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The effectiveness of using concept maps on course interest and learning chemistry

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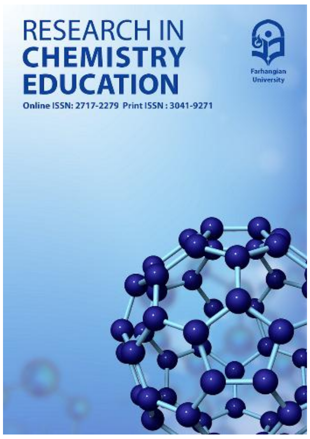

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Abstract:

Background and Objective: The present study aimed to investigate the effectiveness of concept map-based instruction on learning and interest in chemistry. This research was conducted using a quasi-experimental design with a pretest–posttest control group structure. **Methods**: The statistical population comprised eleventh-grade experimental Sciences students in Tabriz out of which a sample of two intact classes from an eleventh-grade cohort at a single school was selected through convenience sampling and randomly assigned to an experimental group (n = 28) and a control group (n = 23). At the beginning of the academic year, both classes were assessed using a written test covering tenth-grade chemistry content and completed the Course Interest Survey by Keller & Subia (1993), which measures motivational dimensions based on the ARCS model (Attention, Relevance, Confidence, Satisfaction). Subsequently, the concepts of the first chapter of eleventh-grade experimental chemistry—including stoichiometry, organic chemistry, periodic table patterns and trends, atomic radius, and elemental reactivity—were taught to the experimental group using concept maps, while the control group received instruction through conventional teaching methods. **Findings**: Following the intervention, both groups were reassessed using a written chemistry test , and they completed the interest questionnaire for the second time. The collected data were analyzed using one-way and multivariate analysis of covariance (ANCOVA/MANCOVA). Results indicated statistically significant between-group differences across all course interest subscales: Attention ($p = 0.001$), Relevance ($p = 0.040$), Confidence ($p = 0.001$), and Satisfaction ($p = 0.034$). Additionally, a significant difference was observed between the groups in chemistry learning outcomes ($p = 0.001$). **Conclusion:** Therefore, it can be concluded that the application of concept maps exerts a significant positive effect on both chemistry learning and students' interest in the subject.

Keywords: Concept mapping, Chemistry learning, Course interest, Eleventh-grade chemistry, Effectiveness

Introduction

Since the onset of the 21st century, the volume of scientific information has surged dramatically, creating a pressing need for individuals with high scientific literacy to analyze and solve complex problems. In today's rapidly evolving world, equipping individuals with the capacity to adapt to change and address emerging challenges is of paramount importance (Kelly, 2022). However, the current landscape within schools is far from promising. There is a notable decline in students' academic performance and interest in science. The scientific knowledge possessed by high school and university students is often characterized by a lack of coherence. Fundamentally, the majority of students are engaged in fragmented learning (BouJaoude & Barakat, 2000). Fragmented learning implies that concepts are taught in isolation, preventing the formation of meaningful connections between concepts in students' cognitive structures. For instance, in 10th-grade chemistry, the instruction on drawing Lewis structures for molecules and ions is dispersed across three separate chapters. Recent studies indicate that students confront two primary challenges in learning: first, comprehending abstract and complex scientific concepts, which often proves difficult; and second, traditional teaching methods that are insufficiently effective in facilitating the learning process (Hattie, 2015).

These challenges are particularly pronounced in chemistry education due to the subject's inherently complex and abstract nature, compounded by the dispersion of content related to a single topic across multiple chapters—and occasionally across several textbooks. Consequently, chemistry has been widely recognized within educational systems as a particularly demanding discipline. The challenging nature of chemistry is not merely a generalized assertion but rather an empirically documented reality within science education research. These difficulties stem from chemistry's interdisciplinary identity—integrating experimental science, mathematics, and laboratory skills—as well as from the non-linear and fragmented organization of its content in curricular materials. In no other subject within the mathematical or experimental science fields is such a confluence of demands simultaneously observed: abrupt transitions to abstract reasoning, cumulative knowledge construction, high visualization requirements, computationally intensive problem-solving, and essential dependence on laboratory work. Core concepts such as atomic structure, chemical bonding, and chemical reactions necessitate deep conceptual understanding and advanced spatial visualization abilities, with which many students struggle and often become confused. Furthermore, topics such as Lewis structures and stoichiometry present additional difficulties for learners due to the scattered presentation of related content across textbooks. It is precisely for this reason that these subject areas frequently become critical tipping points contributing to declines in students' academic achievement (Tsaparlis, 2016).

