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The Impact of Nonlinear Learning on Cognitive Load in Student Rock Climbers: A Comparison of Theoretical and Practical Tasks

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Abstract

This study investigated the comparative effects of nonlinear and linear pedagogical approaches on theoretical knowledge acquisition and practical sport climbing performance. A total of 157 university students were randomly assigned to either a nonlinear or linear learning condition. Theoretical knowledge was measured using a standardized test, practical skills were evaluated through International Federation of Sport Climbing (IFSC) competition scoring, and cognitive load was assessed using the Cognitive Load Scale. Results from a one-way analysis of variance (ANOVA) indicated that participants in the nonlinear learning environment achieved significantly higher theoretical knowledge, $F(1, 198) = 26.43$, $p < .01$, and demonstrated improved practical climbing performance, $F(1, 198) = 9.30$, $p < .01$. Correlation analyses revealed positive associations between nonlinear environments and germane load for theoretical tasks ($r = .179$, $p = .0028$) and practical tasks ($r = .358$, $p < .01$). A negative correlation between knowledge application and learning environment ($r = -.206$, $p = .001$) suggested that nonlinear learning more effectively supports higher-order application skills. Nonlinear environments were also linked to increased germane load ($r = .179$, $p = .0028$) and reduced extraneous load ($r = -.182$, $p = .001$). Overall, findings indicate that nonlinear learning enhances both theoretical and practical outcomes through greater cognitive engagement and personalization. Educators are encouraged to integrate nonlinear elements into instructional design, and future research should examine these impacts longitudinally across diverse subjects.

Introduction

The educational landscape has long emphasized the importance of optimizing learning environments to enhance cognitive processing and skill acquisition. Cognitive load theory (CLT), introduced by Sweller (1988),

has played a pivotal role in understanding the constraints of human cognitive architecture and their implications for instructional design. CLT distinguished three types of cognitive load: intrinsic load, which reflects the inherent complexity of the material; extraneous load,

which arises from the manner in which information is presented; and germane load, which involves the cognitive effort required to process and integrate information into long-term memory (Sweller et al., 2011). Effective instructional strategies aim to balance these loads to facilitate optimal learning.

In skill-based learning, traditional linear learning environments have long dominated, characterized by structured, sequential presentation of content. Recent pedagogical advancements, however, highlight the benefits of nonlinear learning environments. Nonlinear pedagogy, which emphasizes flexibility and learner autonomy, enables students to engage with content in a self-directed manner (Chow et al., 2023). This approach aligns with constructivist theories of learning, which advocate active engagement and knowledge construction through exploration and discovery. Empirical studies (Chow et al., 2021; Lee et al., 2014) demonstrate that nonlinear learning environments accommodate individual differences and promote deeper engagement, particularly in physical education and skill development contexts.

The dichotomy between theoretical knowledge learning and practical skill learning presents unique challenges for cognitive load management. Theoretical learning, often situated in classroom settings, involves comprehension and memorization of abstract concepts, whereas practical skill learning requires hands-on practice, feedback, and refinement techniques. Sports learning theories emphasize repeated practice and technique refinement, as critical for skill acquisition in activities such as rock climbing (Blakely et al., 2021).

Rock climbing, with its blend of theoretical knowledge and practical skill requirements, provides an ideal context for examining the effects of different learning environments on cognitive load and performance. Theoretical aspects include understanding techniques, safety protocols, and route planning, while practical aspects involve physical execution, coordination, and real-time decision-making. Research in this area offers valuable insights into how instructional design influences learning outcomes.

Although rock climbing demands a high degree of physical proficiency (Maciejczyk et al., 2021), emerging research underscores the critical role of cognitive processes in performance, particularly in task adaptation and learning (Orth et al., 2018; Vasile et al., 2022). The ability to manage cognitive resources while executing complex movements is hypothesized to differentiate novice from expert climbers. This gap in understanding

motivates further investigation into how different climbing tasks influence cognitive load (Blakely et al., 2021).

Objectives

This study aims to examine the effects of nonlinear and linear learning environments on the acquisition of theoretical knowledge and practical sport climbing skills. In addition, it seeks to investigate the cognitive load associated with these learning environments and task types. Specifically, the study analyzes how the theoretical knowledge tasks (e.g., understanding and memorizing abstract concepts) and practical sport skill tasks (e.g., executing and coordinating climbing movements) influence intrinsic, extraneous, and germane cognitive load. By comparing the differential impacts of nonlinear and linear learning environments on these forms of cognitive load, the research contributes to a deeper understanding of how instructional design and task characteristics shape learning outcomes.

This study seeks to compare the effects of nonlinear and linear learning environments on theoretical knowledge acquisition. This includes how these environments influence learning outcomes related to understanding and memorizing abstract concepts, principles, and information. This objective is grounded in the hypothesis that nonlinear environments—due to their flexibility and learner-centered structure—will lead to better theoretical knowledge acquisition by reducing intrinsic load and enhancing germane load.

The research objectives are as follows:

(1) To quantify the cognitive load experienced by student rock climbers during both theoretical knowledge acquisition and practical rock climbing practice utilizing the Cognitive Load Scale.

(2) To compare the levels of cognitive load elicited by theoretical knowledge tasks and practical climbing tasks among novice to intermediate-level student climbers using analysis of variance (ANOVA).

