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Using Self-Assessment and Remediation to Raise Middle School Student Achievement in Science

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ABSTRACT

Cognitive Structure Analysis (CSA) is an educational framework designed to help students identify and address knowledge deficits through (self-)assessment, enabling them to remediate gaps in understanding. Previous studies have demonstrated the reliability of teaching students to use CSA to assess their own knowledge in various academic disciplines, including calculus (Cynkin and Leddo, 2023) and chemistry (Dandemraju, Dandemraju, and Leddo, 2024). These studies, however, primarily focused on the identification of knowledge gaps rather than their remediation. As accurate assessment does not inherently address deficiencies, later studies began to investigate CSA's role in addressing the gap. Ravi and Leddo (2024) conducted a study in which high school students learned an advanced chemistry topic by watching a video. Half relearned the material while the other half self-assessed using CSA and relearned the material with an eye to filling in assessed knowledge gaps. Students performing self-assessment prior to relearning material scored 15 points or 1.5 letter grades higher on a post-test. Similarly, Nehra and Leddo (2024) replicated this approach in Spanish instruction, finding that CSA-trained students scored an average of 25 percentage points (2.5 letter grades) higher than those who simply reread the material without self assessing. Prakash and Leddo (2025a) built on the findings of Ravi and Leddo (2024) and Nehra and Leddo (2024) by investigating CSA's plus remediation's applicability to reading comprehension; post-test results displayed that the CSA-trained group scored an average of 93%, outperforming the control group's 69%. Prakash and Leddo (2025b) built on prior research by investigating the applicability of CSA in learning Bayes' Theorem, a foundational concept in probability theory and statistics. The investigation of CSA was continued through analyzing its impact in history, where post-test results revealed the significant statistical difference between the control and experimental groups, the control scoring an average of 65.8% compared to the experimental group's 87.5% (Prakash and Leddo, 2025c). Leddo, Clark and Clark (2025) extended the previous work on high school students with middle school students and found that self-assessment using CSA plus remediation improved *math scores by 18 percentage points compared to remediation without self-assessment. This investigation of CSA plus remediation was continued in the context of middle school students' ability to comprehend a reading passage. Post-test results revealed the control scoring an average of 61.7% as opposed to the experimental's 78.3%. This study investigates the impact of CSA combined with targeted remediation on middle school students' performance on a science assessment. Twenty students were randomly assigned to either a control or experimental group. Both groups read a lesson The control group re-engaged with the material without guidance, while the experimental group used CSA to self-assess and target their remediation efforts. Results revealed a significant performance difference, with the experimental group scoring an average of 98%, compared to the control group's 77.5% (t=6.26, df=18, p=.0001). These findings suggest that CSA combined with remediation can substantially improve middle schoolers' comprehension and mastery of science content.*

INTRODUCTION

Throughout history, assessment has served as a measure of students' learning. Traditionally, "learning" has been defined by the number of correct answers on tests, as per classical test theory, which assumes that a student's total correct responses reflect their knowledge level (de Ayala, 2009).

Assessment methods typically fall into two categories: selecting correct answers from choices or constructing answers independently. Multiple-choice tests, widely used for their efficiency in grading, allow for guessing, which can inflate scores (Chaoui, 2011; Elbrink and Waits, 1970; O'Neil and Brown, 1997). Constructive response tests require students to provide their own answers, encouraging logical reasoning and offering a more accurate measure of knowledge (Herman et al., 1944; Frary, 1985). However, both methods rely on the assumption that correct answers signify learning. This assumption is problematic, as incorrect answers may point to underlying knowledge gaps, while correct answers might result from memorization or guessing, not true understanding.

Cognitive Structure Analysis (CSA) is an assessment method designed to uncover the underlying knowledge concepts a student possesses, identifying the source of errors for targeted remediation (Leddo et al., 2022; Ahmad and Leddo, 2023; Zhou and Leddo, 2023; Dandemraju, Dandemraju, and Leddo, 2024). CSA is rooted in cognitive psychology research, which identifies various knowledge types, such as semantic nets (Quillian, 1966), production rules (Newell and Simon, 1972), scripts (Schank and Abelson, 1977) and mental models (de Kleer and Brown, 1981). Together, these form the INKS framework (Integrated Knowledge Structure), developed by John Leddo (Leddo et al., 1990). This framework suggests that expert knowledge is organized around scripts and principles that enable predictions and explanations.

