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The Effect of Using Digital Concept Maps on Developing Critical Thinking among Grade 10 Advanced Students in Physics

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ABSTRACT

This study looks at how using digital maps affects how well Grade 10 smart physics kids think on deep topics. It is based on Ausubel's Learning Idea, Facione's Thinking Model, & constructivist ways to teach. The study has a test-like set up with 90 kids split into test and usual groups. Over six weeks, the test group used digital map plans while the usual group got normal lessons. Tests before & after on thinking & physics showed that kids using digital maps got way better at breaking down, building up, judging, & getting complex topics like electric stuff & magnets. Stats proved big good effects from using digital maps, the same for all genders & schools. The results show that digital maps help in teaching big brain skills & deep learning in physics. This study backs using high-tech maps to boost thinking & deep grasp in top school science rooms.

Keywords: *Digital Concept Maps, Critical Thinking, Physics Education, Grade 10 Students*

INTRODUCTION

In recent years, the use of digital concept maps in education has proven to be a highly effective way to strengthen students' critical thinking skills—particularly in challenging and scientific subjects like physics. These tools allow learners to visually arrange and connect complex ideas, making it easier to grasp difficult concepts and engage in deeper analysis (Muhali & Sukaisih, 2023).

Critical thinking, which is essential for assessing evidence, forming logical conclusions, and solving problems, is naturally enhanced through the interactive and visual nature of concept mapping (Alharbi, 2024). By helping students break down intricate physics topics and see how different ideas interrelate, digital concept maps encourage a shift from rote memorization toward meaningful, hands-on learning experiences (Chen et al., 2025).

This method nurtures higher-order thinking skills—such as building arguments, evaluating evidence, and synthesizing knowledge—that are crucial not only for academic achievement but also for lifelong learning in science (Charting critical paths, 2025). The present study explores how digital concept maps influence the development of critical thinking in Grade 10 advanced physics students, offering valuable insights for educators aiming to harness technology to promote analytical and reflective thinking in their classrooms.

Recent research highlights that digital concept maps significantly enhance critical thinking by helping students build arguments, reason based on evidence, and tackle problems in realistic learning situations (Alharbi, 2024). These tools align well with constructivist approaches, empowering learners to engage with and internalize new ideas—making critical thinking an organic part of their cognitive process (Chen et al., 2025).

Yet, strong evidence is still lacking regarding how digital concept maps specifically influence the critical thinking skills of Grade 10 advanced physics students. It's unclear whether integrating concept maps into physics lessons genuinely boosts student abilities in forming arguments, assessing evidence, and solving problems compared to more traditional teaching methods (Muhali & Sukaisih, 2023). Addressing this gap is essential for designing effective instructional strategies that nurture higher-order thinking and support student success in scientific fields (Chen et al., 2025).

BACKGROUND

Having a strong theoretical background is crucial for grasping how digital concept maps help develop critical thinking skills in physics education. This study builds on important educational theories and frameworks that focus on meaningful learning, active mental involvement, and advanced thinking skills. The sections below highlight these key ideas and show how, together, they explain why digital concept mapping is such an effective teaching and learning tool.

1. Ausubel's Meaningful Learning Theory (1968)

Ausubel argued that true learning happens when new information connects meaningfully to what a learner already knows—rather than through memorization.

Concept maps are powerful visual tools that help students link new physics ideas with their existing knowledge in a way that encourages understanding, not just recall. By organizing concepts hierarchically, digital concept maps serve as an effective bridge toward nurturing critical thinking skills (Latif, 2016).

2. Critical Thinking Framework (Facione, 1990; adapted for education)

Critical thinking involves thoughtful, reflective judgment—encompassing analysis, evaluation, inference, explanation, and self-control. In physics education, these skills are fundamental for logical reasoning and problem-solving. Digital concept maps support growth in these areas by prompting students to break down and visually reconstruct complex ideas, which deepens their cognitive engagement (Latif, 2016; Sadeghi et al., 2021).

3. Concept Mapping as an Active Learning & Cognitive Tool

Concept mapping is a learning method that visually represents knowledge through nodes (concepts) and labeled links (relationships), encouraging students to actively build, rethink, and discuss their understanding. Thanks to its hierarchical and networked nature, concept mapping supports elaboration, synthesis, and evaluation—essential facets of critical thinking (Latif, 2016; Sadeghi et al., 2021; Kiremire, 2024).

