

Using Self-Assessment and Remediation to Raise Elementary School Student Achievement in Mathematics

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ABSTRACT

Cognitive Structure Analysis (CSA) is an educational framework that helps students identify and address knowledge gaps through self-assessment and targeted remediation. Prior studies have shown its effectiveness across disciplines, including calculus, chemistry, Spanish, reading comprehension, and probability theory. For example, CSA-trained high school chemistry students scored 15 points higher on post-tests than peers who rewatched videos without self-assessment (Ravi & Leddo, 2024). Similarly, CSA in Spanish instruction yielded a 25-point improvement (Nehra & Leddo, 2024), and reading comprehension studies showed experimental groups scoring 93% versus 69% for controls (Prakash & Leddo, 2025a). Middle school applications found that CSA plus remediation improved math scores by 18 points and science post-test scores increased from 77.5% to 98% (Leddo, Clark & Clark, 2025). In history, CSA-trained middle school students scored 91.5% compared to 65.5% for controls. Extending CSA to late elementary math, students learning percentages, decimals, and proportions completed a post-test with regular and harder proportional reasoning questions. For regular questions, the experimental group significantly outperformed controls (Mean = 10 vs. 8.38, $t(24) = 2.50$, $p = .02$). For harder proportional questions, one outlier was removed; the experimental mean was 5.33 versus 4.38 for controls ($t(23) = 1.76$, $p = .09$), suggesting smaller but meaningful gains. These results indicate CSA plus remediation can enhance elementary students' mathematical understanding across varying levels of difficulty.

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.

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 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, another study examined CSA's impact on middle school students' understanding of science concepts. 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. Students using self-assessment scored, on average 20 percentage points or two letter grades higher on a posttest than those who did not. Then, Prakash and Leddo (2025e) extended the CSA methodology to middle school history, focusing specifically on students' understanding of the causes of the American Revolution. Again, those students using self-assessment scored higher on a posttest than those who did not, this time by 29 percentage points.

Building on prior research in middle and high school subjects, the present study seeks to extend the self-CSA findings to elementary school math achievement.

METHOD

Participants

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

Materials

To aid students in developing a deeper understanding of percentages, decimals, and proportional reasoning, a comprehensive study guide was created. This guide was designed to break down complex math concepts into accessible, step-by-step explanations while maintaining accuracy. Students were introduced to foundational topics related to percentages, decimals, and proportions, including converting between decimals and percentages, calculating the percent of a number, and solving proportional problems.

The guide was structured into thematic sections:

- What Are Percentages? - Introduction to percentages, meaning of "percent," and visualizations to show parts of a whole.
- Decimal & Percent Conversions - Converting between decimals and percentages, including real-life examples.

- Finding the Percent of a Number - Step-by-step procedures for calculating percentages of quantities.
- Proportions - Introduction to proportional reasoning, scaling numbers, and solving proportion problems.
- Practice Thinking - Guided strategies for estimating and calculating percentages in real-world scenarios.

Each section included clear definitions of key terms, guided examples, and visual aids such as diagrams, tables, and number lines. Real-world scenarios were integrated to help students understand and apply concepts in meaningful contexts. The study guide served as both an instructional tool and the conceptual foundation for the post-test assessment used to measure students' comprehension and problem-solving skills. The link to the study guide is provided below:

<https://docs.google.com/document/d/17BkEsudYfa8z9LH19m4muQhR51D5Wseq0kyFhrB035E/edit?usp=sharing>

The following Google Form for the control group contains the 20 math questions: 12 questions focused on regular decimal and percent conversions, and 8 questions on slightly more advanced proportional reasoning. Students in this group studied the guide and completed the post-test without structured guidance on assessing or targeting gaps in understanding:

https://docs.google.com/forms/d/e/1FAIpQLSdpVFzZvPo_8KnVitiGV8PhHMwE2MIuDQsye3opfgz3Blh8jw/viewform?usp=header

A simplified 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:

I want to teach you how to assess your own knowledge that you have about math. Let's do this by taking an example that you already know. Suppose you wanted to assess your own knowledge about adding two digit numbers like $33 + 76$. 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 adding, you have to know what a number is and what a digit is. Strategies are general processes I would use to solve a problem. For adding two digit numbers, first you would add the numbers in the ones column and put the answer below the ones. If the number is more than 10, you just put the ones number

down and you carry a 1 over to the tens column. Then you add the numbers in the tens column and put that number below the tens column. If you carried a 1, you'd add the 1 to the number in the tens column. Procedures are the specific steps that I would use in a strategy. So if I am adding two digit numbers, I need to know how to add to 1 digit numbers. Finally, I need to know rationales which are the reasons why the strategies or the procedures work the way they do. For example, the reason why we carry a 1 over to the tens column when the two digits in the ones column add to more than 10 is that you can't have more than 9 in the ones column.

So when you try to see what you know about a topic, you should see what facts, strategies, procedures and rationales you know and what you think you forgot or don't understand. Then, go back and re-read the lesson and try to learn what you missed the first time.