(3) To determine whether differences in cognitive load between these task types correlate with performance metrics on subsequent climbing routes.

Literature review

Nonlinear Learning

Nonlinear learning refers to an educational approach in which learners engage with content in a flexible, non-sequential manner that encourages exploration and self-directed learning (Chow et al., 2021).

In physical education contexts, nonlinear pedagogy enables students to interact with learning materials according to their individual needs and preferences, supporting a more personalized learning experience (Machado et al., 2018). In contrast, traditional skill instruction typically relies on linear learning methods, characterized by structured progression from simple to complex tasks with extensive repetition (e.g., drilling specific footwork techniques). However, research indicates that nonlinear pedagogical approaches—emphasizing exploratory movement, problem-solving, and contextual interference—can foster more robust and adaptable motor skills (Shapiro, 2008; Lee et al., 2014).

Cognitive Load in Behavioral Science

Cognitive Load Theory (CLT; Sweller, 1988) posits that learning efficiency is optimized when the demands on working memory are aligned with the learner's available cognitive resources. In skill acquisition, particularly in complex domains such as rock climbing, excessive cognitive load can impede performance and hinder the formation of stable schemas (He et al., 2022). Rock climbing presents substantial cognitive demands, requiring individuals to simultaneously process perceptual information about route features, plan movement sequences, regulate physical exertion, and maintain spatial awareness (Vasile et al., 2022). Effective instructional design therefore seeks to reduce extraneous load while optimizing intrinsic and germane loads to support efficient learning (Paas et al., 2010). CLT provides a critical framework for understanding how different teaching methods can either facilitate or constrain cognitive processing and learning outcomes (Kalyuga et al., 2010).

“Theoretical” vs. “Practical” Tasks

Theoretical knowledge tasks involve understanding and memorizing abstract concepts, principles, and information. The intrinsic load associated with these tasks is determined by the complexity and abstractness of the material. According to Sweller et al. (2011), theoretical tasks can impose high intrinsic cognitive load when the content is dense or conceptually demanding. Extraneous load in theoretical learning is influenced by the clarity and structure of instructional materials; well-organized presentations can reduce unnecessary cognitive effort and support more efficient processing.

Practical tasks, such as those involved in rock climbing, require physical execution and procedural memory, demanding coordination, precision, and real-time decision-making. Intrinsic load in these tasks

is shaped by the inherent difficulty of climbing techniques and movements. Practical tasks may also generate substantial extraneous load when instructions or demonstrations are unclear or when the learning environment contains distracting elements. Germane load is strengthened through repeated practice and feedback, which support the automation of skills and the development of muscle memory (Paas & Sweller, 2012). Practical skill learning in rock climbing involves developing both physical and cognitive abilities through structured practice and targeted feedback (Schmidt & Mamede, 2020). Effective skill acquisition requires repeated practice to refine techniques and improve motor control (Ericsson, 2020). This includes learning specific movement patterns, enhancing hand-eye coordination, and building muscle memory (Draper et al., 2011). Feedback plays a critical role by enabling climbers to adjust their techniques and improve performance over time (Macnamara & Maitra, 2019). The integration of cognitive strategies with physical practice is essential for mastering complex skills required in climbing (He et al., 2022).

Measurement of Cognitive Load and Practical Skills in Rock Climbing

Accurate measurement of cognitive load is crucial for evaluating instructional effectiveness and understanding learners' mental processes. Multiple methods have been developed to assess cognitive load, including subjective self-report scales, physiological indicators, and performance-based metrics (Sweller et al., 2011). Paas et al. (2010) introduced a widely used nine-point subjective rating scale that has been validated across numerous studies for its reliability and simplicity. This scale allows learners to report their perceived mental effort, providing insights into cognitive load during task performance (Leppink et al., 2013). In addition, advancements in neuroimaging and eye-tracking technologies offer objective measures of cognitive load by monitoring brain activity and visual attention patterns (Brünken et al., 2010).

Assessing practical skills in rock climbing requires evaluating both the physical execution and technical proficiency of climbers (Maciejczyk et al., 2021). Traditional assessment methods include observational checklists and standardized scoring systems, such as those developed by the International Federation of Sport Climbing (IFSC), which assess speed, accuracy, and technique (Draper et al., 2011).

Nonlinear learning environments are expected to

support more effective acquisition of theoretical knowledge and practical sport skills than linear learning environments (Chow et al., 2023). This expectation is grounded in the premise that nonlinear environments allow learners to navigate and select materials according to their individual needs and preferences, potentially reducing cognitive load and enhancing engagement (Chow et al., 2021; Lee et al., 2014). In contrast, linear learning environments may be less responsive to individual learner differences, which can result in less effective learning outcomes (Sweller et al., 2011).

Conceptual framework

Independent Variables: Learning Approach (Categorical)

The study examines two types of learning environments: nonlinear and linear. Nonlinear learning environments are characterized by flexibility, learner autonomy, and a non-sequential approach to content interaction, encouraging self-directed learning and exploration (Chow et al., 2021; Lee et al., 2014). This approach aligns with constructivist theories, which emphasize active learner engagement and knowledge construction through exploration and discovery (Shapiro, 2008). In contrast, linear learning environments follow a structured, sequential presentation of content, requiring all learners to follow a predetermined path (Sweller et al., 2011). This traditional approach is less adaptive to individual learner needs and preferences.

