MANAGING COGNITIVE LOAD IN A BLENDED LEARNING ENVIRONMENT TO IMPROVE STUDENTS' CRITICAL THINKING SKILLS: AN EXPERIMENTAL STUDY

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ABSTRACT

Critical thinking is recognized as one of the core skills of 21st century. It fosters knowledge construction and enhances students' performance and learning outcomes by encouraging them to question assumptions and draw meaningful conclusions. In order to process information mental effort is required. This mental effort is known as cognitive load. learning is affected without effective cognitive load management. Although technology is integral part of blended learning, there are challenges in balancing cognitive load with technology use to foster critical thinking without causing cognitive overload. The current study examines how students' critical thinking abilities are improved in a blended learning environment through cognitive load management. This study employed a true experimental research design. All educational institutions in District Abbottabad, Hazara Division, Khyber Pakhtunkhwa, constituted the population of this study. From a sample of 32 students, 17 were randomly assigned to the control group, while 15 were assigned to the experimental group. To accurately measure the effect, only the experimental group received a treatment comprising of worked examples, completion tasks, scaffolding and instant feedback, whereas the control group did not. Two valid and reliable instruments, adapted from NASA-TLX and WGCTA were used to assess cognitive load and critical thinking skills. Data analysis included paired sample t-tests, Mann-Whitney U-tests, Welch's t-tests, Wilcoxon Signed Rank Test, independent samples t-tests as well as descriptive statistics. The critical thinking skills were found to improve more in an experimental group ($p < 0.05$) as compared to control group. It was concluded that in the absence of effective cognitive load management, learning is hindered. This study recommends that cognitive load management is crucial in a blended learning environment to facilitate the cultivation of critical thought among learners.
Keywords: Cognitive load Management, Blended Learning, Critical Thinking, Scaffolding.

INTRODUCTION

The capacity to engage in critical reading and listening by responding to what is read or heard through thorough evaluation requires a specific set of critical thinking abilities and attitudes. At its core, critical thinking is made up of a series of interconnected critical questions and the corresponding capacity and inclination to ask and respond to them appropriately (Suryanti et al., 2018). These skills include evaluation, explanation, interpretation, and inference, which have been shown to improve significantly through inquiry-based learning models that emphasize critical questions (Payu et al., 2022). Critical thinking and learning are closely interconnected processes that enhance knowledge acquisition and application. In critical thinking, Information is objectively analyzed and evaluated to formulate reasoned judgments, which is essential for effective learning as it encourages learners to actively engage with, question, and reflect upon new information rather than passively receive it (Tugirin et al., 2025). The benefits of both traditional classroom instruction and electronic learning are combined in blended learning settings, making it a more effective and practical method for promoting critical thinking in students. In the learning process, it transforms students from passive learners to active learners, improving their ability to analyze, interpret, and evaluate subjects (Haftador et al., 2023).

Cognitive load refers to the mental effort required to process information in working memory during learning tasks. The aim of cognitive load theory is to improve instructional design. This is achieved through effective cognitive load management, which is the central concept of Cognitive Load Theory (CLT) and leads to improved learning outcomes (Skulmowski & Xu, 2022). There is insufficient exploration in the current literature regarding the measurement and balancing of different types of cognitive load (intrinsic, extraneous, and germane) when using digital tools, such as interactive simulations. Most research has focused on reducing extraneous cognitive load; however, how digital tools can be used to manage intrinsic and germane cognitive load remains underexplored (Surbakti et al., 2024). Poorly structured blended materials and redundant media can lead to increased extraneous cognitive load, which detracts from learning efficiency. This occurs because learners must expend additional cognitive resources on interpreting and navigating the instructional design rather than focusing on the learning content itself. Effective instructional design should minimize redundancy and irrelevant information to enhance learning outcomes (Müller & Wulf, 2023). Studies have demonstrated that blended learning models that incorporate experiential and inquiry-based approaches contribute to significant gains in students' critical thinking abilities (Indarta et al., 2025). Research gaps in cognitive load management in blended learning environments to optimize critical thinking skills of students include a lack of extensive empirical studies specifically investigating how cognitive load influences critical thinking outcomes within blended learning contexts (Surbakti et al., 2024; Hasanah and Malik, 2020). longitudinal experimental studies tracking how cognitive load management affects the progression of critical thinking skills over time in blended learning settings are notably lacking, which limits understanding of sustained learning benefits (Zou et al., 2025). These identified gaps expose the importance of extensive experimental studies that explores tailored cognitive load management strategies within blended learning, explicitly targeting critical thinking skill enhancement while considering individual learner differences and using robust assessment frameworks (Surbakti et al., 2024; Lu, 2021).

The digital divide (digital tools, reachability, practical abilities and application are contributors of digital divide which became more pronounced after COVID-19) (Norman et al.2022; Ritzhaupt et al., 2020), designing learning environments sensitive to Variations in learner characteristics (Antonenko et al., 2020) , people lifestyle considerations (Sharif & Gilbert, 2015; Young & Asino, 2020) and accessibility (Estes et al., 2020) are examples of serious problems that educational technology researchers consider when focusing their research. In blended learning environment teachers face challenges in adapting instructional strategies, involving students, and cognitive load management. In blended learning, the absence of real-time feedback can prevent students from promptly addressing misunderstandings, resulting in an elevated cognitive load, as they are unable to self-correct (Eslit, 2023). This study is about cognitive load management in blended learning environment to enhance critical thinking abilities of students. The ever-increasing volume of digital data creates information overload, making knowledge work increasingly complex. Being able to avoid distractions and focus on what is currently relevant requires considerable (significant) mental processing capacity (Gauselmann et al., 2023). In literature how cognitive load and critical thinking in learners are related in blended learning environment had not been thoroughly studied (Alismaiel, 2022; Almarzuqi et al., 2024), hence current research closed a study area.The literature emphasized the advantages of blended learning for critical thinking, but the complicated effects of cognitive load remain poorly understood, suggesting an important field for research. In addition, this study looked into approaches to manage cognitive load and provided access to high-quality critical thinking skills in online learning in an effort to close the digital and cognitive divides.