Improving student learning requires allotting an active role to them rather than a passive one, which is achieved by changing the educational approach and forcing teachers to search for better methods. In this regard, research indicates that concept map is a learning strategy capable of facilitating meaningful learning among students and displaying interrelationships between curricular content hierarchically. By establishing logical connections between concepts, concept maps foster conditions conducive to active learning, enabling students to attain higher levels of abstract thinking through engagement in the learning process. Concept maps serve as an efficient tool for organizing knowledge and reinforcing the understanding of scientific concepts (Anastasiou, 2024); structurally, they consist of concepts (typically enclosed in circles or boxes) and the relationships between them (represented by linking lines and linking words) (Novak & Cañas, 2008). By establishing meaningful connections between concepts, concept maps contribute to deeper and more significant learning outcomes (Tootoonchi Asrehazari & Morsali, 2013).

Concept maps contribute to improved learning through various mechanisms. Primarily, they promote meaningful learning. Furthermore, concept maps can serve as instruments for evaluating and assessing students' comprehension. By having students construct these maps, educators can identify learners' strengths and weaknesses, thereby tailoring instructional plans to address their specific needs. By simplifying complex information and providing an organized structure, concept maps assist in reducing cognitive load (Schroeder et al., 2018). Moreover, by integrating verbal and visual components, they align with the principles of Dual Coding Theory, thereby facilitating the more effective organization of information within memory (Kirschner & Hendrick, 2020). Given these advantages, the implementation of concept maps in chemistry education warrants consideration as an effective strategy within authentic classroom settings. This approach is anticipated to improve the comprehension of complex chemical concepts by fostering active student participation, thereby rendering learning more meaningful and durable.

Various studies have examined the effectiveness of concept maps on students' cognitive variables. Others have investigated their impact on affective and emotional variables, such as attitude, motivation, and enjoyment of learning. However, only a limited number of studies have specifically explored these variables within the context of chemistry education—including BouJaoude & Attieh (2008), Šket et al. (2015), Talbert et al. (2020), and Wang et al. (2020)—and have confirmed the positive influence of concept maps on these outcomes. Nevertheless, other studies, such as Anastasiou et al. (2024), have assessed the effectiveness of concept maps in chemistry as comparatively lower than that of other subject areas. Still others, such as Oliver (2009), have found no significant effect of concept maps in chemistry instruction. Furthermore, no direct or targeted study was identified that explicitly investigates the application of concept maps in relation to students' interest in chemistry.

Accordingly, the present study adopts an empirical approach to examine the impact of concept map-based instruction on both the learning of chemistry concepts and students' interest in the subject among eleventh-grade learners. Guided by this rationale, the research seeks to address the following question: Is the implementation of concept maps effective in enhancing students' learning outcomes and interest in chemistry?

Research Background

Concept maps were introduced as effective tools for organizing and representing knowledge. These tools continue to be employed as powerful methods for facilitating meaningful learning and integrating new information with prior knowledge (Novak, 2010). The primary theoretical foundation underpinning concept maps is David Asubel's Theory of Meaningful Learning. In contrast to rote learning, meaningful learning occurs when the learner consciously and explicitly links new concepts to their existing cognitive structure. Concept maps serve as instruments for establishing these connections and elucidating the relationships between concepts, thereby functioning as facilitators of meaningful learning (Novak & Cañas, 2008).

Concept maps require learners to actively engage in the selection, organization, and integration of information, thereby personally constructing knowledge and fostering deeper understanding (Boghossian, 2006). A study by Safari et al. (2023) demonstrated that the role of the learning environment and constructivist instructional methods in cultivating and reinforcing students' interest in subject matter, academic vitality, and school engagement is considerable. A prominent feature of constructivist pedagogy is the emphasis on interaction and communication among teachers, students, and peers. Teacher-student and peer relationships exert a direct influence on students' interest in learning, academic vitality, and school engagement, thereby enhancing their motivation. Consequently, it is recommended that educators employ active listening techniques and adopt active teaching-learning approaches—such as constructivist methods—to effectively promote these outcomes.

The impact of concept maps on affective domains has also been examined and substantiated across various studies. Several investigations have reported that the utilization of concept maps, by providing a clear structural organization of content, can mitigate learner confusion and anxiety while enhancing perceptions of control over the subject matter (i.e., self-efficacy). In a comprehensive meta-analytic study conducted by Nesbit and Adesope (2006), findings indicated that the effect of concept mapping on learning outcomes was superior to that of traditional instructional methods, demonstrating that the integration of concept maps can exert a robust influence on learning efficacy. Furthermore, in a comparative study by Karakuyu (2010) examining the implementation of concept maps versus conventional teaching approaches, it was observed that students in the experimental group exhibited a significantly more positive attitudinal disposition than those in the control group. The results also revealed that instruction in concept mapping techniques was more effective than traditional pedagogy in fostering academic achievement among students enrolled in physics courses.