Dependent Variables

Cognitive Load (Continuous)

Cognitive load is defined as the mental effort required to perform a learning task and is measured using the Cognitive Load Scale. This variable reflects the demands placed on working memory during both theoretical and practical tasks.

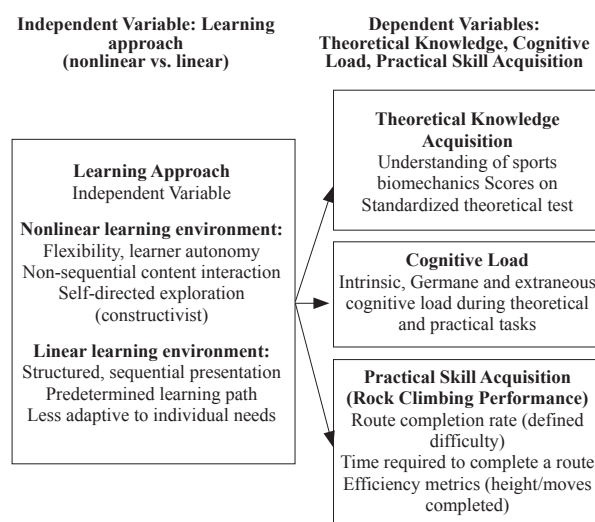
Theoretical Knowledge Acquisition

Theoretical Knowledge is assessed by measuring learner's understanding of sports biomechanics. It is operationalized as scores on a standardized theoretical knowledge test.

Practical Skill Acquisition (Rock Climbing Performance)

Practical skill acquisition is operationalized through quantifiable measures based on the International Federation of Sport Climbing (IFSC) competition scoring system. These include the successful completion rate of routes of a defined difficulty, time required to complete a route, and efficiency metrics such as number of heights or moves completed.

The independent variables are the types of learning environments: nonlinear learning environments, characterized by flexibility and learner autonomy, and linear learning environments, characterized by structured, sequential content presentation (Paas & Sweller, 2012; Lee et al., 2014). The dependent variables are the learning outcomes, specifically the acquisition of theoretical knowledge and practical sports skills.



Note: The present study focuses on the direct effects of learning approach on cognitive load and learning outcomes; potential indirect or mediating relations are acknowledged but were not formally test in the current analysis

Figure 1 Conceptual framework: Effects of nonlinear vs. linear learning approach on cognitive load, theoretical knowledge, and sport climbing performance

Hypotheses

Hypothesis 1

H_0 : There is no significant difference in the acquisition of theoretical knowledge content between students in nonlinear learning environments and those in linear learning environments.

H_1 : Students in nonlinear learning environments will demonstrate significantly better acquisition of theoretical knowledge content compared to those in linear learning environments.

Hypothesis

H_0 : There is no significant difference in the acquisition of practical sports skills, such as rock climbing, between students in nonlinear learning environments and those in linear learning environments.

H_1 : Students in nonlinear learning environments will have significantly better acquisition of practical sports skills compared to those in linear learning environments.

Research methodology

This study employed a one-factor experimental design to examine the effects of nonlinear and linear learning environments on cognitive load, theoretical knowledge acquisition, and rock-climbing skill performance. The independent variable was the type of learning environment, with two levels: nonlinear and linear. All participants completed both types of learning tasks: (a) theoretical knowledge acquisition; and (b) climbing skill performance, within the learning environment to which they were assigned.

Participants were randomly assigned to one of the two groups:

Group 1: Nonlinear Learning Environment + Theoretical Knowledge Task + Rock Climbing Task

Group 2: Linear Learning Environment + Theoretical Knowledge Task + Rock Climbing Task

Participants underwent a three-week instructional program designed to teach foundational rock-climbing skills. At the end of the instructional period, cognitive load, theoretical learning acquisition, and practical climbing performance were assessed. Comparisons between the two groups allowed the study to determine how different learning environments influenced cognitive load, theoretical knowledge outcomes, and practical skill performance.

Population and samples

The target population for this study consisted of university students aged 19–26 years who had prior experience in rock climbing. This age range ensured that participants were within a developmental stage in which physical and cognitive abilities are relatively stable. To control for physical fitness that may influence climbing performance, participants were also required to have a body mass index (BMI) within the healthy range of 18.5–24.9.

Random sampling was used to select participants from the eligible university student population, ensuring that each individual had an equal chance of being included and reducing sampling bias. The participants were then randomly assigned to either the nonlinear or linear learning environment group enhancing internal validity by ensuring comparable baseline characteristics.

The required sample size was calculated using G*Power software. Using a medium effect size (Cohen's $d = 0.25$) an alpha level of .05, and a desired statistical power of 0.95, the analysis indicated a minimum sample size of 142 participants. To strengthen reliability, random sampling was extended to include 157 participants in

total, with 78 assigned the nonlinear learning environment and 79 to the linear learning environment.