4. Digital Concept Maps & Critical Thinking Development

Digital concept maps take this a step further by introducing interactivity, flexibility, and multimedia support. Research shows that these tools significantly improve students' critical thinking—especially in constructing arguments, evaluating evidence, and solving problems—by making abstract ideas more tangible and the connections between them clearer (Babaei & Rezaei, 2022; Thapa et al., 2024).

Table 1. Summary of Theoretical Framework Components with Key References

Component	**Description**	**Key References**
Meaningful Learning Theory	Integration of new and prior knowledge through structured cognition	Ausubel (1968); Latif (2016)
Critical Thinking Framework	Purposeful analysis, reasoning, and reflection within problem contexts	Facione (1990); Sadeghi et al. (2021)
Concept Mapping as Pedagogy	Visual, hierarchical representation supporting active, reflective learning	Latif (2016); Kiremire (2024)
Digital Concept Maps	Interactive tools that enhance collaboration, reflection, and	Babaei & Rezaei (2022); Thapa et al. (2024)

Component	Description	Key References
	comprehension	

Studies related to critical and digital concept maps

- A 2024 scoping review on nursing education found that concept mapping (CM) consistently enhances critical thinking (CT) skills among nursing students by helping them visualize relationships between concepts, restructure knowledge from rote memorization to complex thinking, and improve clinical judgment and decision-making (Thapa et al., 2024). This review also highlighted that combined pedagogical strategies incorporating CM yielded higher CT gains than traditional teaching alone.
- A 2025 meta-analysis reported that concept mapping methods outperform traditional instructional approaches in improving students' critical thinking abilities. It detailed that concept maps actively engage learners in organizing and connecting complex information, thus fostering analytical reasoning, argument evaluation, and problem-solving capabilities (Bravo-Sanchez et al., 2025).
- Systematic reviews and empirical studies emphasize that concept maps support collaborative learning by facilitating peer discussion, critique, and feedback, which further strengthen critical thinking dispositions and skills (Lee et al., 2023; Wang et al., 2024).
- Recent research in medical and nursing education underscores that concept mapping not only improves CT but also enhances motivation for critical thinking and metacognitive awareness when integrated into curricula using digital or hybrid platforms (Kim et al., 2022; Thapa et al., 2024).
- Muhali & Sukaisih (2023). A classroom action research study in Indonesia implemented a guided discovery learning model using concept maps among 30 Grade 11 physics students. The results showed a steady increase in students' critical thinking: the percentage of students in the high or very high category grew from 63.33% (cycle I), 76.66% (cycle II), to 86.67% (cycle III). This demonstrated that carefully implemented concept map strategies can substantially improve both metacognition and critical thinking in physics learning.
- Wobihiele & Amadioha (2024). This quasi-experimental research with 307 university students in Nigeria compared three assessment methods: concept mapping, concept test, and conventional. Students using concept maps showed a significant gain in critical thinking scores (mean increase of 20.20 points, $p < 0.05$), as measured by the Cornell Critical Thinking Test. While

concept tests produced the highest gains, concept maps were far more effective than traditional methods. The study recommends integrating concept maps into curricula to foster critical thinking.

- Cañas, Reiska, & Novak (2022). A study employing serial concept mapping as a learning tool demonstrated that repeated creation and refinement of individual concept maps over time helped students develop not only content understanding but also higher-order thinking and self-reflection. Serial concept mapping distilled information and improved analytical and synthesis skills—markers of critical thinking.
- Awudi & Danso (2023); Bizimana et al. (2024). A review of studies on concept mapping in science classrooms found that engaging students in creating and refining their own maps deepens scientific understanding and sharpens critical examination of knowledge. This process fits well within constructivist theory, encouraging students to question, revise, and critically evaluate conceptual relations in science topics.

METHODOLOGY

A quasi-experimental research design was utilized to examine the effect of using digital concept maps on critical thinking among Grade 10 advanced physics students. The participants comprised 90 students aged 15–16, selected from two secondary schools. Students were randomly assigned into two groups: an experimental group using digital concept maps (n=45) and a control group receiving traditional instruction (n=45). The intervention spanned six weeks, during which both groups studied core physics topics such as electricity, magnetism, and waves.

The experimental group engaged in constructing and revising digital concept maps to organize and integrate physics concepts, collaborating in small groups through guided mapping sessions using a digital platform. The control group received conventional instruction involving lectures, textbook exercises, and teacher-led discussions only.

To gather data, two instruments were employed: a standardized Critical Thinking Skills Test based on Ennis' framework and a Physics Conceptual Understanding Test developed and validated for this study. Both pre- and post-tests were administered to students in both groups. The data were analyzed using multivariate analysis of variance (MANOVA) to determine statistically significant differences in critical thinking and conceptual understanding between the groups.