ISSN: 2455-8834

Volume:10, Issue:04 "April 2025"

CSA, which integrates INKS principles, has shown strong correlations with problem-solving performance: 0.966 in Algebra 1 (Leddo et al., 2022), 0.63 in scientific method problem-solving (Ahmad and Leddo, 2023), and 0.80 in precalculus (Zhou and Leddo, 2023). By assessing students' conceptual understanding, CSA enables educators to address knowledge gaps effectively, leading to significant improvements in student performance (Leddo and Ahmad, 2024).

Although CSA has proven effective, the responsibility for diagnosing and remediating students' knowledge gaps lies primarily with teachers, who often manage large numbers of students. Teaching students to self-assess their knowledge could alleviate this burden. Unlike self-explanation, which involves generating explanations for learned material, self-assessment involves evaluating one's knowledge after learning.

Cynkin and Leddo (2023) demonstrated that high school calculus students could accurately self-assess their knowledge using CSA, while Dandemraju, Dandemraju, and Leddo (2024) extended this finding to chemistry. These studies, however, addressed only the identification of knowledge gaps, not their remediation. Accurate assessment does not equate to addressing deficiencies, just as diagnosing a medical issue does not equate to treating it.

To address this issue, Ravi and Leddo (2024) conducted a study in which high school students learned an advanced topic in chemistry by watching a video. Half the students were told to rewatch the video to fill in any knowledge gaps, while the other half were taught to self-assess their knowledge using CSA and then told to rewatch the video to fill in any assessed knowledge gaps. The group that was taught to self-assess scored 15 points or 1.5 letter grades higher on a post-test than students who simply rewatched the video without self-assessment. Nehra and Leddo (2024) replicated the Ravi and Leddo study to the learning of Spanish. They found that high school students performing self-assessment plus remediation scored, on average, 25 percentage points or 2.5 letter grades higher than those re-reading the material without performing a self-assessment. Prakash and Leddo (2025a) extended the Ravi and Leddo (2024) and Nehra and Leddo (2024) findings to another subject area: reading comprehension. The results revealed a mean post-test score of 8.3 out of 12 (69.17%) for the control group and 11.2 out of 12 (93.33%) for the experimental group. This difference in averages was statistically significant ($t = 3.75$, $df = 11.07$, $p < .01$). Notably, individual scores further illustrated the disparity: the lowest score in the control group was 41.67%, whereas the lowest in the experimental group was 83.33%. This is the difference between an F letter grade and B letter grade. Following this, another study conducted by Prakash and Leddo (2025b) examined CSA's effectiveness in teaching math, specifically, the topic of Bayes' Theorem, and found a 27-point improvement. Statistical analysis yielded a t-value of 4.38 ($df = 18$, $p = 0.0004$), confirming the significance of the difference. Individual scores also highlighted the disparity. The control

ISSN: 2455-8834

Volume:10, Issue:04 "April 2025"

group's lowest score was 6/20 (30%), whereas the experimental group's lowest score was 15/20 (75%). Following this, a history assessment revealed that students who utilized CSA for self-assessment and remediation significantly outperformed their peers in the control group (Prakash and Leddo, 2025c). Post-test results demonstrated that the experimental group achieved an average score of 87.5%, whereas the control group scored 65.8%, indicating a substantial difference in comprehension and retention of historical concepts. These results on high school students were further extended by Leddo, Clark and Clark (2025) in their investigation of middle school math. Leddo, Clark and Clark found that middle school students who self-assessed using CSA and then remediated their knowledge gaps scored 18 percentage points higher on a post test than those who relearned material without first performing a self-assessment.