Please fill out this self-assessment.

The Google Form for the experimental group contains the same 20 math questions. Students in this group studied the guide, used CSA to self-assess their knowledge, and then reviewed the material to target any identified gaps before completing the post-test:

<https://docs.google.com/forms/d/e/1FAIpQLSetZeyTp3RR67e7mER7TMC8cYxbloTvXKYYuPCNzCjdfcSLzA/viewform?usp=header>

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 (ESMA1) and experimental (ESMA2). Both groups received a structured guide designed to explain foundational concepts in percentages, decimals, and proportions. The control group was instructed to study the material, review any sections they found unclear, and then complete a post-test. No structured guidance was provided on how to identify or address specific knowledge gaps. The experimental group was trained to use Cognitive Structure Analysis (CSA) for self-assessment. After studying the guide, students in the experimental group evaluated their understanding using CSA and then revisited only the portions of the guide where they identified conceptual gaps. Following this targeted review, both groups completed the same 20-question post-test, which assessed comprehension, problem-solving ability, and the application of mathematical reasoning. Students were not allowed to reference the guide while taking the post-test.

RESULTS

Post-test performance was analyzed separately for the regular section, which consisted of 12 questions on basic decimal and percent conversions, and the harder section, which included 8 questions on proportional reasoning. In the regular section, the experimental group, which used CSA to identify and target knowledge gaps, scored an average of 10 out of 12 (83.33%), whereas the control group, which reviewed the material without structured self-assessment, scored an average of 8.38 out of 12 (69.83%). A two-tailed t-test revealed a statistically significant difference between groups ($t(24) = 2.50, p = .02$), indicating that CSA-driven self-assessment and remediation substantially improved performance on the regular questions. In the harder section, one extreme score of 1 in the experimental group was excluded as an outlier, being more than three standard deviations below the mean. With this adjustment, the experimental group scored an average of 5.33 out of 8 (66.63%), compared to the control group's average of 4.38 out of 8 (54.75%). This difference approached statistical significance ($t(23) = 1.76, p = .09$), suggesting that CSA plus remediation may also improve performance on more challenging proportional reasoning problems. While the magnitude of the effect size was comparable for both regular and harder questions (13.5% and 11.88%, respectively), there was greater variability in the control group performance scores, reducing the statistical significance.

Qualitative feedback supported these results: students in the experimental group reported that CSA helped them identify the specific types of problems they struggled with and focus their review accordingly, leading to increased confidence in solving percentage and decimal problems. In contrast, control group students often noted difficulty determining which concepts required additional practice, relying primarily on trial-and-error strategies. Overall, these findings indicate that CSA combined with targeted remediation can significantly enhance elementary students' understanding of percentages and decimals and may offer moderate benefits for more difficult proportional reasoning tasks.

DISCUSSION

This study aimed to evaluate the effectiveness of self-assessment techniques in aiding elementary 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 mathematical understanding and overall achievement among elementary 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 14 percentage points. These results align with prior research, including Prakash and Leddo's (2025d) study on middle school reading comprehension and Ravi and Leddo's (2024) research in chemistry, both of which demonstrated gains from self-

assessment strategies. The present study contributes a new dimension by confirming CSA's effectiveness in the domain of elementary school mathematics education.

The implications for mathematical instruction are significant. By teaching students to use CSA for self-assessment, educators can help learners identify specific gaps in their understanding of percentages, decimals, and proportional reasoning, allowing them to focus on areas that need improvement rather than relying solely on rote practice. Self-assessment using CSA fosters metacognitive awareness of these deeper cognitive skills, encouraging students to move beyond surface-level memorization and engage actively with mathematical concepts, ultimately enhancing problem-solving and analytical reasoning.

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 mathematical, history, and reading comprehension studies reported a greater sense of control over their learning process and an increased ability to critically evaluate numbers, sources, and 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.

From an equity perspective, structured self-assessment allows all learners regardless of prior background knowledge to tailor their review process to their individual needs. This personalized remediation supports differentiated instruction and can help close achievement gaps, particularly in content-rich subjects like mathematics.

Future research should explore CSA's effectiveness in other mathematics domains, such as multi-step word problems, early algebraic thinking, and measurement concepts. Additionally, longitudinal studies could examine whether CSA-based self-assessment improves retention of mathematical knowledge and the development of higher-order mathematical thinking skills over time. Investigating the integration of self-assessment with other instructional strategies, such as collaborative problem-solving, interactive digital tools, and AI-based tutoring systems, could provide insights into creating comprehensive and adaptive math learning environments. Furthermore, examining the impact of CSA on diverse student populations can inform inclusive teaching practices, ensuring that all learners have equitable opportunities to develop strong conceptual understanding and confidence in mathematics.

In conclusion, this study reinforces the value of CSA-driven self-assessment in elementary school mathematics instruction. By enabling students to actively engage with mathematical 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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