Studies have also been conducted investigating the application of concept maps and their efficacy within the domain of chemistry education. In research conducted by Boujaoude (2008), concept maps were employed as an instructional tool for teaching acid-base titration concepts. The results demonstrated a notably high level of effectiveness for instruction utilizing concept mapping. In a study by Šket et al. (2015), which aimed to examine the impact of concept map integration in chemistry instruction on the effective completion of tasks involving organic reaction content, a concept map depicting reactions of hydrocarbons, halogenated organic compounds, and oxygen-containing organic compounds was developed. The findings indicated that this approach facilitated students' more effective problem-solving with respect to organic reaction-related tasks.

The findings of research conducted by Mesrabadi et al. (2016) indicate that the implementation of concept map-based instruction, in comparison to conventional teaching methods, exerted a positive influence on students' scores in the domains of comprehension and application; however, it did not demonstrate a statistically significant effect at the level of knowledge retention. Generally, the utilization of concept maps yielded favorable outcomes with respect to students' academic achievement in the course of experimental sciences.

In another study conducted by Kardan et al. (2016), the impact of concept mapping on the academic achievement of male and female secondary school students in physics was investigated. Within this experimental research design, the effects of instruction utilizing teacher-provided concept maps and instruction incorporating student-constructed concept maps (a combined provision-and-construction group) were compared against a control group receiving conventional instruction. The findings revealed that post-test scores of students in both the combined experimental group and the teacher-constructed map group were significantly higher than those of the control group. Consequently, it was concluded that instruction facilitated by concept mapping contributed to enhanced academic achievement scores among students. Furthermore, the qualitative component of this study indicated that educators and instructors emphasized three principal themes regarding the efficacy of concept map application: 'holistic perspective,' 'self-regulated learning,' and 'the development of critical thinking'.

In a meta-analytic study, Sayadi et al. (2018) examined 28 experimental and quasi-experimental studies and concluded that concept map-based instruction exerts a positive and statistically significant effect on learners' academic achievement indicators across cognitive, metacognitive, and affective domains. Furthermore, the results indicated that concept maps constructed by learners themselves yielded a larger effect size compared to researcher-constructed maps. Given the substantial effect size observed, the authors recommend that educational policymakers and administrators integrate concept mapping instruction into curricula at both school and higher education levels as an evidence-based strategy to enhance learners' academic achievement.

Bressington et al. (2018), in a review concluded that concept mapping facilitates meaningful learning and constitutes a constructive and valuable learning strategy for bridging theoretical knowledge with practical application.

Wang et al. (2020), in an experimental study, investigated the efficacy of three distinct concept map-related activities on the learning outcomes of undergraduate chemistry students. The study employed three randomly assigned groups, each engaged in a specific task: (1) translating a complete concept map into a coherent paragraph, (2) completing missing concepts within a partially constructed concept map, and (3) filling in absent relational labels in an incomplete concept map. The results revealed no statistically significant differences in performance among the three groups, suggesting that the utilization of concept maps—

irrespective of the specific activity type—can contribute to the enhancement of students' learning. Nevertheless, the task involving the translation of a complete concept map into paragraph format yielded a marginally more favorable effect on learning outcomes. The researchers attributed this slight advantage to the more active cognitive engagement required of students during the translation process. These findings underscore the importance of learners' active involvement in working with concept maps and indicate that greater student participation in the construction and interpretation of concept maps is likely to foster deeper and more effective learning.

The research conducted by Nasirpour et al. (2020) demonstrates that the integration of concept maps into biology instruction significantly enhances students' academic achievement. Students who received instruction through this approach attained notably higher scores compared to their counterparts in the control group. This improvement was evident across both lower-order cognitive skills (e.g., recall) and higher-order levels within Bloom's taxonomy. Accordingly, the authors conclude that educators' adoption of concept mapping as an instructional strategy can facilitate deeper and more efficient learning, while also promoting the development of students' abstract reasoning abilities.

Abraha (2024) examined the efficacy of concept mapping in enhancing students' academic performance employing a mixed-methods research design. The findings indicated that instruction utilizing concept maps was more effective than the traditional lecture-based approach in teaching the topic of cell division. However, several challenges were identified that may impede the successful implementation of concept mapping, including instructors' lack of prior experience with the technique, time constraints, student absenteeism, and insufficient pedagogical support from teachers. These contextual and logistical factors were found to significantly influence the feasibility and effectiveness of integrating concept maps into instructional practice.

In a study conducted by Bolatli (2024) investigating the impact of concept mapping on cognitive load and academic achievement among students enrolled in an anatomy course, the results revealed that post-test performance in the experimental group (utilizing concept maps) was significantly higher than that of the control group. Moreover, the cognitive load experienced by students in the control group was substantially greater than that reported by the experimental group. These findings indicate that the integration of concept maps can effectively reduce extraneous cognitive load while concurrently enhancing academic achievement.