Research instruments

Cognitive load scale

Cognitive load was measured using a modified version of the Cognitive Load Scale grounded in Cognitive Load Theory (Paas & Sweller, 2012; Leppink et al., 2014). This adapted scale, previously validated across multiple studies, assessed intrinsic, extraneous, and germane cognitive load experienced during learning. Participants completed the scale immediately after each instructional session to capture their perceived mental effort.

Practical skill performance assessment (IFSC Scale)

Practical climbing performance was evaluated using a simulated competition format based on the scoring criteria of the International Federation of Sport Climbing (IFSC). Three IFSC-certified judges independently scored each participant's performance, assessing route completion, technical movement quality, safety practices, and overall execution. The final performance score was calculated as the average rating of the three judges' ratings, with strong inter-rater reliability. (Intraclass Correlation Coefficient (ICC) = .92)

Theoretical knowledge test

A comprehensive test consisting of multiple-choice and short-answer questions was used to assess participants' understanding of sports science, particularly biomechanics principles. The test covered essential aspects of rock climbing, including rope management, belaying techniques, route reading, and training program design. Three experts in physical education and exercise science reviewed the test items to ensure content validity. The instrument demonstrated strong internal consistency (Cronbach's $\alpha = .85$).

Data analysis

Before conducting the analyses, the assumptions for ANOVA were examined. Normality was assessed to ensure that the distribution of the dependent variable was approximately normal within each group. Homogeneity of variances was evaluated to confirm that the variances across groups were comparable. Independence of observations was also verified. Meeting these assumptions ensured the validity and reliability of the ANOVA results.

A repeated measures ANOVA was used to examine the effects of the learning environment (nonlinear vs. linear) on cognitive load and performance outcomes

across both theoretical knowledge and practical sports skills tasks.

Hypothesis 1

A one-way ANOVA was conducted to determine whether there was a significant difference in the theoretical knowledge acquisition between the nonlinear and linear learning environment groups.

Dependent Variable: Theoretical knowledge acquisition

Independent Variable: Type of learning environment (nonlinear vs. linear)

Hypothesis 2

A one-way ANOVA was conducted to whether there was a significant difference in the practical sports climbing skills acquisition between the two learning environment groups.

Dependent Variable: Practical sports climbing skills acquisition

Correlation Analysis

Pearson's correlation coefficient was used to examine the linear relationships between the type of learning environment (Renshaw et al., 2015) and the cognitive load dimensions (Leppink et al., 2013), as well as between these cognitive load dimensions and learning outcomes (theoretical knowledge acquisition and practical sports skills acquisition). Correlation coefficients were computed to determine the strength and

direction of these relationships, and significance levels were assessed using p-values.

Results

Descriptive statistics

Descriptive statistics, illustrated in the box plot in Figure 2, were calculated for each type of cognitive load (intrinsic, extraneous, and germane) and for each performance measures (Knowledge Understanding and Memory, Knowledge Application, and IFSC Skill Performance) across the two learning environments (nonlinear and linear). Means and standard deviations were computed to summarize central tendency and variability for all variables.

Levene's test results indicate that the assumption of homogeneity of variances was met for most variables, as the significance values (p-values) exceeded .05. Extraneous Load showed a p-value of .050, which lies at the threshold of significance and suggests marginal evidence of heterogeneity.

In contrast, IFSC Skill Performance yielded a significant Levene's test result ($p = .024$), indicating unequal variances between groups for this. Therefore, the ANOVA results for IFSC Skill Performance were interpreted using the robust statistical alternative, Welch's ANOVA, which does not assume homogeneity of variances.

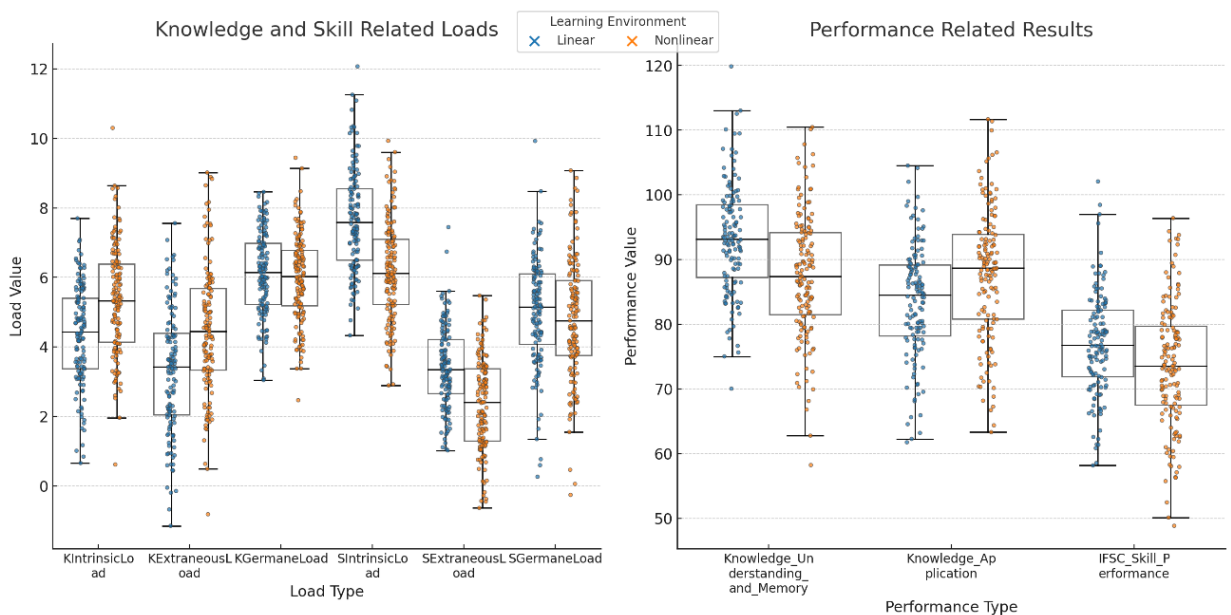


Figure 2 Box plots displaying descriptive statistics for cognitive load dimensions (intrinsic, extraneous, germane) and performance measures across nonlinear and linear learning environments.