LITERATURE REVIEW

Evaluation of facts, evidence, observations, and arguments to reach a conclusion is known as critical thinking. In critical thinking, learners plan, monitor, and correct their own learning without any guidance or reminders from others. It needs agreement with strict excellence criteria as well as a thoughtful understanding of how to apply them. It requires excellent information sharing and solution finding abilities, along with commitment to countering egocentric and sociocentric biases in their original form (Verma et al., 2022). CLT focuses on lowering cognitive load to avoid overloading working memory, which can hinder learning and critical thinking. However, this approach has been criticized for failing to adequately support critical thinking development, as it frequently favors direct instruction over inquiry-based methods (Kim et al., 2025). Empirical studies also demonstrate positive student perspectives of blended learning environments developed to enhance critical thinking, highlighting the critical role of pedagogical, social, and technical design elements in fostering engagement and cognitive skill development (Lu, 2021). In the present age of information overload, fake news and social media, critical thinking plays a key role in analyzing information to distinguish truth from falsehood. It helps to avoid personal prejudices and biases (Brahim, 2024).

Blended learning is the combination of virtual and traditional instruction. Both modalities, if not designed properly, can create unnecessary cognitive load. Cognitive load theory provides a key framework to improve the effectiveness of blended learning by managing intrinsic, extrinsic, and germane cognitive load in complex multimedia environments (Firdaus et al., 2025). Cognitive Load Theory presents that human working memory has a limited capacity. Human working memory can store about seven pieces of information but can process only two to four elements simultaneously. Learning is affected by tasks that require processing too many interacting elements at the same time (Safiah et al., 2020). Instructions should be prepared in such a way that they reduces extraneous load, match intrinsic load withthe students' capabilities, and increase germane load for schema construction (Anmarkrud et al., 2019). According to CLT, our deep thinking requires a lot of information that is [schematically] stored in long-term memory. The knowledge has two types "biologically primary knowledge," or information that we may learn on our own (like knowing a language), and "biologically secondary knowledge," which we must intentionally educate (like most of what we study in school). Since critical thinking is biologically primary, it cannot be taught. Critical thinking can only be cultivated by in-depth content knowledge. Critical thinking skills are non-transferable. There are two opposing viewpoints on the definition of critical thinking and its cultivation. Siegel, Kuhn, Bayer and Lipman consider that critical thinking is a blend of traits (such curiosity, fairness, and open-mindedness) and abilities (like reasoning, argument analysis, and evidence evaluation). This perspective holds that with the right instruction and practice, we can teach critical thinking and foster it in different educational contexts. But Sweller and Willinghum believed that critical thinking is more of a generic talent or natural capacity that everyone possesses from birth and it is unteachable (Ellerton & Dewey, 2022).

Richard Mayer's Cognitive Theory of Multimedia Learning (CTML), which emphasizes the interaction between spoken and visual information, describes how people learn from multimedia sources. The three main concepts of CTML are finite capacity(fixed amount can be stored in it), dual channels (i.e., verbal and visual information is processed in separate channels), and active processing (i.e., integrating and organizing relevant information into coherent structures in long term memory). This theory is also based upon Cognitive load theory and several other theories (Mayer, 2024). John Sweller's Cognitive Load Theory (CLT) presents three types of cognitive load: intrinsic, extraneous, and germane. Cognitive load is vital for educational technologies and instructional design. Educators can improve learning outcomes by reducing extraneous cognitive load and increasing germane cognitive load. Intrinsic cognitive load deals with the inherent complexity of a learning task or concept. Intrinsic cognitive load can be managed by reducing the complexity of information through chunking (dividing complex material into smaller, more manageable units) or by increasing the learners' level of expertise (Sweller, van Merriënboer, & Paas, 2019). Extraneous cognitive load is defined as the mental effort demanded by elements unrelated to the learning objective, such as disorganized instruction or unrelated information. Germane cognitive load represents the mental energy required to transfer information from short-term memory to long-term memory by schema formation (Clark & Kimmons, 2023).

Physical actions like expressions, handling objects and gestures, object manipulation, and bodily movements influence cognitive processes. As a result, cognitive load can be distributed more effectively. On the other hand, in the absence of physical activities the students feel higher cognitive load. Embodied cognition means that thinking and learning are related to physical actions. By connecting thinking and learning with physical actions, an effective instructional frame can be designed, where physical activities help to reduce cognitive load. This shows that physical demand is an indicator of cognitive load (Castro-Alonso et al., 2024). Mental workload is the mental demand of the task, which is influenced by task complexity, environment and human level of expertise. Cognitive load can be managed by controlling these factors carefully. Therefore, it can be inferred that mental demand is an important indicator of cognitive load. (Mohammadian et al., 2022). Managing temporal demand, or time pressure, can enhance task performance by allowing individuals to focus better and make improved results. However, excessive time pressure can lead to increased cognitive load, resulting in errors and reduced level of performance. Balancing temporal demand with effective cognitive load management is necessary for optimizing students learning outcomes (Ren et al., 2025). Performance and cognitive load are interrelated. High unnecessary cognitive load leads to human errors and poor task performance. Studies indicate that high performance is evidence that cognitive load is being managed properly (Ghalenoei et al., 2021). Mental and physical energy utilized to achieve a certain goal or result is known as effort (Halperin & Vigotsky, 2024). Increased effort leads to increased performance, which indicates that applying more effort reduces the cognitive load (Minkley et al., 2021). An increased cognitive load is not only related to frustration but also with anxiety and decreased performance. Greater frustration is reported in higher load conditions than in lower load conditions.