The research by Anastasiou et al. (2024) further emphasized that, although concept mapping constitutes a highly effective instructional strategy in chemistry education, its relative impact appears comparatively modest when contrasted with its efficacy in other scientific disciplines. Specifically, the overarching trend across studies suggests that concept maps yield stronger learning outcomes in physics and biology than in chemistry. In interpreting this disciplinary variation, Anastasio proposed three plausible explanations for the comparatively diminished effectiveness observed in chemistry instruction: (1) the predominant emphasis on laboratory-based activities in chemistry education, which may limit opportunities for concept map integration; (2) the more frequent utilization of alternative visual representations—such as chemical diagrams, molecular models, and structural formulas—as primary instructional tools in chemistry; and (3) the greater focus of physics instruction on abstract theoretical concepts, which may align more naturally with the hierarchical and relational structure inherent to concept maps.

Nevertheless, a limited number of studies have reported that concept mapping may not demonstrate substantial efficacy under certain conditions. For instance, Oliver (2009) concluded in his research that concept maps, when employed in isolation and without integration with complementary instructional methods, may exhibit inherent limitations. Similarly, the findings of Barchok et al. (2011) indicated that collaborative concept mapping did not exert a statistically significant effect on the academic achievement of high-ability students, nor did it significantly influence learners' attitudes or motivation. Their results suggested that, for more proficient learners, the concept mapping approach offered minimal advantage over traditional instructional methods and proved ineffective in fostering positive shifts in attitude or motivational orientation. These findings collectively underscore that the body of research on concept mapping does not exhibit complete consensus; rather, outcomes vary depending on contextual factors, learner characteristics, and implementation strategies.

Methodology

The present study is applied in terms of purpose and quasi-experimental in terms of methodology, employing a pretest-posttest design with a control group. The target population comprised all eleventh-grade students enrolled in the experimental sciences field at a public high school in Tabriz during the academic year of 2025–2026. The research sample was selected via convenience sampling and consisted of two intact classes of eleventh-grade experimental sciences students (Class 1 & Class 2), totaling 51 participants. One class was assigned as the control group (n = 23), and the other as the experimental group (n = 28). The final sample size reflects the number of participants remaining after accounting for attrition throughout the study period.

At the beginning of the academic year, students in both classes were administered a written examination assessing their prior knowledge of foundational chemistry topics from the tenth-grade curriculum. Additionally, they completed the Course interest survey developed by Keller and Subia (1993). The instructional content delivered during the first academic term encompassed the concepts presented in Chapter 1 of the eleventh-grade chemistry textbook, including stoichiometry, hydrocarbons, patterns and trends in the periodic table, atomic radius, and the reactivity of elements.

In the experimental group, instructional content was delivered through the systematic integration of concept maps. During each instructional session, the instructor presented concept maps aligned with the lesson content. These visual representations were delivered partially via PowerPoint slides and partially through real-time construction on the classroom whiteboard. Throughout the instruction, the core concepts and the interrelationships among them were explicitly and systematically explained to students, thereby facilitating a structured and hierarchical understanding of the subject matter.

The control group received instruction through traditional teacher-centered methods, comprising teacher lectures, explicit explanation of concepts, and guided problem-solving exercises. To minimize the potential influence of confounding variables, instruction in both classes was delivered by the same instructor under comparable temporal and environmental conditions. Upon completion of the instructional period, students in both groups were administered a researcher-developed written achievement test assessing their mastery of the chemistry content covered during the intervention. Additionally, they once again responded to the items of Course interest survey developed by Keller & Subia (1993) to measure any changes in their affective engagement with the subject matter.

The collected data were analyzed using one-way and multivariate analysis of covariance (ANCOVA) to examine between-group differences while controlling for pretest scores. The instrumentation employed in this study consisted of two primary measures: (1) a researcher-developed written achievement test, designed to assess students' conceptual understanding and application of the targeted chemistry topics, and (2) Course interest survey (Keller & Subia, 1993), utilized to evaluate learners' motivational and attitudinal dispositions toward the discipline.

Chemistry Learning Assessment Instrument: To collect data and evaluate chemistry learning outcomes, a researcher-developed Chemistry Learning Test was employed. This instrument comprised 13 constructed-response (essay-type) items. The pretest was designed to assess foundational knowledge drawn from the tenth-grade chemistry curriculum, whereas the posttest focused on the instructional content covered in Chapter 1 of the eleventh-grade chemistry textbook. To establish validity, the Chemistry Learning Test was reviewed by a panel of subject-matter experts, including two university-level chemistry professors and four experienced secondary-school chemistry teachers. All experts confirmed the instrument's face and content validity, affirming that the items adequately represented the intended learning objectives and were appropriately aligned with the instructional content. Reliability was estimated using the test-retest method. The instrument was administered to a pilot sample of chemistry students on two separate occasions, and the correlation coefficient between the two administrations was calculated as r = 0.71, indicating acceptable temporal stability and internal consistency for the purposes of this study.

