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Temporal reasoning as a cognitive predictor of students' understanding of population growth limits and carrying capacity across grade levels

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Abstract

This study examined temporal reasoning as a cognitive predictor of students' understanding of population growth limits and carrying capacity across grade levels. Specifically, it investigated the relationship between temporal reasoning and conceptual understanding, its predictive power, and differences across grade levels. A quantitative descriptive–correlational design with a comparative component was employed involving 150 junior high school students from Grades 8 to 10. Data were gathered using a Temporal Reasoning Test and a Conceptual Understanding Test on population ecology. Mean, standard deviation, Pearson correlation, simple linear regression, and one-way ANOVA were used for data analysis at a 0.05 level of significance.

Findings revealed that students demonstrated a high level of temporal reasoning ability (M = 25.76), while their conceptual understanding was at a moderate level (M = 22.61). A weak but significant positive relationship was found between temporal reasoning and conceptual understanding (r = 0.236, p = 0.0036). Regression analysis showed that temporal reasoning significantly predicted conceptual understanding, accounting for only 5.6% of the variance. Significant differences were also found across grade levels, with Grade 10 students outperforming lower grade levels in both temporal reasoning and conceptual understanding.

The study concludes that while students possess relatively strong temporal reasoning skills, their conceptual understanding of population ecology remains moderate. Temporal reasoning contributes significantly, though modestly, to conceptual learning, suggesting that other cognitive and instructional factors are also involved. The findings highlight the importance of integrating temporal cognition-focused strategies in science instruction to enhance students' understanding of dynamic ecological systems.

Keywords: Temporal reasoning; Conceptual understanding; Population growth limits; Carrying capacity; Science education; Grade level differences

1. Introduction

Population ecology is fundamental to science education, as it enables learners to understand how populations respond to changing environmental conditions. Key concepts such as population growth limits and carrying capacity elucidate why populations cannot increase without bound. Mastery of these concepts requires students to analyze temporal patterns rather than depend on static information. Nevertheless, students often exhibit limited comprehension of these ideas, largely because of their abstract and dynamic nature [1,2].

A significant challenge arises from the inherently temporal nature of population growth. Population dynamics develop over time, often following patterns such as rapid expansion and subsequent stabilization. Understanding these processes requires students to interpret how past conditions influence present states and to anticipate future outcomes.

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However, many learners remain limited to linear models of growth and overlook the impact of limiting factors, indicating a persistent gap in their conceptual understanding of ecological systems [3,4].

These difficulties underscore the significance of cognitive processes that facilitate understanding of change over time. Temporal reasoning, in particular, is a crucial yet frequently neglected skill. It encompasses organizing sequences, comprehending duration, and interpreting evolving trends. In science education, temporal reasoning allows students to explain dynamic processes, interpret graphical data, and identify cause-and-effect relationships within complex systems [5,6].

Despite its importance, temporal reasoning has received relatively little attention in science education research. Most studies emphasize general cognitive skills such as critical thinking, problem-solving, and mathematical reasoning, often neglecting the distinct contribution of temporal cognition. This oversight results in a significant gap in the literature, especially since many scientific concepts, particularly in biology and environmental science, are fundamentally time-dependent and require temporal processing for full comprehension [7,8].

The complexity of population ecology concepts further highlights the need to investigate temporal reasoning. Comprehending population growth limits and carrying capacity involves integrating multiple interacting variables, such as resource availability, environmental resistance, and population size. These variables interact continuously over time. Consequently, students must interpret growth curves, differentiate between exponential and logistic patterns, and explain equilibrium states, all of which require robust temporal reasoning skills [9,10].

Furthermore, carrying capacity is not solely a theoretical construct but is directly connected to real-world concerns such as sustainability and environmental management. A thorough understanding of this concept equips students to analyze ecological challenges and make informed decisions regarding resource utilization. Without the capacity to comprehend temporal changes in systems, students may struggle to relate classroom knowledge to practical applications, thereby reinforcing the gap between conceptual understanding and real-world relevance [11,12].

An additional consideration is the influence of cognitive development across grade levels. As students advance in their education, they are expected to acquire more sophisticated reasoning abilities, including abstract and systematic thinking. Although this progression suggests that older students should understand complex concepts more effectively, research shows that this development is often inconsistent. Many students continue to struggle with interpreting dynamic systems, suggesting that exposure to the content alone does not guarantee a deeper understanding [13,14].