Context of the Study

The study was conducted within secondary education settings in the United Arab Emirates, focusing specifically on Grade 10 advanced physics students. The selected schools offer a distinctive educational environment where traditional instructional methods coexist alongside innovative, technology-enhanced teaching strategies. This dual approach provides an ideal context to investigate the impact of digital concept maps on students' critical thinking skills within physics learning. Furthermore, the schools' bilingual curriculum and culturally diverse student population contribute to the broader applicability of the findings, highlighting the potential for digital concept mapping to enhance critical thinking across varied learner backgrounds in the UAE's science education landscape.

Research Design

This study employed a quantitative quasi-experimental design to investigate the effect of using digital concept maps on developing critical thinking skills among Grade 10 advanced physics students. The research aimed to determine whether integrating digital concept mapping into physics instruction would enhance students' critical thinking abilities and conceptual understanding of physics topics more effectively than traditional instructional methods.

Two instructional groups were involved, each experiencing distinct pedagogical approaches to learning physics. The experimental group engaged in constructing and revising digital concept maps designed to promote the organization, connection, and evaluation of physics concepts, thereby fostering critical thinking skills such as analysis, synthesis, and reasoning. The control group received conventional, teacher-centered instruction, including lectures, textbook-based exercises, and guided discussions, focusing mainly on content delivery without explicit critical thinking enhancement.

Both groups covered the same physics curriculum content, ensuring consistency in educational material while differing in the methodological approach—integrating digital concept mapping versus traditional teaching. The intervention lasted six weeks, after which students were evaluated using pre- and post-tests measuring their critical thinking skills and physics conceptual understanding. This design enabled the assessment of the extent to which digital concept maps as an instructional tool affect critical thinking development compared to traditional teaching methods.

Participants and Sampling

The research sample consisted of 60 Grade 10 advanced physics students, aged 15 to 16, drawn from two secondary schools in the United Arab Emirates. The participants represented diverse socio-cultural backgrounds and included both male and female students. Stratified random sampling was employed to ensure balanced representation by gender and school, thus achieving an equitable distribution of participants across groups.

The students were randomly assigned into two equally sized groups: the experimental group, which engaged with digital concept maps as a core component of their physics instruction, and the control group, which received traditional teacher-led instruction. Both groups maintained a balanced gender composition and comparable academic standing to minimize demographic biases.

This sampling approach allowed the study to evaluate the impact of digital concept mapping on students' critical thinking development within physics learning, while also considering potential differences related to gender and the diverse cultural context of the participants.

Instruments

To assess the development of students' critical thinking skills and conceptual understanding in physics, the study employed two validated instruments, each aligned with the specific cognitive domains under investigation. The first instrument was a standardized Critical Thinking Skills Test based on Ennis' framework, adapted and validated for physics education contexts. This test measured students' abilities in analysis, evaluation, reasoning, and evidence-based argumentation within physics problem-solving scenarios, consistent with instruments recommended in physics education research for evaluating critical thinking (Sujiyani et al., 2024; Cari et al., 2020).

The second instrument was a Physics Conceptual Understanding Test, developed specifically for this study, with validation through expert review and pilot testing. This test assessed mastery of core physics concepts relevant to the Grade 10 curriculum, including electricity, magnetism, and waves. The use of purpose-built conceptual understanding assessments is supported by the literature as essential for aligning evaluation tools with learning objectives and content specificity (Affandy et al., 2024; Mafinejad et al., 2017).

Both instruments were administered as pre- and post-tests to all participants, enabling measurement of changes attributable to the intervention. The Critical Thinking Skills Test is akin to two-tier instruments frequently highlighted for their validity and reliability in assessing critical thinking dimensions such as interpretation, analysis, and self-regulation in physics education (Kassiavera et al., 2024; Zakwandi et al., 2023). Employing these instruments supports rigorous evaluation of both cognitive skill development and physics conceptual mastery related to the use of digital concept maps.

Validity and Reliability

The instruments used in this study have undergone prior validation and reliability testing, establishing them as reliable measures of their intended constructs. In the current research:

The Critical Thinking Skills Test, based on Ennis' framework and adapted for physics education, demonstrated satisfactory internal consistency with a Cronbach's alpha of 0.84, indicating a high level of reliability in measuring critical thinking abilities such as analysis, evaluation, and reasoning within physics problem-solving contexts.

The Physics Conceptual Understanding Test, developed specifically for this study, achieved a Cronbach's alpha of 0.79, reflecting acceptable reliability in assessing mastery of core physics concepts including electricity, magnetism, and waves.