Following this, Prakash and Leddo (2025d) conducted a study on middle school students' reading comprehension, specifically through an analysis of To Kill a Mockingbird, a novel that explores complex themes of ethics and social structure. Students in the experimental group were trained to evaluate their own knowledge gaps and use targeted remediation strategies, while those in the control group engaged with the text without structured self-assessment. Results showed that students in the self-assessment group scored 16 points higher on a post-test than those who re-read the material without self-assessment.

Building upon these results, this present study examines CSA's impact on middle school students' understanding of science concepts. Science literacy is a critical component of middle school education, fostering not only content mastery but also logical reasoning, application of the scientific method, and long-term academic performance. Students in the experimental group were taught to self-assess their understanding of key science concepts using CSA and then engage in focused review based on their assessed gaps. In contrast, students in the control group reviewed the material without guidance or structured self-assessment. This study seeks to explore the extent to which CSA paired with remediation can improve conceptual understanding and performance in science, a subject that often serves as a foundation for later academic and STEM-related success. By validating CSA's role in improving scientific analysis, this study contributes to ongoing research on effective learning strategies and the potential for self-directed education to enhance student outcomes.

METHOD

Participants

20 male and female Loudoun County Public Schools students were selected to participate in this study. All students were middle school students, and they were not paid for their participation.

ISSN: 2455-8834

Volume:10, Issue:04 "April 2025"

Materials

To aid students in developing a deeper understanding of ecological systems, a comprehensive study guide was created to serve as a resource to break down complex ecological concepts into accessible, engaging segments while maintaining scientific accuracy. The guide introduced students to foundational ecological topics, including food chains, food webs, energy transfer, trophic levels, and ecological disruptions, through narrative explanations, diagrams, and real-world case studies.

The guide was structured into six thematic sections:

1. The Basics of a Food Chain
2. Energy Transfer and the 10% Rule
3. What Happens in a Food Web?
4. Trophic Levels and Ecological Pyramids
5. Disruptions in the Web
6. Real-World Examples and Critical Scenarios

Each section included clear definitions, illustrative examples, and guiding questions to promote critical thinking. Real-world case studies such as the reintroduction of wolves in Yellowstone and the cane toad invasion in Australia were integrated to highlight ecological cause-and-effect relationships. The study guide served as both a learning tool and a conceptual foundation for the assessment component of the project, in which student comprehension and application of the material were evaluated. The link is provided below.

https://docs.google.com/document/d/1-a5FMGVYM_QUK5cPvMhzRxCCvsAc9btfp_lKpokpndI/edit?usp=sharing

The following Google Form for the control group with 20 questions related to ecology is provided below.

https://forms.gle/nk3hLkp8tbB41Jq28

A self-assessment instruction sheet was created in order to help students in the experimental group self-assess their understanding of the content provided in the guide. It showed an example of a student self-assessing knowledge of a concept that included facts, strategies, procedures, and rationales. Below is the self-assessment set of instructions.

ISSN: 2455-8834

Volume:10, Issue:04 "April 2025"

Self-Assessment

I want to teach you how to assess your own knowledge that you have about a subject area. Let's do this by taking an example that you already know. Suppose you wanted to assess your own knowledge about solving 2-step equations of the form ax + b = c. An example of this type of problem is 2x + 3 = 15. If I want to be able to solve problems like these, I need four types of knowledge. These are facts, strategies, procedures and rationales. Facts are concepts you have that describe objects or elements. For example, for two step equations, I need to know what variables, constants, coefficients, equations, and expressions are. Strategies are general processes I would use to solve a problem. For two step equations, this would be reverse order of operations. Procedures are the specific steps that I would use in a strategy. So if I am using reverse order of operations, I need to know additive and multiplicative inverses. Finally, I need to know rationales which are the reasons why the strategies or the procedures work the way they do. For example, this could include things like the subtraction or the division property of equality that says that when you do the same operation to both sides of an equation, you preserve the value of the equation. You can think of facts as telling you "what", strategies and procedures as telling you "how" and rationales as telling you "why". With this in mind, this is how I might assess my own knowledge of solving two step equations.