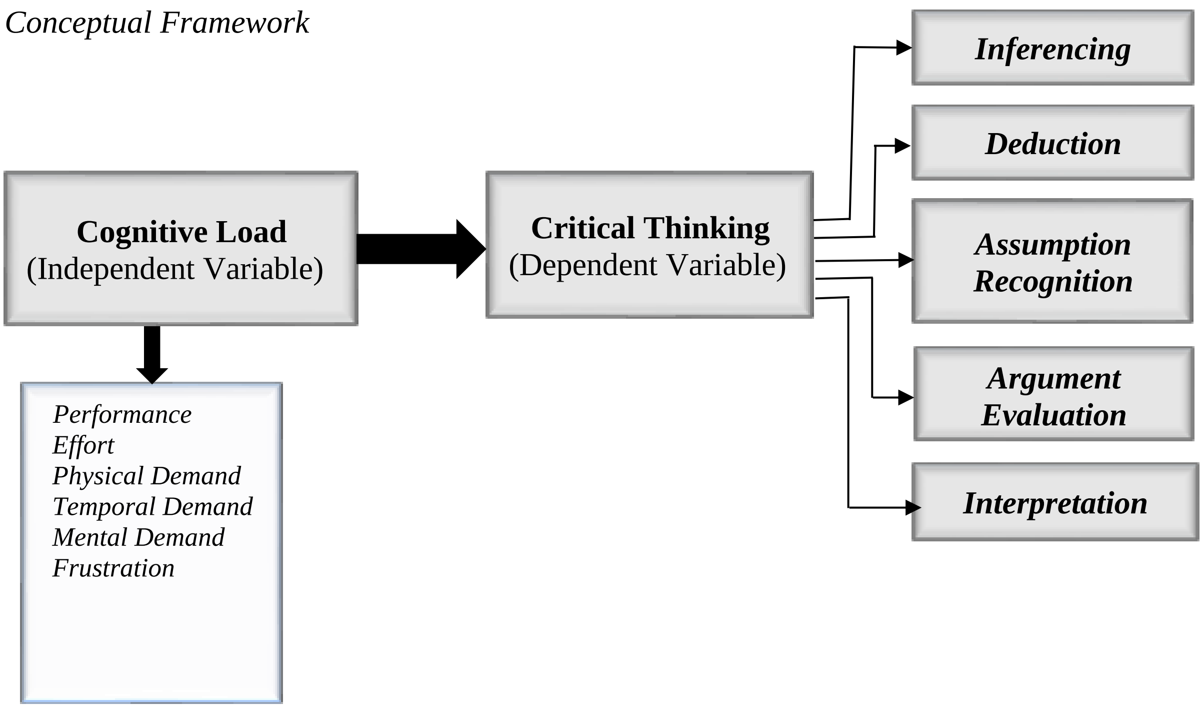
There is brief investigation in literature connecting the effects of cognitive load directly to the cultivation of critical thinking skills in blended learning settings. This area requires further exploration to understand how three types of cognitive load (intrinsic, extraneous, and germane) specifically affect critical thinking development (Vasilaki & Mavrogianni, 2025). While cognitive load theory has been explored flexibly in education, its specific interaction with critical thinking skills in a blended learning environment needs further examination (Feldon et al., 2019). While technology is an important component of blended learning, there are challenges in balancing cognitive load with technology use to foster critical thinking without causing cognitive overload. This includes addressing digital literacy disparities that may hinder the effectiveness of blended learning approaches (Ardianti et al., 2020). Current study highlights the essential role of instructional strategies for cognitive load management and enhancement of human cognitive abilities. In this regard, this study is significant because it expands the understanding of how cognitive load affects critical thinking skills in a blended learning environment. Gaining insight into how cognitive load affects critical thinking skills can result in improved teaching methods that raise student learning outcomes (Yennita and Zukmadini, 2021).

Conceptual Framework

Conceptual framework is a research tool that is either written or visual, explaining the concepts, variables and relationships of the study. It is developed from a literature review and builds the foundation for the research study. Conceptual Framework of the study showing the dimensions of both independent and dependent variables is given in figure 1.

Figure 1

Conceptual Framework



Research Objectives

The objectives of this study are to measure

1. The amount of cognitive load that blended learners encounter during their studies.
2. The level of blended learners' critical thinking skills.
3. The effect of cognitive load on blended learners' critical thinking abilities.

Research Questions

Research questions of the study are stated below.

1.1 What is the amount of cognitive load experienced by blended learners in their studies?

2.1 What critical thinking skills do the blended learners possess?

3.1 What is the level of performance of learners in their studies in blended learning environment?
3.2 What is the level of effort applied by learners while studying in blended learning environment?
3.3 What is the level of mental demand faced by learners during their studies in blended learning environment?
3.4 What is the level of temporal demand faced by learners during their studies in blended learning environment?
3.5 What is the level of physical demand faced by learners during their studies in blended learning environment?
3.6 What is the frustration level of learners during their studies in blended learning environment?

Hypotheses

1. H_{01}: The effect of performance on critical thinking abilities of learners in blended learning environment is not significant.

2. H_{02}: There is insignificant effect of effort on critical thinking skills of learners in blended learning environment.