Course interest survey: This instrument, originally developed by Keller and Sobia (1993), comprises 34 items and is structured around four subscales derived from the ARCS model of motivation: Attention, Relevance, Confidence, and Satisfaction. Scoring is based on a 5-point Likert-type scale, with responses ranging from 1 to 5 or 5 to 1, depending on the directionality of the item. For positively worded items, a response of 'Strongly Agree' is assigned a score of 5, followed by 'Agree' (4), 'Undecided' (3), 'Disagree' (2), and 'Strongly Disagree' (1). Negatively worded items are reverse-scored to maintain directional consistency across the scale. Consequently, higher total scores on this instrument reflect greater levels of motivational engagement and interest in the subject matter, whereas lower scores indicate diminished motivation and affective involvement.

Results

Table 1 presents the means and standard deviations of the subscales of the Interest in the Course interest survey for both the experimental and control groups at pretest and posttest stages. The results indicate that the pretest means of the two groups were approximately equivalent across all subscales, suggesting initial comparability between groups prior to the intervention. Following the instructional period, the posttest mean scores for all subscales of the Course interest were higher in the experimental group relative to the control group, indicating a more favorable affective response among students who received concept map-based instruction. Additionally, Table 1 reports the results of the Shapiro–Wilk test, which was conducted to assess the normality of variable distributions within each group. As shown in the table, the Shapiro–Wilk test yielded non-significant results for all variables ($p > .05$), indicating no statistically significant deviation from normality. Consequently, it can be concluded that the assumption of normal distribution was met for all measured variables, thereby supporting the appropriateness of employing parametric statistical analyses for subsequent hypothesis testing.

Table 1- Descriptive Statistics for the Subscales of course Interest and Academic Performance in the Experimental and Control Groups

Variable	Testing Phase	Group	M	SD	Shapiro–Wilk	p
Attention	Pretest	Experimental	23.25	4.97	0.93	0.67
		Control	20.87	4.79	0.94	0.27
	Posttest	Experimental	27.68	4.42	0.98	0.80
		Control	22.09	4.67	0.93	0.28
Relevance	Pretest	Experimental	25.61	5.94	0.97	0.62
		Control	23.26	5.53	0.94	0.18
	Posttest	Experimental	28.89	5.57	0.95	0.24
		Control	24.39	5.28	0.93	0.09
Confidence	Pretest	Experimental	22.04	4.11	0.95	0.23
		Control	20.39	4.97	0.92	0.07
	Posttest	Experimental	25.39	4.36	0.97	0.81
		Control	21.48	5.56	0.92	0.08
Satisfaction	Pretest	Experimental	30.64	6.71	0.97	0.69

		Control	27.43	6.41	0.97	0.73
	Posttest	Experimental	33.82	6.42	0.94	0.19
		Control	28.30	6.22	0.95	0.24
Academic Performance	Pretest	Experimental	4.88	1.97	0.93	0.09
		Control	4.98	1.90	0.92	0.08
	Posttest	Experimental	11.50	3.25	0.99	0.09
		Control	7.99	3.62	0.97	0.69

Note. M = Mean; SD = Standard Deviation. Values for Shapiro–Wilk statistic and significance (p) are reported to assess the normality of distribution for each variable within groups. Non-significant p-values (p > .05) indicate that the assumption of normality was satisfied for all measured variables.

To examine the efficacy of implementing concept maps on the subscales of Course interest, Multivariate Analysis of Covariance (MANCOVA) was employed. Prior to conducting the MANCOVA, the underlying statistical assumptions were rigorously evaluated across the study groups. Figure 1 illustrates the results of the homogeneity of regression slopes assumption test for the pretest and posttest scores of Course interest subscales in both the experimental and control groups. As depicted, the regression slopes were parallel across the two groups, indicating that the relationship between the covariate (pretest scores) and the dependent variables (posttest subscale scores) remained consistent across the different levels of the independent variable (i.e., group membership). This finding confirms that the assumption of homogeneity of regression slopes was satisfied, thereby supporting the validity of proceeding with the MANCOVA for hypothesis testing.