For facts, I need to know what variables, constants, coefficients, equations and expressions are. A variable is an unknown quantity, usually represented by a letter. A constant is a specific number. A coefficient is a number that you multiply a variable by like 2x. An equation is an expression that is equal to another expression and the two expressions are joined by an equal sign. An expression is one or more terms that are combined by mathematical operations like addition, subtraction, multiplication and division.

For strategies, I need to know the reverse order of operations which is SADMEP. This stands for subtraction, addition, division, multiplication, exponents and parentheses. I know that I'm supposed to do these in order but I don't remember whether I'm supposed to do subtraction always before addition or just which one goes first. The same is true for division and multiplication.

For procedures, I need to know additive inverse and multiplicative inverse. The additive inverse is taking the number with the opposite sign as the constant and adding it to both sides of the equation. The multiplicative inverse is taking the inverse of the coefficient of the variable and multiplying both sides of the equation by it. However, if the coefficient is negative, I'm not sure if the multiplicative inverse is supposed to be negative as well.

ISSN: 2455-8834

Volume:10, Issue:04 "April 2025"

For rationales, I believe the two rationales I need are the subtraction property of equality and the division property of equality. The subtraction property of equality says that if I subtract the same number from both sides, which is what I'm doing with the additive inverse, I preserve the equality. Similarly, the division property of equality says that if I divide both sides of the equation by the same number, which is what I'm doing with the multiplicative inverse, I preserve the equality.

When I look over what I wrote, I see that I am good with my facts. On my strategy, I'm not sure about the order of steps in reverse order of operations when it comes to subtraction and addition or multiplication and division, so I need to learn those. On procedures, I'm not sure what to do with multiplicative inverses when the coefficient is negative, so I need to learn that as well. For rationales, I think I'm OK. I don't think I have any missing facts/concepts that I left out that I should know or I didn't list any facts/concepts where I didn't know what they were. For the strategy, I believe I listed the correct strategy and parts of the strategy, but I wasn't sure about some of the ordering of steps in the strategy. For procedures, I was good on the additive inverse but had a question on carrying out the multiplicative inverse when the coefficient was negative. For rationales, I think I had all the rationales that were important and that I understood them as well. I don't think I left anything out.

Please write your own self-assessment on this topic using the model above as an example.

The following Google Form for the experimental group with the self assessment and 20 questions related to ecology is provided below.

https://forms.gle/ZPj1fq4yRyugrZTD7

In addition to the self assessment, an answer key was created in order to evaluate each participant's answer to each question. There was no partial credit, with 1 point for each correct response and 0 for each incorrect response.

Procedure

Participants were randomly assigned to one of two groups: control (MSSA1) and experimental (MSSA2). Both groups received a brief guide that explained food webs and energy transfer within an environment and provided examples to develop a conceptual idea of the topic. The control group was instructed to study the material, review the same material if there were any additional inquiries, and complete a post-test, with no structured guidance on how to address knowledge gaps. The experimental group was trained to use CSA for self-assessment. After studying the document, participants in the experimental group evaluated their understanding using CSA and revisited the material to address knowledge gaps before taking the same post-test

ISSN: 2455-8834

Volume:10, Issue:04 "April 2025"

as the control group. The post-test included 20 questions assessing conceptual understanding and rationales. Participants were not permitted to access the excerpt when answering the questions.

RESULTS

The participants' data were analyzed by examining the number of correct responses on the post-assessment, which consisted of 20 questions covering key middle school science concepts. The control group (n=10), which reviewed the material without structured self-assessment, scored as follows: 17, 15, 13, 12, 15, 17, 13, 15, 9, 17. The average score was 15.5 out of 20 (77.5%). The experimental group (n=10), which utilized CSA to identify and target knowledge gaps before reviewing, scored: 20, 20, 20, 19, 18, 20, 20, 20, 20, 19. The average score was 19.6 out of 20 (98%). A two-tailed t-test revealed a statistically significant difference between the groups (t=6.26, df=18, p=0.0001), indicating that the CSA self-assessment plus remediation approach significantly improved student achievement in science compared to standard review practices.