3. H_{03}: The effect of mental demand on critical thinking skills of learners in blended learning environment is insignificant.

4. H_{04}: Physical demand has insignificant effect on critical thinking skills of learners in blended learning environment.

5. H_{05}: There is no significant effect of temporal demand on critical thinking skills of learners in blended learning environment.

6. H_{06}: Frustration insignificantly affects the critical thinking skills of learners in blended learning environment.

METHODOLOGY

Research Design

The present work is a quantitative research technique grounded in the positivist research paradigm to examine the effect of cognitive load on critical thinking skills in blended learning environment. The study measured cognitive load effect on learners' critical thinking abilities using a is pretest-posttest randomized experimental design, is a type of experiment in which participants are randomly allocated to either the treatment group, which receives an intervention, or the control group, which receives no treatment. The measurement is performed twice: before the treatment and after it (Choueiry, 2021).

Population and Sample

Population of the study was all the educational institutions of district Abbottabad of Hazara division of Khyber-Pakhtunkhwa. To guarantee that there was enough statistical power to identify meaningful effects, the study employed simple random sampling to select the participants. First, a list of all 9th-grade students enrolled in the selected high schools of District Abbottabad was obtained from the school administration. The study selected sample, in which 32 students were selected randomly, ensuring that each student had an equal opportunity to participate in the study. For a comparison, this 32 students sample was divided into experimental group (15 students) and the control group (17 students). Experimental group contained 15 participants while control group had 17 members. Because some students finished the pretest but not the posttest, they were not included in the final analysis, which is why there was a little difference in group size. Since matching scores are necessary for pretest–posttest comparisons, only students with complete data were kept. Research shows that dropout and availability cause unequal group members but it does not invalidate an experiment. A comparatively limited sample size of only 32 students was chosen due to student unavailability. A simple random sample is an arbitrarily chosen subset of a population. Simple random sampling is the simplest probability sampling method because it requires random selection and not much prior knowledge about population. Due to randomization, sample have high internal and external validity, as well as a lower chance of research biases (Thomas, L., 2023). According to the website of center of governance and public accountability (Cgpa, 2025) total number of schools in district Abbottabad are given in table 1.

Table 1

Total Number of Schools in District Abbottabad

	Population			Sample	
Level/No of Schools	**For Boys**	**For Girls**	**Total**	**Experimental Group**	**Control Group**
Primary Schools	993	556	1549		
Middle Schools	88	88	176		
High Schools	66	39	105	15	17
Higher Secondary Schools	14	7	21		
Total	**1161**	**690**	**1851**		

Instrument

Participants' critical thinking abilities were evaluated both before and after the cognitive load intervention using an instrument containing five items representing five dimensions of critical thinking. Aspects of critical thinking are all measured by the instrument based upon assessment tool called Watson Glaser Critical Thinking Appraisal (WGCTA). The validity and reliability of WGCTA have already been confirmed for students in education majors to assess their critical thinking abilities (Gadzella & Gadzella, 2003). WGCTA has internal consistency with Cronbach's alpha 0.74 and confidence interval 0.689 – 0.791. It has strong split half reliability with Spearman Brown coefficient r = 0.78 and Guttman split half coefficient r = 0.78. Factor analysis indicates strong construct validity of this tool. Its subscales are related but distinct which supports construct validity (Hassan & Madhum, 2007). NASA-TLX is valid and reliable tool in the education majors. The re-test reliability coefficients of this scale and its subscales ranges from 0.516 to 0.753 ($p < 0.01$), indicating the scale has good re-test reliability. For NASA-TLX, both the split-half reliability and Cronbach's alpha coefficient are more than 0.80. The scale has good internal consistency. Factor analysis revealed that the scale has strong structural validity (Xiao et al., 2005). Pilot tests were not conducted because of these tools' well-established validity and reliability in education. The acquired data was subjected to reliability and validity tests to confirm that both tools were appropriate for the purpose of this study.

Table 2

Reliability and Validity Statistics for Data Collection Tools

Cognitive Load Rating Scale			**Critical Thinking Test**		
D	**Co**	**Statistics**	**D**	**Co**	**Statistics**
Mental Demand	0.802	Cronbach's α	Assumption Recognition	0.597	Cronbach's α
Temporal Demand	0.841	$\alpha = 0.837$	Argument Evaluation	0.715	$\alpha = 0.911$
Effort	0.891	KMO = 0.74	Deduction	0.796	KMO = 0.769
Frustration	0.770	Bartlett's Test	Interpretation	0.953	Bartlett's Test
Physical Demand	0.187	$\chi^2 = 40.80$	Inferencing	0.884	$\chi^2 = 58.511$
Performance	0.230	$p < 0.001$			$p < 0.001$

Key: **D** = Dimensions **Co** = Correlations

Data Collection

Pretest

In the pretest a WGCTA-based critical thinking test was administered to both control and experimental groups to assess five major dimensions of critical thinking: assumption recognition, argument evaluation, deduction, interpretation, and inference. The test consisted of forty multiple-choice questions. Each of the five dimensions of critical thinking was assessed through eight questions. Each question had one correct answer and was given one mark, making a total score of 40.

Intervention Procedure

When completing online learning exercises, participants reported varied levels of cognitive stress. The study successfully supplied scaffolding to students in order to lower intrinsic and extraneous cognitive load while increasing germane load, which enhances performance. The study aided and provided feedback to students, helping them to focus on relevant topics while reducing distractions. Worked examples are another way to reduce intrinsic and irrelevant cognitive load while boosting relevant load. The study broke down problems into digestible chunks and defined the particular techniques needed to solve them, allowing students to focus their cognitive energies on establishing schemas and critical thinking skills. Students studied the worked examples and then solved similar problems on their own, reducing their mental load through a process known as the fading effect. The transient information effect occurs when students struggle to absorb and remember important data because teachers present it fast or for a short period of time. This often leads to frustration and poor learning outcomes. To reduce this effect, the study presented students with more thorough and consistent information, giving them enough time to absorb and recall the material. Taking advantage of the completion problem effect, the study gave students a partially solved problem and asked them to finish the remaining part, which reduced the cognitive work required to complete assignments.

