development in teacher education institutions to better prepare future teachers for authentic classroom practice and meaningful science learning implementation.

4. CONCLUSION

This study demonstrates that integrating concept mapping and authentic assessment through a structured four-phase model not only improves conceptual understanding but also addresses critical gaps in teacher education, particularly in higher-order thinking, knowledge integration, and assessment competence. The findings highlight that without structured support, pre-service teachers tend to develop fragmented knowledge, which may hinder their effectiveness in real classroom settings. Therefore, this study provides a concrete pathway for transforming teacher education practices by promoting meaningful learning, reflective thinking, and authentic evaluation. Ultimately, this research contributes to the future of elementary science education by offering an evidence-based model that bridges theory and practice, enhances teaching readiness, and supports more effective and meaningful assessment systems.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
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R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
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CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

Informed consent was obtained from all participants prior to inclusion in the study.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [GH], upon reasonable request.

REFERENCES

[1] C. T. Machado and A. A. Carvalho, "Concept mapping: benefits and challenges in higher education," *Journal of Continuing Higher Education*, vol. 68, no. 1, pp. 38–53, 2020, doi: 10.1080/07377363.2020.1712579.
[2] S. Kamble and S. Jagtap, "Use of concept mapping as a tool for education field," in *2023 6th IEEE International Conference on Advances in Science and Technology (ICAST 2023)*, 2023, pp. 607–611, doi: 10.1109/ICAST59062.2023.10454945.
[3] C. Valls-Bautista and J.-F. Álvarez-Herrero, "Using concept maps to improve pre-service teachers' learning of scientific concepts," *Knowledge Management and E-Learning An International Journal*, vol. 18, no. 1, pp. 24–38, 2025, doi: 10.34105/j.kmel.2026.18.002.
[4] S. Himangshu-Pennybacker, "Transforming science pedagogy: using concept mapping to design an interdisciplinary approach to teaching middle school science," in *Communications in Computer and Information Science*, Springer, 2016, vol. 635, pp. 265–274, doi: 10.1007/978-3-319-45501-3_21.
[5] M. Koc, "Pedagogical knowledge representation through concept mapping as a study and collaboration tool in teacher education," *Australasian Journal of Educational Technology*, vol. 28, no. 4, pp. 656–670, 2012, doi: 10.14742/ajet.833.
[6] N. Didis, Ö. Özcan, and A. Azar, "What do pre-service physics teachers know and think about concept mapping?" *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 10, no. 2, pp. 77–87, 2014, doi: 10.12973/eurasia.2014.1031a.
[7] N. Bulunuz and O. S. Jarrett, "Understanding of earth and space science concepts: strategies for concept-building in elementary teacher preparation," *School Science and Mathematics*, vol. 109, no. 5, p. 276, 2009, doi: 10.1111/j.1949-8594.2009.tb18092.x.
[8] N. J. Marín-Rodríguez, B. V. G. Morán, and F. S. Gerardou, "Scientometric analysis of active learning and authentic assessment between 2002 and 2024: Recent trends and further research," in *The Emerald Handbook of Active Learning for Authentic Assessment*, E. Vilalta-Perdomo, A. Scroccaro, D. E. Salinas-Navarro, and R. Michel-Villarreal, Eds., Leeds, U.K.: Emerald Publishing Limited, 2025, pp. 15–35, doi: 10.1108/978-1-83797-857-120251002.
[9] B. Ilmiwan, Festiyed, and Usmeldi, "Development of authentic assessment that based on scientific approach to improve students' skills of science process in physics learning," *Journal of Physics: Conference Series*, pp. 1–7, 2019, doi: 10.1088/1742-6596/1185/1/012033.
[10] W. B. Sabtiawan, L. Yuanita, and Y. S. Rahayu, "Effectiveness of authentic assessment: performances, attitudes, and prohibitive factors," *Journal of Turkish Science Education*, vol. 16, no. 2, pp. 156–175, 2019, doi: 10.12973/tused10272a.
[11] R. Brown, "Authentic assessment: using assessment to help students learn," *RELIEVE - Revista Electronica de Investigacion y Evaluacion Educativa*, vol. 21, no. 2, pp. 1–8, 2015, doi: 10.7203/relieve.21.2.7674.
[12] G. Sagers, "Authentic assessment in a beginning cybersecurity course: a pilot study," in *Proceedings-2021 International Conference on Computational Science and Computational Intelligence (CSCI 2021)*, 2021, pp. 1108–1112, doi: 10.1109/CSCI54926.2021.00234.
[13] W. N. Arlianty, B. W. Febriana, A. Diniaty, and L. Fauzi'ah, "Designing assignment using authentic assessment," in *AIP Conference Proceedings*, 2017, pp. 1–5, doi: 10.1063/1.5016009.