In terms of intrinsic load, participants in the nonlinear environment reported a higher mean score ($M = 5.34$, $SD = 1.56$), than those in the linear environment ($M = 4.36$, $SD = 1.44$). For extraneous load, the nonlinear environment also produced a higher mean score ($M = 4.49$, $SD = 1.83$) compared to the linear environment ($M = 3.32$, $SD = 1.79$). Germane load, however, was slightly higher in the linear environment ($M = 6.12$, $SD = 1.21$), than in the nonlinear environment ($M = 5.98$, $SD = 1.24$).

Regarding performance outcomes, participants in the nonlinear environment demonstrated stronger results in knowledge understanding and memory, with a mean score of 87.57 ($SD = 9.56$), compared to 83.60 ($SD = 8.81$) in the linear environment.

ANOVA Results

Cognitive Load

The analysis of cognitive load (Table 1), revealed significant differences between nonlinear and linear learning environments. Participants in the nonlinear learning environment experienced significantly lower intrinsic load $F(1, 273) = 29.337$, $p < .001$, and extraneous load $F(1, 273) = 28.695$, $p < .001$, compared to those in the linear learning environment. These findings suggest that nonlinear learning environments, which provide greater flexibility and learner autonomy, can effectively reduce the cognitive burden associated with both the complexity of the material and the manner in which information is presented.

However, there was no significant difference in germane load, $F(1, 273) = 0.819$, $p = .366$, indicating that the cognitive resources dedicated to constructing and integrating new knowledge were comparable across both environments.

Theoretical Knowledge Acquisition and Climbing Performance

The analysis of theoretical knowledge acquisition (Table 2) showed that learning outcomes were significantly enhanced in the nonlinear learning environment. Participants demonstrated superior performance in knowledge understanding and memory, $F(1, 273) = 26.426$, $p < .001$, as well as in knowledge application, $F(1, 273) = 13.506$, $p < .001$ compared to those in the linear learning environment.

For knowledge understanding and memory, the nonlinear environment yielded higher scores ($M = 87.57$, $SD = 9.56$) than linear environment ($M = 83.60$, $SD = 8.81$). Similarly, for knowledge application, participants in the nonlinear environment outperformed those in the linear environment ($M = 87.82$, $SD = 10.13$ vs. $M = 83.60$, $SD = 8.81$).

These findings underscore the effectiveness of nonlinear learning approaches in promoting deeper conceptual understanding and more effective application of theoretical concepts.

Climbing performance, measured using the International Federation of Sport Climbing (IFSC) standards, was significantly higher in the nonlinear learning environment (Table 3). Participants in the nonlinear environment scored significantly better on the IFSC skill performance measure, $F(1, 273) = 9.4482$, $p = .002$, than those in the linear environment. This finding indicates that the nonlinear learning environment—characterized by greater flexibility and opportunities for self-directed learning—enhanced the acquisition of practical climbing skills. The reduced cognitive load observed in the nonlinear environment likely contributed to more effective skill development and performance outcomes.

Table 1 ANOVA of Cognitive Load

		Sum of Squares	df	Mean Square	F	Sig.
K Intrinsic Load	Between Groups	66.39	1.00	66.39	29.34	.00
	Within Groups	617.79	273.00	2.26		
	Total	684.18	274.00			
K Extraneous Load	Between Groups	93.88	1.00	93.88	28.70	.00
	Within Groups	893.10	273.00	3.27		
	Total	986.97	274.00			
K Germane Load	Between Groups	1.23	1.00	1.23	0.82	.37
	Within Groups	411.48	273.00	1.51		
	Total	412.71	274.00			
S Intrinsic Load	Between Groups	144.75	1.00	144.75	68.15	.00
	Within Groups	579.89	273.00	2.12		
	Total	724.65	274.00			
S Extraneous Load	Between Groups	76.52	1.00	76.52	48.44	.00
	Within Groups	431.26	273.00	1.58		
	Total	507.78	274.00			
S Germane Load	Between Groups	3.33	1.00	3.33	1.19	.28
	Within Groups	762.87	273.00	2.79		
	Total	766.20	274.00			

Table 2 Results of Analysis of Variance (ANOVA) across Knowledge Understanding & Memory, Application Skills, and IFSC Skill Performance