Another method, the collective memory effect, shortens the time required for a task by allowing pupils to communicate, which not only saves time but also enhances teamwork and collaboration. To minimize the split-attention effect, the study presented all important information on one slide rather than numerous slides, reducing the physical demands of the task and unnecessary cognitive load. All the effects described above are described in cognitive load theory. Only the experimental group received a treatment aimed at reducing cognitive load, whereas the control group participated in unsupervised online learning in a computer laboratory. Cognitive load is handled by offering both face-to-face and offline sessions via recorded lectures. The lessons are distributed to the participants via a WhatsApp group.

Posttest

Following the cognitive load intervention, individuals in both the control and experimental groups retook the test. Each participant's data was collected to assess any gains in their critical thinking skills (assumption recognition, argument evaluation, deduction, interpretation and inferencing).

RESULTS AND INTERPRETATION

The current study analyzed the collected data using variety of statistical techniques using Microsoft Excel and Python programming language. Following the verification of their respective assumptions, descriptive statistics, paired sample t-test, Mann-Whitney U-test and Welch's t-test were used.

The study performed descriptive statistics to describe the collected data of participants about their critical thinking skills as shown in table 3.

Table 3

Both Groups: Descriptive Statistics for Critical Thinking Scores

Group	Test	Mean	SE	Md	Mo	SD	S^2	K	Sk	R
Control	Pretest	17.2	0.94	16.0	15.0	3.89	15.2	- 0.24	0.68	13.0
Control	Posttest	18.8	0.94	18.0	18.0	3.89	15.2	0.24	- 0.27	15.0
Experimental	Pretest	15.8	0.78	15.0	13.0	3.00	9.03	- 0.57	0.75	9.00
Experimental	Posttest	28.7	1.10	29.0	37.0	7.73	59.8	- 1.64	- 0.15	21.0

Key: **SE** = Standard Error, **Md** = Median, **Mo** = Mode, **SD** = Standard Deviation, S^2= Variance, **K** = Kurtosis, **Sk** = Skewness and **R** = Range.

Table 3 shows various statistical measures of overall critical thinking scores in pretests and posttests of participants in both control and experimental groups.

Table 4

Control Group: Level of Critical Thinking Skills

Dimensions	Pair	Mean	N	SD	df	t	P
Assumption Recognition	Pretest	3.176	17	1.510	16	-4.243	0.001
	Posttest	5.118	17	1.409			
Argument Evaluation	Pretest	4.118	17	1.495	16	0.899	0.382
	Posttest	3.765	17	1.602			
Deduction	Pretest	4.000	17	1.500	16	0.566	0.579
	Posttest	3.765	17	1.715			

Interpretation	Pretest Posttest	4.000 3.765	17 17	1.500 1.715	16	0.566	0.579
Inferencing	Pretest Posttest	1.529 1.824	17 17	0.875 1.590	16	-0.814	0.428

Table 4 shows the results of paired sample t-test. Table shows the mean scores of each dimension of critical thinking in both pretest and posttest, indicating that there is no statistically significant improvement across four dimensions of critical thinking (p-value > 0.05). The mean score for assumption recognition in pretest is 3.176 while in posttest it is 5.118, indicating that assumption recognition is the only dimension which was improved in the posttest as indicated by p-value < 0.05.

Table 5

Control Group: Improvement in Overall Critical Thinking Scores

Overall Scores	Pair	Mean	N	SD	Df	t	P
Critical Thinking Scores	Pretest Posttest	17.18 18.82	17 17	3.89 3.89	16	1.7116	0.1063

Table 5 reveals that the p-value is greater than 0.05, hence the null hypothesis that there is no significant change between the pretest mean (17.18) and posttest mean (18.82) of critical thinking scores among control group participants cannot be rejected. This means that students in the control group exhibited no significant improvement in their overall critical thinking score.

Figure 2

Line Chart (Control Group)