[14] T. Hartsell, "Visualization of knowledge with concept maps in a teacher education course," *TechTrends*, vol. 65, no. 5, pp. 847–859, 2021, doi: 10.1007/s11528-021-00647-z.
[15] B. A. Schwendimann, "Concept maps as versatile learning, teaching, and assessment tools," in *Learning, Design, and Technology: An International Compendium of Theory, Research, Practice, and Policy*, J. M. Spector, B. B. Lockee, and M. D. Childress, Eds., Cham: Springer International Publishing, 2023, pp. 631–693, doi: 10.1007/978-3-319-17461-7_86.
[16] O. N. Kaya, "A student-centred approach: assessing the changes in prospective science teachers' conceptual understanding by concept mapping in a general chemistry laboratory," *Research in Science Education*, vol. 38, no. 1, pp. 91–110, 2008, doi: 10.1007/s11165-007-9048-7.
[17] A. Yulianto, W. Sopandi, Riandi, and G. Hamdu, "Assessing teachers' readiness for science learning in elementary school: a Rasch analysis of the nature of science, RADEC, and science process skills," *Multidisciplinary Science Journal*, vol. 8, no. 9, p. 2026475, 2026, doi: 10.31893/multiscience.2026475.
[18] J. Liu and Q. Zhang, "Rethinking authentic assessment in mathematics education: a holistic review," in *Proceedings of the International Group for the Psychology of Mathematics Education*, 2021, pp. 206–213.
[19] S. M. Sit and L. Zeller, "Authentic assessments for an in-person or online science course for preservice teachers," *Journal of College Science Teaching*, vol. 53, no. 3, pp. 245–252, 2024, doi: 10.1080/0047231X.2024.2338037.
[20] C. Mellon and Y. Emmett, "Subjectivity and agency in initial teacher education: the role of authentic assessment," in *Innovations in Assessment, Student Experience and Professional Development in Higher Education: Contemporary Global Perspectives*, G. Chikwa, Ed., Leeds, U.K.: Emerald Publishing Limited, 2025, pp. 61–73, doi: 10.1108/978-1-83549-958-020251005.
[21] L. Cao, "Mixed method designs," in *Doing Early Childhood Research: International Perspectives on Theory and Practice*, S. A. Rolfe and I. Siraj-Blatchford, Eds., London, U.K.: Routledge, 2020, pp. 193–208, doi: 10.4324/9781003115403-13.
[22] J. D. Novak and D. B. Gowin, *Learning how to learn*. Cambridge University press, 1984.
[23] X. Chen, "Developing critical thinking through scaffolded peer feedback: an action research on heuristic design," *Frontiers in Psychology*, vol. 17, p. 1711768, 2026, doi: 10.3389/fpsyg.2026.1711768.
[24] T. G. K. Bryce and E. J. Blown, "Ausubel's meaningful learning re-visited," *Current Psychology*, vol. 43, no. 5, pp. 4579–4598, 2024, doi: 10.1007/s12144-023-04440-4.
[25] E. H. Eshuis, J. ter Vrugte, and T. de Jong, "Supporting reflection to improve learning from self-generated concept maps," *Metacognition and Learning*, vol. 17, no. 3, pp. 691–713, 2022, doi: 10.1007/s11409-022-09299-7.
[26] R. Katagall, R. Dadde, R. H. Goudar, and S. Rao, "Concept mapping in education and semantic knowledge representation: an illustrative survey," *Procedia Computer Science*, 2015, vol. 48, pp. 638–643, doi: 10.1016/j.procs.2015.04.146.
[27] S. K. Kamble and B. L. Tembe, "The effect of concept maps on achievement and attitude in a mechanical engineering course," in *Proceedings of IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE 2012)*, 2012, p. W1B1-W1B4, doi: 10.1109/TALE.2012.6360399.
[28] K. M. Roessger, B. J. Daley, and D. A. Hafez, "Effects of teaching concept mapping using practice, feedback, and relational framing," *Learning and Instruction*, vol. 54, pp. 11–21, 2018, doi: 10.1016/j.learninstruc.2018.01.011.
[29] G. H. V. Rensburg, Y. Botma, and L. Roets, "Educators' ability to use concept mapping as a tool to facilitate meaningful learning," *Contemporary Nurse*, vol. 59, no. 3, pp. 238–248, 2023, doi: 10.1080/10376178.2023.2223714.
[30] G. Rice and A. Saterbak, "Work in progress: exploring developing knowledge of mathematical modeling skills using concept maps," in *2023 ASEE Annual Conference & Exposition*, 2023, pp. 1–7, doi: 10.18260/1-2--44257.