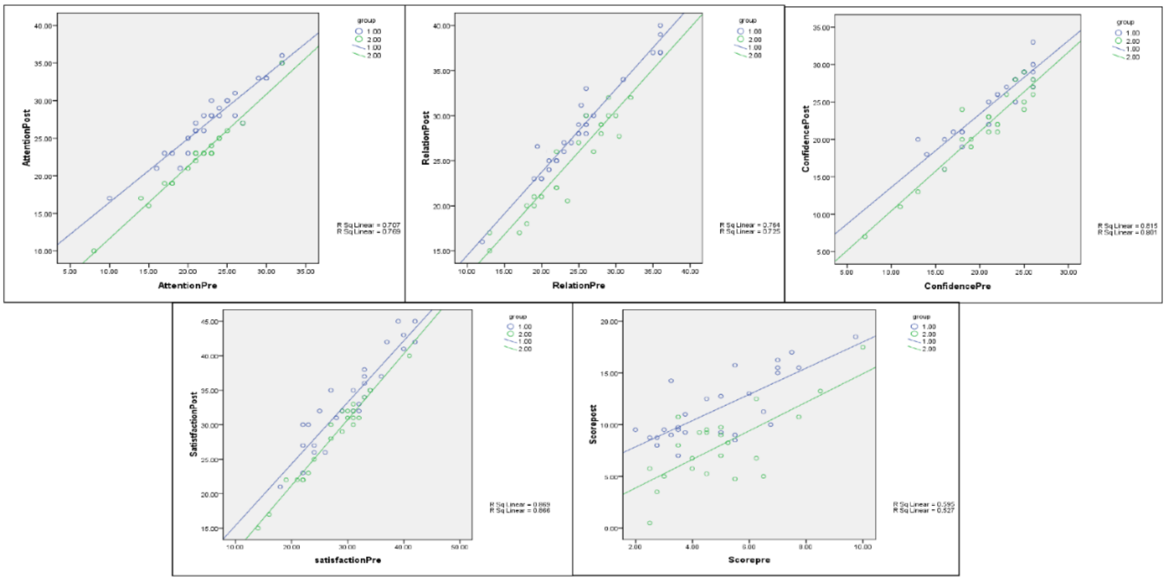

Figure 1- Homogeneity of regression slopes for pretest and posttest scores of the subscales of course interest and chemistry learning

Levene's test was employed to assess the assumption of homogeneity of variances, with the results presented in Table 2. The findings indicate that Levene's test was not statistically significant for any of the variables—namely, Attention, Relevance, Confidence, Satisfaction, or Chemistry Learning. Consequently, the variances of the experimental and control groups did not differ significantly across the subscales of Course interest and the chemistry learning measure. Thus, the assumption of homogeneity of variances was satisfied, supporting the appropriateness of proceeding with parametric covariance-based analyses.

Table 2- Results of Levene's Test for Homogeneity of Variances for the Subscales of Course Interest and Chemistry Learning between the Experimental and Control Groups

Dependent Variable	df_1	df_2	F	p
Attention	126	1	1.544	0.216
Relevance	126	1	1.561	0.235
Confidence	126	1	0.494	0.483
Satisfaction	126	1	0.015	0.902
Chemistry Learning	126	1	—	0.360

Note. df_1 = degrees of freedom for the effect (between groups); df_2 = degrees of freedom for error (within groups); F = Levene's F statistic; p = significance level; non-significant p-values ($p > .05$).

Results of Levene's Test (table 2) for Homogeneity of Variances for the Subscales of Course interest and Chemistry Learning Between the Experimental and Control Groups indicate that the assumption of homogeneity of variances was met for all dependent variables, supporting the validity of subsequent parametric analyses. The F-value for Chemistry Learning was not reported in the original output; however, the non-significant p-value suggests no violation of the homogeneity assumption for this variable.

The results of Box's M test, conducted to examine the equality of covariance matrices for the dependent variables across the experimental and control groups, indicated that the assumption of homogeneity of covariance matrices was satisfied (*Box's* $M = 9.66, F = 0.89, p \geq .53$). This non-significant result confirms that the covariance structures of the dependent variables did not differ significantly between the two groups, thereby supporting the appropriateness of proceeding with multivariate covariance-based analyses. The results of the multivariate analysis are presented in Table 3. The multivariate test statistics revealed a statistically significant difference between the experimental and control groups across the subscales of the Course interest, indicating that the implementation of concept map-based instruction exerted a meaningful effect on learners' affective engagement with the subject matter.

Table 3- Multivariate Analysis Results for the Comparison of Experimental and Control Groups across the Subscales of Course Interest

Test Statistic	Value	F	Hypothesis df	Error df	p
Pillai's Trace	0.68	14.92	4	44	< .001
Wilks' Lambda	0.32	14.92	4	44	< .001
Hotelling's Trace	2.15	14.92	4	44	< .001
Roy's Largest Root	2.15	14.92	4	44	< .001

Note. All four multivariate test criteria—Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root—yielded statistically significant results ($p < .001$). Hypothesis df = degrees of freedom associated with the between-groups effect; Error df = degrees of freedom associated with within-groups variability.