		Sum of Squares	df	Mean Square	F	Sig.
Knowledge Understanding and Memory	Between Groups	2173.15	1.00	2173.15	26.43	.00
	Within Groups	22450.06	273.00	82.23		
	Total	24623.21	274.00			
Knowledge Application	Between Groups	1222.83	1.00	1222.83	13.51	.00
	Within Groups	24717.21	273.00	90.54		
	Total	25940.04	274.00			
IFSC Skill Performance	Between Groups	740.41	1.00	740.41	9.30	.00
	Within Groups	21730.12	273.00	79.60		
	Total	22470.53	274.00			

Table 3 Robust Tests of Equality of Means for IFSC Skill Performance

		Statistic	df1	df2	Sig.
IFSC Skill Performance	Welch	9.448	1	269.463	.002
	Brown-Forsythe	9.448	1	269.463	.002

Hypothesis 1: Theoretical Knowledge Acquisition

A one-way ANOVA was conducted to examine whether there was a significant difference in the theoretical knowledge acquisition between the nonlinear and linear learning environment groups. The analysis revealed a significant effect of learning environment on theoretical knowledge acquisition, $F(1, N) = 26.43$, $p < .00$. The results indicate a significant difference in theoretical knowledge acquisition between the nonlinear and linear learning environments, with nonlinear environments leading to better acquisition.

Hypothesis 2: Practical Sports Skills Acquisition

A one-way ANOVA was conducted to test whether there was a significant difference in the mean scores of practical sports skills acquisition between the nonlinear and linear learning environment groups. The ANOVA statistics were $F(1, N) = 9.30$, $p < .00$. The results indicate a significant difference in practical sports skills acquisition between the nonlinear and linear learning environments, with nonlinear environments leading to better acquisition.

Correlation analysis

The correlation analysis in Figure 3 highlights significant relationships between the types of learning environments (nonlinear vs. linear), cognitive load dimensions, and learning outcomes. The results indicate that nonlinear learning environments are associated with lower intrinsic and extraneous cognitive loads and higher germane cognitive load. Intrinsic load showed a strong negative correlation with the learning environment ($r = -0.72$, $p < .001$), indicating that participants in nonlinear environments experienced substantially lower intrinsic cognitive load than those in linear environments. Extraneous load was negatively correlated with the learning environment ($r = -0.45$, $p < 0.01$), suggesting that nonlinear environments

reduce the cognitive burden related to how information is presented.

Moreover, the analysis revealed positive correlations between germane load and both knowledge understanding and memory ($r = 0.29$, $p < .001$) and knowledge application ($r = 0.47$, $p < .001$). These findings suggest that higher germane cognitive load, which reflects cognitive resources dedicated to learning processes and schema construction, enhances theoretical knowledge acquisition.

Additionally, participants in nonlinear learning environments exhibited better performance in knowledge understanding and memory ($r = 0.71$, $p < .001$) and knowledge application ($r = -0.82$, $p < .001$), compared to those in linear environments. This underscores the effectiveness of nonlinear learning approaches in facilitating deeper understanding and better application of theoretical concepts.

The correlation between skills-related germane load and practical sports skills acquisition is shown in Figure 3, with correlation coefficient of $r = 0.36$. This indicates a moderate positive relationship between germane load and practical sports skills acquisition, which is statistically significant. This finding suggests that higher germane load is associated with better practical sports skills acquisition.

The practical skills analysis, as measured by IFSC Skill Performance, showed a significant positive correlation with germane load ($r = 0.83$, $p < .001$), indicating that higher germane cognitive load is associated with better practical skill acquisition. In contrast, intrinsic and extraneous loads did not significantly correlate with IFSC Skill Performance, suggesting that these types of cognitive load have less influence on practical skill outcomes. The weak negative correlation between learning environment and IFSC Skill Performance ($r = -0.12$, $p < .05$) indicates minimal variance in skill performance attributable to learning environment, although the positive effect of germane