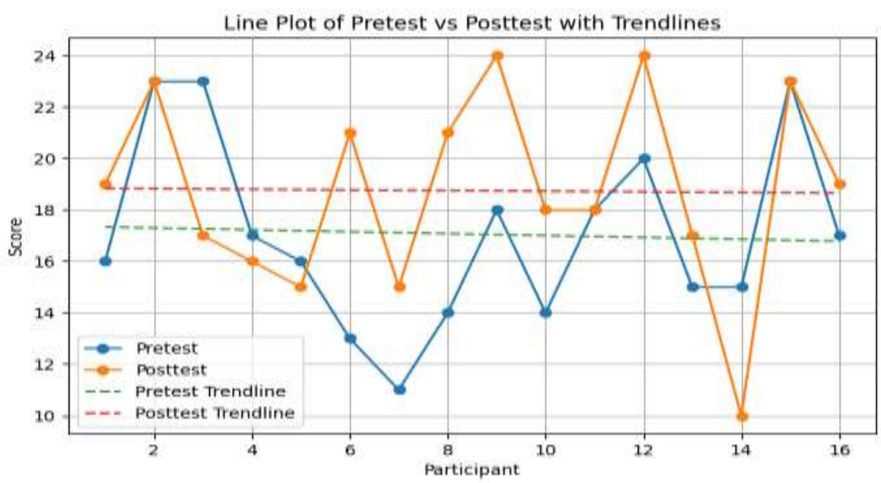


Table 6

Experimental Group: The Level of Critical Thinking Skills

Dimensions	Pair	Mean	N	SD	df	t	p
Assumption Recognition	Pretest	3.20	15	1.082	14	-8.367	8×10^{-8}
	Posttest	6.53	15	1.302			
Argument Evaluation	Pretest	3.53	15	1.186	14	-3.462	0.004
	Posttest	5.67	15	1.633			
Deduction	Pretest	3.27	15	1.334	14	-3.259	0.005
	Posttest	5.87	15	2.264			
Interpretation	Pretest	4.13	15	1.552	14	-3.855	0.002
	Posttest	6.33	15	1.718			
Inferencing	Pretest	1.67	15	0.724	14	-5.350	1×10^{-4}
	Posttest	4.27	15	1.944			

Table 6 shows the results of paired sample t test. The study selected this test because difference scores of all the five dimensions of critical thinking were normally distributed. The exam was designed to determine whether there was significant improvement in the experimental group students' critical thinking skills before and after the intervention. The table shows the mean scores for all five dimensions of critical thinking in both pretest and posttest. The p-value < 0.05 is indicating a statistically significant improvement in all.

Table 7

Experimental Group: Improvement in Overall Critical Thinking Scores

Overall Scores	Test	Mean	N	SD	t	p
Critical Thinking Scores	Pretest	15.80	17	3.00	-5.3831	0.0001
	Posttest	28.67	17	7.73		

The paired samples t-test produced a p-value less than 0.05, indicating a statistically significant difference between pretest and posttest scores in the experimental group. This shows that the intervention improved pupils' critical thinking ability. A p-value much less than 0.05 implies a high statistically significant improvement in mean scores of overall critical thinking scores (15.80 to 28.67 as shown in table 7).

Figure 3

Line Chart (Experimental Group)

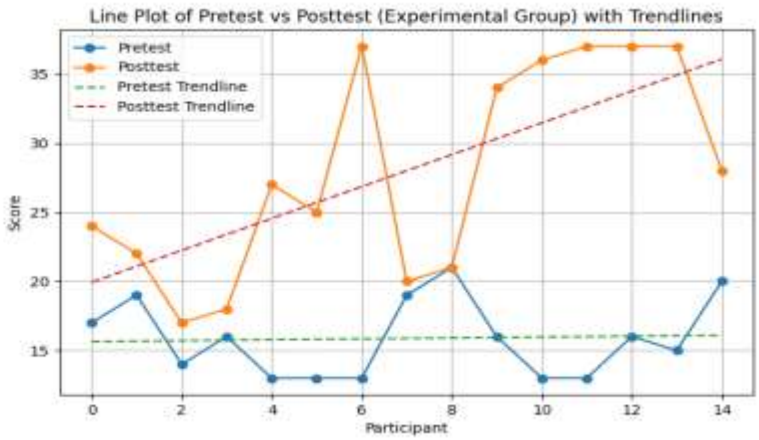


Table 8

Difference in Overall Scores in Pretests of Both Groups

Overall Scores	Group	Mean	N	SD	T	p
Critical Thinking Scores	Experimental	15.80	15	3.00	99.0	0.286
	Control	17.18	17	3.89		

The study performed Mann-Whitney U test to predict the difference between pretest scores of both groups. As p value is greater than 0.05, the null hypothesis that there is no significant difference between the distributions of scores of two groups cannot be rejected (p-value > 0.05) and the alternative hypothesis that there is a statistically significant difference between the distribution of scores of the control and experimental groups cannot be accepted (see table 8).

Table 9

Difference in Overall Scores in Posttests of Both Groups

Overall Scores	Group	Mean	N	SD	df	t	p
Critical Thinking Scores	Experimental	28.67	15	7.73	20	4.456	0.002
	Control	18.82	17	3.89			

The research study employed **Welch's t-test** to predict the difference because assumption of homogeneity of variances did not exist. As the p value is much less than 0.05, the null hypothesis that there is no significant difference between the posttest scores of experimental and control groups can be rejected (see table 9). Posttest mean (28.67) for students in experimental group is statistically significantly different from posttest mean (18.82) of students in control group. This shows greater improvement in experimental group compared to the control group.

Table 10

Both Groups: Level of Critical Thinking Skills in Pretest

Dimensions	Test	Group	$\overline{x}$	n	SD	df	t	P
Assumption Recognition	Independent Samples T-Test	Control	3.18	17	1.51	30	-0.05	0.96
		Experimental	3.2	15	1.08			

Argument Evaluation	Mann-Whitney U-Test	Control	4.12	17	1.48		165	0.151
		Experimental	3.6	15	1.29			
Deduction	Independent Samples T-Test	Control	4.00	17	1.5	30	1.45	0.157
		Experimental	3.27	15	1.33			
Interpretation	Mann-Whitney U-Test	Control	4.35	17	1.37		120	0.800
		Experimental	4.47	15	1.49			
Inferencing	Mann-Whitney U-Test	Control	1.59	17	0.92		114	0.578
		Experimental	1.67	15	0.69			

An independent samples t-test can be performed to evaluate whether the pretest scores of the two groups differ significantly, provided the data is normally distributed. However, when the assumption of normality was violated, the study employed the non-parametric Mann-Whitney U test to compare the groups. If the p-value exceeds 0.05, the null hypothesis that there is no significant difference between the two groups' pretest scores cannot be rejected. As p-value for all five dimensions of critical thinking are greater than 0.05, the null hypothesis cannot be rejected. It means that the pretest results for all five dimensions of critical thinking are statistically similar across the control and experimental groups (see Table10).