The results in Table 3 indicate a significant overall difference between the experimental and control groups across the combined dependent variables (i.e., the subscales of Course interest: Attention, Relevance, Confidence, and Satisfaction). The consistency of significance across all four tests strengthens the robustness of this finding. To identify which specific subscales of Course interest accounted for the observed between-group differences, follow-up univariate Analyses of Covariance (ANCOVA) were conducted. The results of these univariate ANCOVAs are presented in Table 4.

Table 4- Results of Univariate Analyses of Covariance (ANCOVA) on Posttest Scores Controlling for Pretest scores.

Source	Dependent Variable	Sum of Squares	df	Mean Square	F	p
Group	Attention	312.45	1	312.45	98.61	< .001
	Relevance	145.20	1	145.20	37.49	.040
	Confidence	198.10	1	198.10	20.82	< .001
	Satisfaction	96.75	1	96.75	20.38	.034
Error	Attention	155.60	49	3.17	—	—
	Relevance	190.20	49	3.88	—	—
	Confidence	118.10	49	2.41	—	—
	Satisfaction	232.40	49	4.74	—	—

Note. df = degrees of freedom; *F* = F-statistic from one-way ANCOVA; *p* = significance level.

The results presented in Table 4, indicate the one-way Analyses of Covariance (ANCOVA) results for all four subscales of Course interest. All analyses controlled for pretest scores as covariates. Statistically significant p-values ($p < .05$) indicate that the experimental group (concept map-based instruction) demonstrated significantly higher posttest scores than the control group (traditional instruction) across all four subscales of Course interest —Attention, Relevance, Confidence, and Satisfaction— after adjusting for initial differences: Attention ($F = 98.61, p < .001$), Relevance ($F = 37.49, p = .04$), Confidence ($F = 20.82, p < .001$), and Satisfaction ($F = 20.38, p = .034$). These findings provide robust evidence that the integration of concept mapping into chemistry instruction positively influenced students' Course interest.

Table 5- Results of Univariate Analysis of Covariance (ANCOVA) on Chemistry Learning Posttest Scores Controlling for Pretest Scores

Source	Sum of Squares	df	Mean Square	F	p
Group	168.45	1	168.45	13.72	< .001
Error	602.30	49	12.29	—	—

Note. df = degrees of freedom; *F* = F-statistic from one-way ANCOVA; *p* = significance level

The results presented in Table 5 indicate the one-way Analysis of Covariance (ANCOVA) for the variable of Chemistry Learning. The analysis controlled for pretest chemistry learning scores as a covariate. The statistically significant result ($F(1, 49) = 13.72, p < .001$) indicates that, after adjusting for initial knowledge levels, students in the experimental group (who received concept map-based instruction) achieved significantly higher posttest scores in chemistry learning compared to those in the control group (who received traditional teacher-centered instruction). This finding provides empirical support for the efficacy of concept mapping as an instructional strategy for enhancing cognitive learning outcomes in secondary-level chemistry education.

Discussion and Conclusion

The primary objective of the present study was to investigate the efficacy of concept map-based instruction on students' chemistry learning outcomes and their Course interest. The findings demonstrated that the integration of concept maps into chemistry instruction significantly enhanced students' mastery of chemistry content. Specifically, the academic performance of students who received instruction through concept mapping was markedly superior to that of their counterparts in the control group, who were taught using traditional teacher-centered methods.

These results align with and extend the findings of prior research, including the studies conducted by BouJaoude and Attieh (2008), Šket et al. (2015), and Wang et al. (2020), all of which reported positive effects of concept mapping on chemistry learning. Furthermore, the current findings are consistent with a broader body of literature affirming the instructional value of concept mapping across diverse disciplinary contexts. For instance, research by Nasirpour et al. (2020), Bressington et al. (2018), and Abraha (2024) has similarly corroborated the beneficial role of concept map implementation in fostering learning outcomes in subjects beyond chemistry, thereby underscoring the generalizability and robustness of this instructional strategy.

Concept maps, serving as both educational and cognitive instruments, facilitate the systematic organization and visual representation of knowledge, thereby promoting meaningful learning. Grounded in David Asubel's theory of meaningful learning, this pedagogical approach exerts a significant influence on students' cognitive processing and has the potential to enhance learning engagement and satisfaction. Cognitive processing encompasses fundamental mental operations—including perception, attention, memory, reasoning, problem-solving, and learning—that collectively facilitate the comprehension, integration, and elaboration of information. Instructional methodologies that reinforce cognitive processing typically yield enhanced meaningful learning outcomes and improved academic achievement. Empirical evidence indicates that the implementation of concept maps enhances the mental organization of information and strengthens cognitive processing across multiple levels (Nesbit & Adesope, 2006).