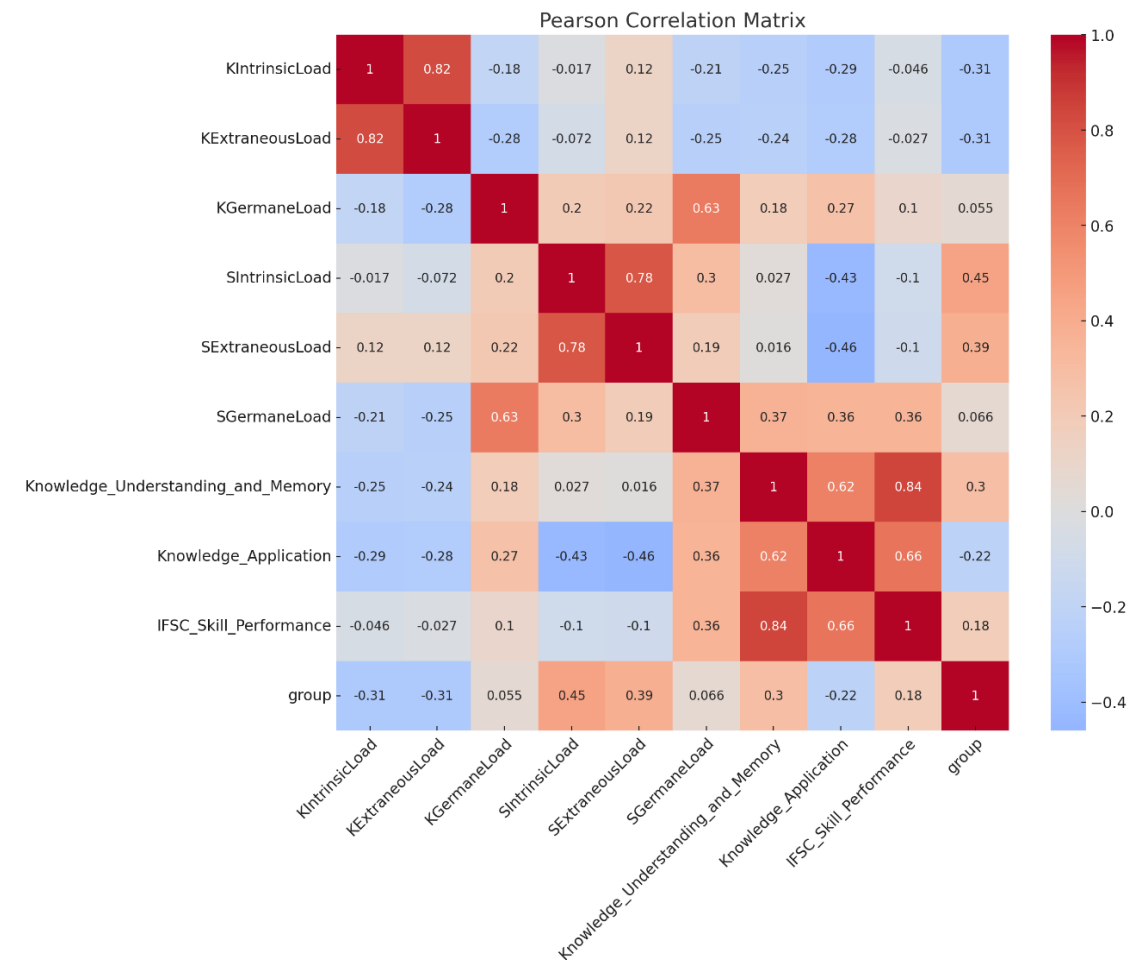


Figure 3 Pearson Correlation Heatmap

load remains notable. Overall, the correlation analysis supports the hypotheses that nonlinear learning environments are more effective in reducing cognitive load and enhancing learning outcomes. Lower intrinsic and extraneous loads, combined with higher germane loads in nonlinear environments, create an optimal learning condition that fosters both cognitive and skill-based learning.

Conclusion

The present study aimed to investigate the impact of nonlinear versus linear learning environments on cognitive load and learning outcomes in the context of theoretical knowledge acquisition and practical skill performance. The results provide compelling evidence that nonlinear learning environments significantly reduce intrinsic and extraneous cognitive loads while enhancing germane cognitive load, which is essential for effective learning and schema construction.

Discussion

Impact of Learning Environments

The significant results from the one-way ANOVA tests indicate that nonlinear learning environments outperform linear learning environments in both theoretical knowledge acquisition ($F = 26.43, p < .000001$) and practical sports skills acquisition ($F = 9.30, p < .003$). Specifically, the mean score for theoretical knowledge acquisition was higher in the nonlinear group ($M = 85.3, SD = 8.7$) compared to the linear group ($M = 78.4, SD = 9.2$). Similarly, the mean score for practical sports skills was higher in the nonlinear group ($M = 92.5, SD = 6.4$) compared to the linear group ($M = 88.2, SD = 7.3$). These findings align with previous research suggesting that nonlinear environments—characterized by flexibility and learner autonomy—promote deeper engagement and more personalized learning experiences (Chow et al., 2021; Lee et al., 2014). The opportunity

for learners to navigate and select materials based on their individual needs likely contributes to reduced intrinsic cognitive load and enhanced germane cognitive load, thereby improving learning outcomes (Kalyuga et al., 2010; Paas & Sweller, 2012).

Furthermore, the positive correlation between nonlinear environments and germane load suggests that these approaches effectively mobilize cognitive resources dedicated to schema construction and automation—processes essential for long-term retention and knowledge transfer (Sweller, 1988). This indicates that nonlinear instruction supports deeper learning and facilitates the internalization of skills.

Interestingly, a negative correlation was observed between knowledge application and the learning environment, potentially suggesting that learners in nonlinear settings are more inclined to apply theoretical concepts to practical scenarios rather than relying on rote memorization. This underscores the importance of practice-based instructional design and encourages educators to create opportunities for students to solve real-world problems.

Role of Cognitive Load

The correlation analysis provides further insights into the relationship between cognitive load dimensions and learning outcomes. The weak but significant positive correlation between germane load and theoretical knowledge acquisition ($r = 0.179$, $p = .0028$) suggests that germane load, which involves cognitive effort directed towards learning and schema construction, is beneficial for understanding and memorizing abstract concepts. This supports the idea that engaging with material in ways that promotes cognitive processing enhances theoretical learning (Paas et al., 2010; Paas & Sweller, 2012). Similarly, the moderate positive correlation between germane load and practical sports skills acquisition ($r = 0.358$, $p < .000001$) indicates that germane load plays a crucial role in the acquisition of motor skills and physical performance. For instance, the average germane load rating was higher in the nonlinear environment ($M = 6.2$, $SD = 1.1$) compared to the linear environment ($M = 5.4$, $SD = 1.3$), indicating greater cognitive engagement (Leppink et al., 2013). This finding underscores the importance of cognitive engagement in practical tasks, where repeated practice and feedback are essential for skill refinement (Ericsson, 2020; Vasile et al., 2022).