[31] C. C. Chang, T. K. Yeh, and C. M. Shih, "The effects of integrating computer-based concept mapping for physics learning in junior high school," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 12, no. 9, pp. 2531–2542, 2016, doi: 10.12973/eurasia.2016.1284a.
[32] A. C. Jeong, R. Wong, and J. B. Mbanzabugabo, "A systematic review of concept mapping and critical thinking: methodological gaps and research directions," *Educational Technology Research and Development*, vol. 73, no. 6, pp. 3543–3567, 2025, doi: 10.1007/s11423-025-10562-2.
[33] Ö. Bilik, E. A. Kankaya, and Z. Deveci, "Effects of web-based concept mapping education on students' concept mapping and critical thinking skills: a double blind, randomized, controlled study," *Nurse Education Today*, vol. 86, p. 104312, 2020, doi: 10.1016/j.nedt.2019.104312.
[34] Y. Xin and Z. Chen, "Research on cross disciplinary practice of creative design curriculum in the era of cultural and technological integration," in *International Conference on Human-Computer Interaction*, 2025, pp. 128–145, doi: 10.1007/978-3-031-93736-1_9.
[35] D. A. H. Hanaor, "Cross-disciplinary integration towards sustainable construction," in *Sustainable Materials for the Built Environment*, D. A. H. Hanaor, Ed., Cham: Springer Nature Switzerland, 2025, pp. 577–597, doi: 10.1007/978-3-031-97818-0_27.
[36] J. T. Tang, M. H. Lin, Y. Y. Jau, W. C. Lan, and H. L. Chou, "Integrating science education through cross-disciplinary digital picture books: 'my helpful friend hydrogen,'" *Science and Education*, vol. 34, no. 4, pp. 2525–2551, 2025, doi: 10.1007/s11191-024-00567-3.
[37] E. Borda, T. Haskell, and A. Boudreaux, "Cross-disciplinary learning: a framework for assessing application of concepts across science disciplines," *Journal of College Science Teaching*, vol. 52, no. 1, pp. 3–5, 2022, doi: 10.1080/0047231X.2022.12315664.
[38] K. A. bin Abdulrahman and S. U. D. Khan, "Concept mapping for students in health professions: enhancing education and application," in *Essential Learning Skills for Health Professions Students*, K. A. bin Abdulrahman and H. Darami, Eds., Singapore: Springer Nature Singapore, 2025, pp. 143–154, doi: 10.1007/978-981-96-5670-7_13.
[39] Y. V. Shao, J. Alvarez, and O. Mironenko, "Enhancing understanding and retention in undergraduate ECE courses through concept mapping," in *2024 ASEE Annual Conference & Exposition*, 2024, pp. 1–13, doi: 10.18260/1-2--47322.
[40] Q. T. Huynh and Y. C. Yang, "Impact of fill-in-the-nodes concept maps on low prior-knowledge students learning chemistry: a study on the learning achievements and attitude toward concept maps," *Chemistry Education Research and Practice*, vol. 25, no. 1, pp. 360–374, 2023, doi: 10.1039/d3rp00238a.
[41] R. Hartmeyer, M. P. Stevenson, and P. Bentsen, "A systematic review of concept mapping-based formative assessment processes in primary and secondary science education," *Assessment in Education: Principles, Policy and Practice*, vol. 25, no. 6, pp. 598–619, 2018, doi: 10.1080/0969594X.2017.1377685.
[42] D. A. Sevost'Yanov, "Social inversions and education," *Vysshee Obrazovanie v Rossii*, vol. 27, no. 12, pp. 39–49, 2018, doi: 10.31992/0869-3617-2018-27-12-39-49.
[43] E. O. Brien *et al.*, "Learning how to become a teacher researcher: using rubrics to support evidence-informed, research-based practice," in *Improving Learning Through Assessment Rubrics: Student Awareness of What and How They Learn*, C. Gonsalves and J. Pearson, Eds., Hershey, PA: IGI Global Scientific Publishing, 2023, pp. 54–74, doi: 10.4018/978-1-6684-6086-3.ch004.
[44] S. Ghosh, M. Bowles, and A. Abeysiriwardhane, "Does excluding students from co-creation of rubrics affect their academic achievement in the associated authentic assessment task?" *Australian Journal of Maritime and Ocean Affairs*, vol. 12, no. 4, pp. 243–258, 2020, doi: 10.1080/18366503.2020.1810602.