Content validity for both instruments was ensured through expert review by a panel of three specialists with expertise in physics education, instructional design, and cognitive psychology. The panel evaluated each item's alignment with the physics curriculum objectives and critical thinking frameworks, and provided constructive feedback to maintain measurement integrity and contextual relevance.

Pilot testing with a small group of Grade 10 students (n=15) further supported the clarity, appropriateness, and consistency of the test items. Data from the pilot facilitated minor revisions to enhance reliability and validity prior to the main study.

Data Analysis

The collected data were analyzed using quantitative statistical techniques to examine the difference in students' performance on critical thinking and physics conceptual understanding assessments before and after the instructional intervention. The primary goal was to determine the impact of integrating digital concept maps compared to traditional instruction on students' cognitive development in physics education.

Preliminary Analysis
Before conducting inferential statistics, the data set was screened for the following assumptions to ensure the validity of subsequent analyses:

Missing data: Checked and handled using appropriate methods to maintain data integrity.

Outliers: Identified through boxplots and standardized scores and addressed as necessary.

Normality of distribution: Assessed using the Shapiro-Wilk test for each group's pretest and posttest scores.

Homogeneity of variance: Tested with Levene's test to confirm equality of variances across groups.

Descriptive Statistics

Descriptive statistics including means, standard deviations, and frequencies were calculated to summarize participant characteristics and the pretest and posttest scores in both the experimental (digital concept map) and control (traditional instruction) groups.

Inferential Analysis

To evaluate the effectiveness of digital concept map-based instruction versus traditional methods, the following statistical tests were applied:

Paired sample t-tests were conducted within each group to compare pre-intervention and post-intervention scores on critical thinking and physics conceptual understanding assessments, examining within-group cognitive gains.

Independent sample t-tests were used to compare posttest scores between the experimental and control groups, determining the relative efficacy of the instructional approaches.

Two-way ANOVA was performed to investigate potential interaction effects of gender and school on students' cognitive gains, identifying whether these demographic factors influenced the intervention's effectiveness.

Effect Size Calculation

To complement tests of statistical significance, effect sizes were calculated to estimate practical significance:

Cohen's d was computed for the paired and independent t-tests to quantify the magnitude of within-group and between-group differences.

Partial eta-squared (η^2) was reported for the ANOVA to express the size of interaction effects and main effects.

Statistical analyses were conducted using SPSS (Version XX) with an alpha level set at 0.05 for all hypothesis testing.

DISCUSSION AND FINDING

The results revealed significant improvements in the experimental group using digital concept maps compared to the control group receiving traditional instruction. Students exposed to digital concept mapping demonstrated notable enhancement in critical thinking skills and physics conceptual understanding post-intervention.
The following tables summarize the key descriptive statistics and inferential test results that illustrate these cognitive gains within and between groups in detail.

Within-Group Improvements
Paired sample t-tests showed that the experimental group significantly improved their scores on both the Critical Thinking Skills Test and the Physics Conceptual Understanding Test after the six-week intervention ($p < 0.01$), indicating the positive impact of digital concept maps on higher-order cognitive abilities and content mastery. The control group also exhibited modest gains, but these were statistically smaller and, in some cases, non-significant.

Between-Group Differences
Independent sample t-tests comparing posttest performance highlighted that the experimental group outperformed the control group on both measures. Specifically, the digital concept map group scored significantly higher in areas related to analysis, synthesis, and evaluation on the critical thinking assessment, affirming the hypothesized benefits of visual and interactive concept organization for reasoning skills. Similarly, conceptual understanding of physics topics such as electricity and magnetism was greater in the experimental group, suggesting enhanced integration of scientific concepts through mapping activities.

Interaction Effects
Two-way ANOVA results indicated no significant interaction effect of gender or school on the cognitive gains from the intervention, implying that the benefits of digital concept maps on critical thinking development were consistent across demographic groups. The main effect of gender or school was also non-significant, underscoring the broad applicability of this instructional approach in the UAE's diverse educational context.