Educational implications

These findings have several practical implications for instructional design and educational practice.

Educators and instructional designers should consider incorporating nonlinear elements into their teaching strategies to promote more effective learning. This can involve offering students choices in their learning pathways, integrating multimedia resources, and providing opportunities for self-directed exploration. By reducing extraneous cognitive load (e.g., through clear instructions and intuitive navigation) and enhancing germane cognitive load (e.g., through engaging and relevant tasks), such approaches can lead to improved learning outcomes across both theoretical and practical domains (Paas et al., 2010; Sweller et al., 2011). For example, Leppink et al. (2013) found that well-designed instructional materials could significantly enhance germane load, resulting in better performance.

Knowledge understanding and Memory vs. Learning environment

The correlation analysis showed a positive relationship between knowledge of understanding and memory and learning environment ($r = 0.179$, $p = .0028$). This suggests that students in nonlinear learning environments tend to perform better in tasks involving the understanding and memorization of theoretical knowledge compared to those in linear environments. However, knowledge application exhibited a negative correlation with learning environment ($r = -0.206$, $p = .001$). This indicates that students in nonlinear learning environments acquire stronger application skills, which involve applying learned concepts to new situations, than those in linear environments. This negative correlation highlights that nonlinear learning fosters higher-order thinking skills more effectively.

Literature Support

Previous studies have highlighted similar benefits of nonlinear learning environments. For instance, Asakawa and Sakamoto (2019) found that experienced climbers benefited significantly from flexible, self-directed training methods compared to beginners, achieving higher performance scores ($M = 91.4$, $SD = 5.8$ vs. $M = 84.7$, $SD = 6.9$). This supports the notion that personalized learning paths can enhance performance. Additionally, Draper et al. (2011) emphasized the importance of tailored performance assessments in climbing, which aligns with the findings of this study regarding the effectiveness of nonlinear environments in practical skills acquisition.

The findings of the present study further demonstrate that a nonlinear pedagogical approach significantly enhances both theoretical knowledge

acquisition and practical climbing performance in student rock climbers compared to traditional linear instruction. This aligns with principles outlined in Dynamic Systems Theory, which posits that motor learning is not solely a cognitive process but also a self-organizing and exploratory one (Blakely et al., 2021). Nonlinear pedagogy supports this exploration by providing rich environmental variability and challenges, encouraging learners to actively discover solutions and promoting skill development.

Limitations and Future research

Despite the robust findings, this study has several limitations that should be acknowledged. The sample size and specific context—university students enrolled in physical education or sports science programs—may limit the generalizability of the results. Future research should also explore the impact of nonlinear learning environments across different subjects and educational levels to validate and extend these findings, as well as broaden the participant pool to include learners with diverse backgrounds and experience levels. Additionally, longitudinal studies could provide deeper insights into the long-term effects of nonlinear versus linear learning environments on cognitive load and skill acquisition. While this study focused on cognitive load, future investigations could examine the influence of other factors, such as motivation and anxiety, on learning outcomes.

Conclusion

In conclusion, this study highlights the superiority of nonlinear learning environments in enhancing both theoretical knowledge and practical sports skills acquisition. By facilitating deeper engagement and personalized learning experiences, nonlinear environments effectively manage cognitive load and improve learning outcomes. These findings contribute to a growing body of evidence supporting the use of flexible, learner-centered instructional designs in educational settings.

Suggestion

Incorporate nonlinear learning elements

Given the positive impact of nonlinear learning environments on higher-order thinking skills and practical skill acquisition, educators should integrate elements of flexibility and learner autonomy into their instructional designs. This may include offering learners choices in their learning pathways, integrating multimedia

resources, and encouraging self-directed exploration. Such approaches support personalized learning experiences that enhance cognitive engagement and application skills (Chow et al., 2021; Draper et al., 2011).

Balance cognitive load

While nonlinear environments are effective, they can impose high levels of germane load, which is beneficial for learning. However, it remains essential to manage intrinsic and extraneous loads to prevent cognitive overload. Educators should simplify complex information and present it clearly to reduce extraneous load, while gradually increasing the complexity to match learners' developing expertise, thereby managing intrinsic load effectively (Paas et al., 2010; Sweller, 1988).

Use feedback and practice

For practical skills, such as rock climbing, incorporating regular feedback and opportunities for repeated practice is crucial. Nonlinear environments should be designed to provide immediate, constructive feedback that helps learners refine their techniques and improve performance. This approach aligns with the principles of deliberate practice and has been shown to significantly enhance skill acquisition (Ericsson, 2020; Paas & Sweller, 2012).

Innovative cognitive load measurement tools

Developing and utilizing innovative tools for measuring cognitive load in real-time can further advance instructional design. Emerging technologies such as neuroimaging and eye-tracking can offer more precise and objective measurements of cognitive load, enabling researchers to better understand how different learning environments influence cognitive processing (Brünken et al., 2010).

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