[45] J. Barria-Pineda, P. Menon, J. Guerra, and P. Brusilovsky, "Concept maps and open learner models in a computer networking course," *IEEE Transactions on Education*, vol. 68, no. 5, pp. 447–458, 2025, doi: 10.1109/TE.2025.3593411.

[46] S. Njoroge, A. E. Pearson, and H. Dillon, "Concept mapping for cognition in numerical methods," in *2024 ASEE Annual Conference & Exposition*, 2024, pp. 1–11, doi: 10.18260/1-2--48488.

[47] J. Kochenberger and C. Sen, "Protocol study: patterns of designer behaviors when describing engineering problem domains through concept maps," in *Proceedings of the ASME 2023 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, 2023, pp. 404–414, doi: 10.1115/detc2023-116955.

[48] A. Kapuza, "How concept maps with and without a list of concepts differ: the case of statistics," *Education Sciences*, vol. 10, no. 4, p. 91, 2020, doi: 10.3390/educsci10040091.

[49] S. Bhatia, S. Bhatia, and I. Ahmed, "Automated waterloo rubric for concept map grading," *IEEE Access*, vol. 9, pp. 148590–148598, 2021, doi: 10.1109/ACCESS.2021.3124672.

[50] H. M. Monge, M. D. C. M. Monge, and D. A. López, "The rubric as an instrument for evaluating concept mappings from creative knowledge construction: a participatory proposal," *Profesorado*, vol. 24, no. 1, pp. 246–264, 2020, doi: 10.30827/profesorado.v24i1.8514.

[51] D. Yan, "Rubric co-creation to promote quality, interactivity and uptake of peer feedback," *Assessment and Evaluation in Higher Education*, vol. 49, no. 8, pp. 1017–1034, 2024, doi: 10.1080/02602938.2024.2333005.

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