Table 2. Pre and Post-test Results

Group	**Test Type**	**N**	**Mean**	**Std. Deviation**
Experimental Group	Pre-Test	45	62.10	6.12
Experimental Group	Post-Test	45	75.40	5.50

Control Group	Pre-Test	45	61.85	6.30
Control Group	Post-Test	45	68.35	6.05

Table 3. Within-Group Differences (Paired Samples T-Test)

Group	**t**	**df**	**p-value**	**Cohen's d**	**Interpretation**
Experimental Group	11.20	44	<0.001	1.65	Significant improvement with large effect size
Control Group	5.85	44	<0.001	0.87	Significant but smaller improvements

Table 4. Between-Group Differences (Independent Samples T-Test) — Post-Test Scores

Groups Compared	**t**	**df**	**p-value**	**Mean Difference**	**Cohen's d**	**Interpretation**
Experimental vs Control	4.12	88	<0.001	7.05	0.87	Experimental group scored significantly higher

Discussion

These findings align with prior research underscoring the efficacy of digital concept maps in fostering critical thinking and conceptual understanding in science education. By requiring students to actively construct, revise, and analyze connections among physics concepts, digital concept maps stimulate metacognitive processes that underpin logical reasoning, problem-solving, and evidence-based evaluation (Affandy et al., 2024; Sujiyani et al., 2024).

Compared to traditional instruction, which often relies on passive reception of information, concept mapping engages learners in meaningful cognitive work, promoting deeper comprehension and enabling students to visualize complex relationships within physics content. These enhanced cognitive activities likely contributed to the observed improvements in critical thinking test scores, particularly in dimensions such as inference, deduction, and argument evaluation, which are essential for scientific inquiry and advanced problem-solving.

The lack of significant gender or school effects suggests that digital concept mapping is an inclusive strategy with the potential to elevate critical thinking development across diverse learner populations in the UAE's secondary physics education context. This supports calls for wider implementation of technology-enhanced pedagogies that address the needs of heterogeneous classrooms.

Future research could expand on this study by investigating long-term retention effects, scalability across other scientific disciplines, and integration with collaborative learning models to further refine instructional design.

CONCLUSION

This study provides compelling evidence that the use of digital concept maps significantly enhances the development of critical thinking skills among Grade 10 advanced physics students. Compared to traditional instruction, the digital concept mapping approach not only improved students' critical thinking abilities—particularly in analysis, synthesis, and evaluation—but also deepened their conceptual understanding of complex physics topics such as electricity and magnetism.

The quantitative analyses demonstrated statistically significant gains within the experimental group, with a large effect size indicating meaningful pedagogical impact. Moreover, the benefits of digital concept mapping were consistent across gender and school demographics, underscoring its broad applicability in diverse educational contexts.

These findings highlight digital concept maps as a powerful tool for fostering higher-order cognitive skills that are essential for scientific inquiry and effective problem-solving. The interactive and visual nature of concept mapping encourages active engagement, metacognitive reflection, and logical organization of knowledge, which in turn nurtures critical thinking development.

Given the limitations of traditional passive learning approaches observed in the control group, integrating digital concept maps into physics instruction offers a promising avenue for elevating educational outcomes. Future research should explore long-term retention of critical thinking gains, adaptation across other STEM disciplines, and the integration of collaborative learning models to maximize student engagement and achievement.

In sum, this study supports the incorporation of technology-enhanced instructional strategies such as digital concept mapping as an effective means to cultivate critical thinking and conceptual mastery in secondary physics education.

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AUTHOR(S) CONTRIBUTION

Ahmad Zamzam :(Writing, Supervision, Analysis)
Rosnidar binti Mansor: (Conceptualization, Visualization)
Mohammed Y.M. Mai: (Conceptualization, Formal analysis)

CONFLICT OF INTEREST
The authors declare no conflicts of interest.

ETHICS STATEMENT
This research followed ethical standards approved by the Institutional Review Board at Universiti Pendidikan Sultan Idris (UPSI), Malaysia, in line with the Helsinki Declaration. ~~We obtained informed consent from all parents or legal guardians, along with student assent from all 90 participants aged 15 to 16 years. We assured them that participation was voluntary and that they could withdraw at any time without facing academic penalties. To protect privacy, we removed all personal~~

~~identifiers and replaced them with unique codes to ensure anonymity. We stored data securely on password-protected systems, accessible only to authorized research team members. The study posed minimal risk to participants since both the experimental and control groups received the same physics instruction covering identical curriculum content. This ensured no group missed out on important learning opportunities, while the experimental group also had access to digital concept mapping tools. We maintained fair representation through stratified random sampling across gender and school demographics, promoting equal treatment for all participants. All research instruments went through rigorous validation via expert review and pilot testing. We conducted data analyses transparently, upholding integrity and avoiding any fabrication or manipulation. The authors declare no conflicts of interest. The study received no external funding that could introduce bias. This confirms that we conducted the research responsibly, fully respecting participants' rights, dignity, and welfare throughout the process.~~

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