Table 11

Both Groups: Level of Critical Thinking Skills in Posttests

Dimensions	**Test**	**Group**	$\bar{x}$	**n**	**SD**	df	**t**	**p**
Assumption Recognition	Mann-Whitney U-Test	Control	5.12	17	1.35	-	53.5	0.004
		Experimental	6.67	15	1.35			
Argument Evaluation	Independent Samples T-Test	Control	3.76	17	1.60	30	-3.32	0.002
		Experimental	5.67	15	1.63			
Deduction	Mann-Whitney U-Test	Control	3.76	17	1.82	-	61.0	0.012
		Experimental	6.40	15	2.03			
Interpretation	Mann-Whitney U-Test	Control	4.35	17	2.07	-	196	0.008
		Experimental	6.60	15	1.50			
Inferencing	Mann-Whitney U-Test	Control	1.82	17	1.56	-	210	0.002
		Experimental	4.67	15	1.59			

If the p-value is less than 0.05, the null hypothesis, which states that there is no significant difference between the two groups' posttest scores, can be rejected. Table 11 shows that the p-value for all five dimensions in both groups is much less than 0.05, indicating that the posttest scores of both groups are significantly different for all five dimensions of critical thinking.

Table 12

Experimental Group: Cognitive Load Management

Dimensions	Pair	Mean	N	SD	df	t	p
Mental Demand	Pretest	70.67	15	16.78	14	3.48	0.004
	Posttest	46.33	15	24.38			
Physical Demand	Pretest	53.67	15	17.67	14	-1.85	0.086
	Posttest	44.67	15	30.19			
Temporal Demand	Pretest	60.33	15	22.40	14	-1.28	0.222
	Posttest	49.33	15	21.87			
Performance	Pretest	50.00	15	19.09	14	1.67	0.117
	Posttest	63.67	15	30.79			
Effort	Pretest	57.67	15	18.41	14	-2.63	0.020
	Posttest	43.00	15	23.44			
Frustration	Pretest	64.00	15	21.73	14	-2.19	0.046
	Posttest	45.33	15	23.71			

Table 12 shows that NASA-TLX subscale scores for the experimental group were compared between the pretest and posttest using a series of paired-sample t-tests because difference scores for all six dimensions of cognitive load were normally distributed. The results showed a significant reduction in mental demand, effort and frustration from the pretest to the posttest (Mental Demand: $t = -3.48$, $p = 0.00$; Effort: $t = -2.63$, $p = 0.02$; Frustration: $t = -2.19$, $p = 0.04$). Participants' perceptions of their performance, physical demand, and temporal demand did not show statistically significant changes ($p > 0.05$). Even though participants did not perceive a significant improvement in their task performance, overall critical thinking scores improved in the posttest, indicating that decreases in mental demand, effort, and frustration may have contributed to improved critical thinking performance.

Results show that when the mental demand of a task is reduced, participants experience less frustration and require less effort to complete the task, leading to improved student performance. This clearly shows that when cognitive load is managed effectively, students focus more on the task, and their level of engagement in learning activities increases. As a result, students can utilize more cognitive resources for critical thinking. Ultimately, this enhances performance and improves student learning outcomes. It is evident that, in a blended learning context, cognitive load management is crucial for better cognitive performance.

Table 13

Experimental Group: Cognitive Load Management

Dimensions	Pair	Mean	N	SD	df	t	p
Mental Demand	Pretest	60.00	17	25.65	16	-0.489	0.632
	Posttest	58.24	17	26.68			
Physical Demand	Pretest	38.82	17	28.97	-	0.89	0.370

	Posttest	42.35	17	28.50		(Z VALUE)	
Temporal Demand	Pretest	54.12	17	34.15	16	1.204	0.246
	Posttest	63.82	17	23.49			
Performance	Pretest	70.00	17	21.67	16	0.919	0.372
	Posttest	72.35	17	20.70			
Effort	Pretest	58.82	17	30.21	-	-1.47 (Z VALUE)	0.142
	Posttest	52.35	17	26.76			
Frustration	Pretest	45.29	17	35.84	16	1.454	0.165
	Posttest	55.00	17	29.93			

A paired-samples t-test was used to compare the mean scores of participants in the control group at pretest and posttest. However, when the assumption of normality of difference scores was not met, the Wilcoxon Signed-Rank Test was performed. The Wilcoxon Signed-Rank Test provides a *z* value instead of a *t* value. Table 13 shows that there were no statistically significant changes ($p > 0.05$) between the pretest and posttest mean scores across any of the six dimensions of cognitive load. Although slight increases and decreases were observed, these were not large enough to reach statistical significance. As cognitive load was not managed in the control group, no significant changes in cognitive load were observed.

Table 14

Status of Hypotheses: Acceptance/Rejection

Hypotheses		**Accepted/Rejected**	**Sig.**
Null	H_{01}	Accepted	$p > 0.05$
Alternative	H_1	Rejected	
Null	H_{02}	Rejected	$p < 0.05$
Alternative	H_2	Accepted	
Null	H_{03}	Rejected	$p < 0.05$
Alternative	H_3	Accepted	
Null	H_{04}	Accepted	$p > 0.05$
Alternative	H_4	Rejected	
Null	H_{05}	Accepted	$p > 0.05$
Alternative	H_5	Rejected	
Null	H_{06}	Rejected	$p < 0.05$

Alternative	H_6	Accepted

It is clear from table 14 that three null and three alternative hypotheses are accepted in the study.