Collectively, these issues highlight a significant gap in science education. Although students are expected to grasp time-dependent ecological concepts, they seldom receive explicit support for developing the necessary cognitive skills. Specifically, the predictive role of temporal reasoning in conceptual understanding remains insufficiently examined. Most research focuses on students' knowledge rather than their ability to process temporal change, leaving a crucial aspect of learning inadequately addressed [8,2].

Addressing this gap from an instructional standpoint necessitates integrating cognitive skill development with content learning. Strategies such as graph interpretation, simulations, and inquiry-based methods can enhance students' recognition of temporal patterns. However, the success of these approaches relies on a clear understanding of the contribution of temporal reasoning to conceptual learning, an area that still requires further empirical research [10,1].

In response to these identified gaps, the present study examines temporal reasoning as a cognitive predictor of students' conceptual understanding of the limits to population growth and carrying capacity. It also explores differences across grade levels to elucidate how these skills develop over time. By addressing both cognitive and conceptual aspects of learning, this study seeks to advance understanding of how students engage with complex, time-dependent scientific concepts and to inform more effective instructional practices in science education.

This study investigates temporal reasoning as a cognitive predictor of students' understanding of population growth limits and carrying capacity across grade levels. It specifically examines how students' ability to reason about time influences their conceptual understanding of dynamic ecological processes. Furthermore, the study aims to determine the relationship between temporal reasoning and conceptual understanding and to identify differences across grade levels. This investigation is guided by the research paradigm presented below.

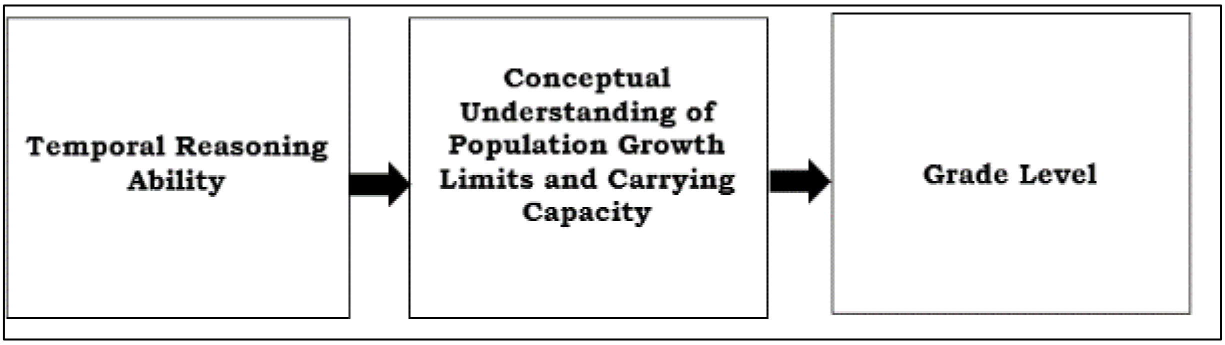

Figure 1 Conceptual Paradigm of the Study

Figure 1 presents the conceptual framework of the study, showing temporal reasoning ability as the independent variable and students' conceptual understanding of population growth limits and carrying capacity as the dependent variable. Grade level is considered a grouping variable to examine differences among students. The framework illustrates the relationship between temporal reasoning and conceptual understanding, which serves as the basis for analyzing how cognitive skills influence students' learning of ecological concepts.

1.1. Research Objectives

The study examined temporal reasoning as a cognitive predictor of students' understanding of population growth limits and carrying capacity across grade levels. Specifically, it sought to:

- Determine the level of students' temporal reasoning ability.
- Assess the level of students' conceptual understanding of population growth limits and carrying capacity.
- Examine the relationship between students' temporal reasoning ability and their conceptual understanding of population growth limits and carrying capacity.
- Determine whether temporal reasoning significantly predicted students' conceptual understanding of population growth limits and carrying capacity.
- Identify differences in temporal reasoning ability across grade levels.
- Determine whether there were significant differences in students' conceptual understanding of population growth limits and carrying capacity across grade levels.

2. Methodology

2.1. Research Design

This study employed a quantitative, descriptive-correlational research design with a comparative component. The design was appropriate, as it aimed to determine the relationship between temporal reasoning and students' conceptual understanding of population growth limits and carrying capacity, and to examine differences across grade levels. Furthermore, regression analysis was utilized to determine whether temporal reasoning significantly predicted students' conceptual understanding.

2.2. Respondents

This study involved 150 students enrolled at Muñoz National High School-Main Junior High School. Respondents were selected to ensure equal representation across grade levels, facilitating meaningful comparisons. The sample comprised students from three grade levels: Grade 8 (50 students), Grade 9 (50 students), and Grade 10 (50 students).