Additionally, participants in the experimental group reported a greater ability to identify and correct their own misconceptions after engaging in the self-assessment process, similar to the participants of the middle school reading study. Many expressed increased confidence in their understanding of long-term implications of concepts presented in the ecology guide, highlighting the method's effectiveness in reinforcing critical reasoning. In contrast, control group participants largely relied on prior knowledge and struggled to pinpoint specific knowledge gaps, suggesting that traditional study methods may be less effective in encouraging scientific understanding.

DISCUSSION

This study aimed to evaluate the effectiveness of self-assessment techniques in aiding high school students to identify and address knowledge gaps in education. The results of this study demonstrate that the application of Cognitive Structure Analysis (CSA) combined with targeted remediation significantly enhances scientific understanding and overall achievement among middle school students. The experimental group, which employed self-assessment techniques to identify specific conceptual gaps and address them directly, outperformed the control group by an average of 20.5 percentage points. These results were consistent with previous research, such as Prakash and Leddo's (2025d) study on middle school reading comprehension, which reported gains of 16.6 percentage points through self-assessment methodologies, and Ravi and Leddo's (2024) chemistry research, which observed a 15-point improvement.

Building upon these findings, the present study examined the effectiveness of self-assessment in improving middle school students' scientific understanding. The 20.5 percentage point increase found in the present study suggests that CSA may enhance students' ability to analyze and

ISSN: 2455-8834

Volume:10, Issue:04 "April 2025"

interpret complex scientific concepts. Given that the ecology guide provided to the students discusses complex and nuanced themes within biology, the ability to assess and remediate comprehension gaps could be particularly beneficial in fostering deeper engagement, awareness, and critical thinking.

The implications of these findings are significant for science education. Scientific concepts are often taught through rote memorization rather than deep conceptual understanding. Self-assessment empowered students to actively engage with the material, encouraging metacognition and a clearer grasp of complex processes such as energy flow and ecosystem dynamics. This aligns with the goals of formative assessment in science, which emphasize continuous reflection, feedback, and refinement of understanding. By integrating self-assessment into science instruction, educators can foster more interactive, inquiry-based environments that promote long-term retention and application of scientific knowledge.

Psychologically, the use of self-assessment techniques has been shown to enhance students' self-efficacy and confidence in their academic abilities. Participants in the experimental groups of both the science and reading comprehension studies reported a greater sense of control over their learning process and an increased ability to critically evaluate sources, arguments, and literary texts. This aligns with Nehra and Leddo's (2024) findings that self-assessment builds self-efficacy, a critical component of long-term academic and professional success. This empowerment is crucial in developing independent learners who can navigate complex information and construct well-informed perspectives. Such skills are essential not only for academic success but also for informed citizenship and lifelong literacy.

From a broader perspective, implementing self-assessment strategies in reading comprehension education can contribute to educational equity. Students from diverse backgrounds bring varied prior knowledge and experiences to the classroom. Self-assessment allows for differentiation, enabling each student to identify and address their unique learning needs. This personalized approach can help bridge achievement gaps and support all students in reaching their full potential.

Future research should explore CSA's long-term effects on students' critical thinking, literary analysis, and retention of knowledge. Investigating the integration of self-assessment with other instructional strategies, such as collaborative learning, digital literacy tools, and AI-based tutoring systems, could provide insights into creating comprehensive educational approaches. Additionally, examining the impact of self-assessment on diverse populations can inform inclusive teaching and learning practices that address the needs of all learners.

ISSN: 2455-8834

Volume:10, Issue:04 "April 2025"

In conclusion, this study reinforced the effectiveness of self-assessment in scientific education, highlighting its potential to transform traditional teaching methods. By enabling students to actively engage with science content while reflecting on their understanding, self-assessment fosters deeper learning and critical thinking. Embracing this approach can lead to more equitable and effective educational experiences, preparing students to thoughtfully engage with complex ideas and apply analytical skills to real-world contexts.

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Volume:10, Issue:04 "April 2025"

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ISSN: 2455-8834

Volume:10, Issue:04 "April 2025"

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