DISCUSSION

This study determines the effect of cognitive load on learners' critical thinking abilities in a blended learning environment. The findings revealed that cognitive load had significant effect on learners' critical thinking abilities, particularly after the use of teaching methods that regulate cognitive load. To participate in blended learning, students must have a wide range of critical thinking abilities, particularly to interact with a variety of digital data (Indah & Kusuma, 2016) and make evaluative judgments about digital content (Boud & Soler, 2016). In addition, they must show reflective practice through interaction in the process of distance learning (Tai et al., 2018). Even though the students during lectures can observe teachers' illustrating or displaying problem-solving procedures in offline classrooms, they must be more adaptable in blended learning mode. The reason for this is that process of thinking is constantly refined in order to improve one's critical thinking abilities (Paul and Elder, 2019). Obtaining these abilities is challenging since it needs extensive application and practice, which can be impeded by weak metacognitive abilities or a narrow mindedness that thinking is difficult and exhausting (Persky et al., 2019).

The study employed worked examples, completion tasks, scaffolding, and quick feedback which all have been found to be effective instructional methods to manage cognitive load. Worked examples, in particular, helped to minimize the unnecessary load by converting complex activities into small easy steps., allowing learners to focus on comprehending and internalizing knowledge rather than problem-solving under pressure (Chen et al., 2023). The current study also emphasizes collaborative human-AI pedagogy. AI-powered solutions, such as intelligent tutoring systems, adaptive learning platforms, and automated assessment technologies, are supplementing conventional teaching methods. While artificial intelligence improves administrative efficiency and tailored teaching tasks, technology does not replace human components of education such as emotional intelligence, critical thinking, and ethical reasoning. Instead, AI acts as a co-facilitator, helping teachers create flexible, student- oriented learning contexts (Qureshi, 2025). This study supports prior research that shows that cognitive load can be efficiently handled through blended learning, which allows students to interact with technology while also collaborating with human teachers. Blended learning decreases needless cognitive load while enhancing germane load, resulting in successful learning when the teacher gives direction, quick feedback, and prompt support.

Cognitive offloading through AI tools involves assigning tasks such as memory retention, decision-making, and information retrieval to external systems (Risko & Gilbert, 2016). Sparrow et al. discovered that regular use of search engines affected users' ability to remember content autonomously, with students focusing more on finding information instead of information itself. Furthermore, cognitive offloading using AI tools may lead to a decrease in cognitive engagement. As AI technologies automate everyday jobs and deliver ready-made solutions, people may become less likely to participate in critical thinking and problem solving (Sparrow et al., 2011). The current study conducted the critical thinking test twice. As an intervention procedure, the study used worked examples to break down complicated critical thinking content into manageable bits.

Similarly, in the completion tasks, the study provided partially solved questions. Participants then completed the questions on their own. These treatments not only eliminated cognitive offloading as well as extraneous load and intrinsic load, but also increased germane load. As a result, the pupils completed the second test more quickly and performed better than the first.

According to cognitive load theory, working memory has a finite capacity that can be overwhelmed by excessive information, limiting learning and decision-making. Similarly, students who are overwhelmed with information from social media struggle to determine what is true which has an impact on both their personal and academic lives (Nuralmi et al., 2024). The same concepts were also supported by this study. To properly manage information overload, instructional design should follow Cognitive Load Theory (CLT). Skills like argument evaluation, interpretation and inferencing, assumption recognition and deduction are effective for assessing the validity and strength of evidence. In this study, students in the experimental group successfully learned critical thinking skills as evidenced by their high marks.

Performance based measures can also be used to measure cognitive load. The basic assumption of performance measures is that overloading working memory capacity might impair learning, resulting in a reduction in performance (Paas and Merriënboer, 1994). In this study participants in the experimental group showed improvement in their performance after intervention which included cognitive load management. This showed that in study participants felt less cognitive load during the posttest which affected the results.

CONCLUSIONS

Based on the results, it was concluded that cognitive load had a significant effect on learners' critical thinking skills in a blended learning environment. This study proves that unnecessary cognitive load hinders learning, whereas effective cognitive load management improves learning. Intervention procedures of the study successfully improved students ‘critical thinking abilities, however, it is worth mentioning that the students in both groups showed similar level of critical thinking skills at the outset. Worked examples, completion tasks, quick feedback, and scaffolding were among the teaching strategies used to regulate cognitive load in accordance with cognitive load theory. Furthermore, the blended learning environment, which included offline video sessions shared via a WhatsApp group, helped learners better manage their time, lowering cognitive load. The blended learning concept also included face-to-face sessions. The study concluded that these intervention measures for regulating cognitive load helped learners enhance their critical thinking skills.

RECOMMENDATIONS

Blended learning environments combine online and in-person training to provide flexible, learner-centered experiences. However, enhancing these settings necessitates paying close attention to learners' cognitive load and critical thinking processes. Integrating behavioral and physiological variables can help to personalize learning and improve outcomes.

1. Instructors should divide content into smaller, more manageable bits to prevent overwhelming students.
2. Using scaffolding (e.g., guided prompts, feedback loops) to progressively increase complexity can help teachers to deliver complex topics.
3. To reduce unnecessary load, visual and multimedia design should avoid redundancy and instead emphasize relevancy. Teachers must apply this practice in the actual classrooms to increase germane load and decrease extrinsic and intrinsic load.

4. Institutional heads and teachers should incorporate problem-based learning activities and case studies that promote analysis, synthesis, and evaluation.
5. Teachers should facilitate synchronous and asynchronous debates that question assumptions and necessitate evidence-based thinking. These practices greatly help in developing critical thinking skills among learners in blended learning settings.

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