2.3. Sampling Method

This study employed stratified random sampling, grouping students by grade level as strata. Respondents were then randomly selected from each grade to ensure equal representation and reduce sampling bias.

2.4. Sources of Data

The data were obtained directly from the respondents through the Temporal Reasoning Test and the Conceptual Understanding Test on Population Growth Limits and Carrying Capacity. All data were primary data collected specifically for this study.

2.5. Instruments

This study employed two primary instruments, both adapted from established, validated tools. The first is a researcher-developed Temporal Reasoning Test used to measure students' ability to understand and analyze temporal patterns in population ecology. The instrument consists of 30 multiple-choice items categorized into four domains: temporal sequencing, trend interpretation, temporal comparison, and prediction/projection. The test was contextualized using concepts related to population growth, limiting factors, and carrying capacity, ensuring alignment with the study's focus. The reliability of the Temporal Reasoning Test was determined using Cronbach's alpha. The instrument yielded an alpha coefficient of 0.91, indicating excellent internal consistency. The instrument underwent content validation by three experts in science education. The computed Content Validity Index (CVI) of 0.86 indicates that the instrument has good content validity.

2.6. Data Collection Procedure

The data collection procedure involved several steps. First, a formal request was submitted to the school administration to conduct the study. Once permission and approval were obtained, the research instruments were reviewed by subject-matter experts to ensure content validity. Respondents were then selected using stratified random sampling. The tests were administered via Google Forms, after which the completed tests were collected, checked, and organized for analysis. Participation in the study was voluntary, and the confidentiality of responses was maintained throughout the process.

2.7. Data Analysis

The collected data were analyzed using statistical methods appropriate to each research question. The mean and standard deviation were calculated to assess students' temporal reasoning ability (Research Question 1) and their conceptual understanding of population growth limits and carrying capacity (Research Question 2). The Pearson product-moment correlation coefficient (Pearson r) was used to examine the relationship between temporal reasoning and conceptual understanding (Research Question 3). A simple linear regression analysis examined whether temporal reasoning significantly predicted students' conceptual understanding (Research Question 4). A one-way analysis of variance (ANOVA) was conducted to identify differences in temporal reasoning ability across grade levels (Research Question 5) and differences in conceptual understanding across grade levels (Research Question 6). If significant differences were found, the Tukey HSD post hoc test identified specific group differences. All statistical analyses were conducted at a 0.05 level of significance.

2.8. Ethical Consideration

Ethical approval was obtained from the school administration, and informed consent was secured from all participants. Participation was voluntary, and all data were treated confidentially.

3. Results and discussion

This study examined temporal reasoning as a cognitive predictor of students' understanding of population growth limits and carrying capacity across grade levels. It determined students' levels of temporal reasoning and conceptual understanding, assessed their relationship and predictive link, and examined differences across grade levels. To achieve these aims, statistical analyses were performed in R (Version 4.5.0; R Core Team, 2025). The relationship between temporal reasoning and conceptual understanding was assessed using Pearson's product-moment correlation coefficient. At the same time, the linear regression was performed to determine whether temporal reasoning significantly predicts conceptual understanding. Furthermore, one-way analysis of variance (ANOVA) was employed to determine whether differences exist in temporal reasoning and conceptual understanding across grade levels, followed by Tukey's Honestly Significant Difference (HSD) post hoc test.

Table 1 Descriptive statistics of temporal reasoning and conceptual understanding scores

Variable	N	Min	Max	Mean	SD
CU_Score	150	12	30	22.61	4.28
TR_Score	150	15	30	25.76	4.11

The students' temporal reasoning and conceptual understanding scores are shown in Table 1. Results show that students obtained a higher mean score in temporal reasoning ($\bar{x}$ = 25.76) compared to conceptual understanding ($\bar{x}$ = 22.61). The results suggest that students handle cognitive demands better when learning sequencing and time-based logic. Moreover, students handle cognitive demands better than the abstract learning needed for conceptual understanding. The Temporal Contiguity Principle may explain this. Learning is more effective when related information is presented in a close temporal sequence, as this reduces the strain on working memory[12]. Temporal reasoning often provides an intrinsic organizational structure or timeline that serves as an external cognitive aid, allowing students to process information as a series of connected links rather than as isolated, complex concepts.