According to Cognitive Load Theory, learning becomes more effective when cognitive load is minimized. Concept maps, by structuring educational content in a graphical format, facilitate more efficient information processing and reduce extraneous cognitive load. Consequently, rather than engaging in rote memorization, students process information in a meaningful and integrative manner. Empirical studies demonstrate that concept maps contribute to enhanced working memory performance and more effective consolidation of information into long-term memory; this improvement is attributed to the superior organization of concepts and the establishment of logical interconnections among them, which collectively facilitate comprehension and retrieval. Concept maps require learners to critically analyze relationships among concepts and construct a coherent, interconnected knowledge network. This cognitive engagement fosters the development of critical thinking abilities and strengthens problem-solving competencies (Bolatli, 2024).

The findings indicate that concept maps have proven effective in enhancing students' interest in chemistry education. In this regard, numerous empirical studies—including Karakuyu (2010) and Sayadi et al. (2018)—have corroborated the efficacy of concept mapping in fostering enthusiasm, cultivating positive attitudes toward the subject matter, and promoting enjoyment throughout the instructional process. These studies collectively suggest that the visual and relational structure of concept maps contribute to increased learner engagement and motivational outcomes in science education contexts.

Concept maps, by providing a transparent and structured representation of content, reduce instructional ambiguity and foster a sense of cognitive confidence. Research indicates that the reduction of cognitive load contributes to heightened intrinsic motivation (Schunk et al., 2014). When learners construct concept maps, they experience an increased sense of agency and control over the learning process. This perceived mastery strengthens academic self-efficacy and enhances Course interest (Nesbit & Adesope, 2006). Furthermore, concept maps enable learners to visualize the connections between novel concepts and their existing prior knowledge. This explicit recognition of conceptual relationships renders learning more meaningful and stimulates intrinsic Course interest (Novak & Cañas, 2008). By offering a holistic overview of the subject, concept maps assist learners in comprehending the significance of individual concepts within a broader conceptual framework. Such comprehensive understanding provokes intellectual curiosity and promotes deeper exploratory engagement with the content (Hay et al., 2008).

Moreover, the process of constructing concept maps constitutes an interactive and creative endeavor that transforms learners from passive recipients into active knowledge constructors. This active participation cultivates a stronger sense of connection and commitment to the subject matter (Bressington et al., 2018).

In summary, concept maps extend beyond their conventional role as mere tools for assessment or knowledge organization; they constitute a potent motivational strategy in educational practice. Through multiple mechanisms—including the enhancement of intrinsic motivation, reduction of academic anxiety, reinforcement of self-efficacy, facilitation of meaningful learning, and promotion of collaborative interaction—concept maps can significantly improve students' attitudes toward learning and cultivate a deeper, more enduring Course interest. To maximize their motivational impact, it is recommended that concept mapping be integrated into instruction as an iterative, reflection-oriented process rather than employed solely as a terminal assignment. Such pedagogical implementation encourages continuous knowledge construction, metacognitive awareness, and sustained learner engagement throughout the educational experience.

In the present study, considerable effort was devoted to controlling potential confounding variables; however, due to the extended duration of the intervention, precise control over all extraneous factors could not be fully achieved. Given that the same instructor taught both the experimental and control groups, the study was conducted using a single-blind design, which may potentially be influenced by teacher awareness effects. To mitigate this threat to internal validity, data collection and the scoring of achievement tests were carried out directly by the researcher to ensure objectivity and consistency.

In light of the findings obtained, several pedagogical recommendations are proposed for chemistry educators. First, it is advisable that instructors develop concept maps for individual chemistry chapters and present them to students at the outset of instruction to provide a coherent conceptual framework. Additionally, teachers may utilize partially completed or scaffolded concept maps as engaging and creative formative assessment tasks to evaluate students' conceptual understanding. Furthermore, chemistry educators within a district or institution are encouraged to collaborate in constructing a shared repository of standardized, incomplete, and blank concept maps aligned with various chemistry topics, thereby establishing a common instructional resource for professional use.

Finally, the design of collaborative group projects—wherein students are tasked with constructing large-scale, creative wall-mounted concept maps for complex topics (e.g., types of organic reactions)—is strongly recommended. Such activities not only promote deep conceptual comprehension but also foster essential collaborative skills, critical thinking, and collective knowledge construction. Implementing these strategies can enhance both the effectiveness of instruction and the quality of student engagement in chemistry education.

Conflict of Interest

The authors have declared no conflicts of interest.

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