Table 2 Summary of Pearson correlation and simple linear regression between temporal reasoning and conceptual understanding

Analysis	Statistic	Value
Pearson correlation	r	0.236
Pearson p-value	*p*	0.0036
Regression slope	β	0.246
Regression intercept	a	16.268
Coefficient of determination	R^2	0.056
Model F-test	F(1,148)	8.764

Table 3 Simple linear regression model predicting conceptual understanding from temporal reasoning

Model	Equation
CU Prediction	CU = 16.27 + 0.25(TR)

Table 2 shows a weak positive correlation between temporal reasoning and conceptual understanding that was statistically significant (r = 0.236, p = 0.0036). In addition, linear regression indicates that temporal reasoning significantly predicts conceptual understanding; however, it only explains approximately 5.6% of the variance (R^2 = 0.056). Moreover, the regression equation indicates that for each 1-point increase in temporal reasoning score, conceptual understanding increases by 0.25 points (Table 3).

Temporal reasoning results show strong predictive power for conceptual understanding. Yet, it produces only minor effects, confirming Rittle-Johnson's 2017 study, which demonstrated how different knowledge types establish a two-way relationship. The framework reveals that students develop an understanding of concepts through their initial ability to use procedural-based logic skills, including temporal sequencing. The correlation is weak because temporal reasoning is a required skill for deep conceptual understanding, but it does not confer complete mastery of that knowledge.

Schneider and Stern stated in their study that multiple diverse factors affect how people understand conceptual knowledge[13]. The regression equation from this study shows that temporal-logic improvements lead to better understanding but inefficient knowledge transfer (β = 0.25). The research supports the Cognitive Load Theory, which Sweller et al. updated by demonstrating that students can comprehend time-based logic through its basic “low-element interactivity.” Still, they will not succeed until they grasp the “high-element interactivity” needed to develop conceptual understanding [14, 15].

Table 4 Conceptual understanding mean scores across different grade levels

Grade	Score[1]
8	20.18 ± 3.92[a]
9	22.18 ± 3.55[b]
10	25.48 ± 3.62[c]

[1]Values are expressed as mean ± SD. In the score column, means followed by the same letters are not significantly different at 5% Tukey's HSD.

Table 4 infers that conceptual understanding scores increase across grade levels. The lowest mean score was for Grade 8 (20.18 ± 3.92), followed by Grade 9 (22.18 ± 3.55), while Grade 10 (25.48 ± 3.62) achieved the highest mean score. These results show a steady increase in conceptual understanding across Grades 8 to 10, in lined with Jerome Bruner's concept of spiral curriculum, where complex subjects are revisited at increasing levels of abstraction to ensure continuous development [15, 16].

Table 5 Temporal reasoning mean scores across different grade levels

Grade	Score[1]
8	24.46 ± 4.36[a]
9	24.84 ± 4.13[a]
10	27.98 ± 2.75[b]

[1]Values are expressed as mean ± SD. In the score column, means followed by the same letters are not significantly different at 5% Tukey's HSD.

Table 5 shows mean temporal reasoning scores across grade levels. Students in Grades 8 and 9 (24.46 ± 4.36) performed at the same level, but students in Grade 10 (27.98 ± 2.75) achieved the highest score. These results indicate that students in Grades 8 and 9 obtained equal scores on the test questionnaire, demonstrating the same level of temporal reasoning ability[17, 18]. The scores of Grade 10 students exceeded those of Grades 8 and 9, indicating that the highest grade level shows significant progress.

In summary, the results show that students who reach higher grade levels (specifically Grade 10) demonstrate greater abilities in time-based reasoning and in grasping the subject matter assessed by the questionnaire. The post hoc Tukey's HSD test results show that all grade levels differ significantly, as each year of education develops students' understanding of concepts at a measurable rate. The significantly higher scores obtained by Grade 10 students align with Piaget's theory of cognitive development, in which adolescents enter the formal operational stage, typically beginning around ages 11-12, transitioning from concrete to abstract, logical, and hypothetical thinking [16, 19].

4. Conclusions

Based on the findings, the following conclusions are drawn:

Students possess relatively strong temporal reasoning skills, enabling them to process sequential and time-based information effectively.

Students demonstrate only moderate conceptual understanding of population growth limits and carrying capacity, highlighting the complexity of abstract scientific concepts.

Temporal reasoning and conceptual understanding are significantly related, indicating that temporal reasoning contributes to conceptual learning.

Temporal reasoning is a significant but limited predictor of conceptual understanding, suggesting that multiple cognitive and instructional variables influence conceptual mastery.

Temporal reasoning ability improves across grade levels, reflecting cognitive development and increased exposure to higher-order thinking tasks.

Conceptual understanding also improves progressively across grade levels, supporting the cumulative nature of learning.

In summary, temporal reasoning supports but does not fully determine conceptual understanding, emphasizing the need for comprehensive instructional strategies.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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