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

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ABSTRACT

Cognitive Structure Analysis (CSA) is an assessment framework designed to identify and address students' knowledge deficits. Through self-assessment students can identify their own knowledge gaps, 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 students learned an advanced chemistry topic by watching a video. Half of the students rewatched to reinforce their understanding, while the other half were trained to use CSA to self-assess their knowledge and then rewatched the video specifically to remediate assessed knowledge gaps. The CSA-trained group outperformed the control group by 15 points (1.5 letter grades) on a post-test. This finding was replicated with other high school students in the subjects of Spanish (Nehra and Leddo, 2024), reading (Prakash and Leddo, 2025a), math (Prakash and Leddo, 2025b) and history (Prakash and Leddo, 2025c). The present study continues the investigation of CSA in academic concepts through analyzing its impact in algebra, particularly that of the exponential topics. 19 middle school students were divided into two groups. Both groups studied two videos about the exponentials, but only the experimental group used CSA to self-assess their knowledge and remediate gaps. Post-test results revealed the significant statistical difference between the control and experimental groups, the control scoring an average of 42% compared to the experimental group's 70.4%.

INTRODUCTION

Throughout history, assessment has served as a measure of students' learning. Traditionally,

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“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 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

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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 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 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%). Prakash and Leddo (2025c) followed up their previous studies showing a similar effect for the subject of history.

All of the previously cited studies investigating self-assessment and remediation were done with high school students. This study extends the previous self-assessment plus remediation work with high schoolers to see if self-assessment using CSA plus remediation can raise student achievement in middle schoolers.

METHOD

Participants

19 male and female Coherence Learning Center (tutoring center) students were selected to participate in this study. All students were middle school students, and they were not paid for their participation.

Materials

A Google Form for the control group with two learning videos for exponents, and a 15 question comprehension test is provided below.

https://docs.google.com/forms/d/e/1FAIpQLScBESLJl23GPhieLYU0WJ0MRHGe-g8XLxKjqnRgwHNXeQ8UxQ/viewform

A self-assessment was created in order to help students in the experimental group re-evaluate their understanding of the content provided in the videos. It showed an example of a student self-assessing knowledge of a mathematical concept that included facts, strategies, procedures, and rationales. It was modeled after the self-assessment template previously reported in Ravi and Leddo (2024).

Self-Assessment: Algebra

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. Fact 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 equally to another expression and the two expressions are joined by an equal

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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 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.

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.

A Google Form for the experimental group with the 2 learning videos, algebra self-assessment, and 15 comprehension questions is provided below.

https://docs.google.com/forms/d/e/1FAIpQLSf7o91fmJszSNqEbwQXaHs_zWSmW0J6sgU6tOtXA0FP-lytfA/viewform?usp=header

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In addition to the math 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 (HA1) and experimental (HA2). Both groups received 2 videos explaining how to simplify exponents. 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 videos, participants in the experimental group evaluated their understanding using CSA and revisited the material to address knowledge gaps before taking the same post-test as the control group. The post-test included 15 questions assessing conceptual understanding and rationales. Participants were not permitted to access the videos or outside resources when answering the questions.

RESULTS

The participants' data were analyzed by examining the number of correct responses on the post-test. The results revealed a statistically significant difference in performance between the two groups. The control group (RA1) achieved a mean score of 6.3/15 (42%), while the experimental group (RA2) scored an average of 10.56/15 (70.4%). Statistical analysis yielded a t-value of 2.70, df = 17, p = .015, confirming the statistical significance of the difference. Individual scores further emphasized this disparity, with the lowest score in the control group being 0/15 (0%), whereas the lowest score in the experimental group was 6/15 (40%). The experimental group demonstrated both a higher mean and a higher floor in performance.

DISCUSSION

This study aimed to evaluate the effectiveness of self-assessment techniques in aiding middle school students to identify and address knowledge gaps in mathematical education. The findings indicate a significant improvement in the experimental group's performance, with a 28.4% higher mean score compared to the control group. These results are consistent with previous research, such as Nehra and Leddo's (2024) study on Spanish language acquisition, which reported substantial gains through self-assessment methodologies, and Ravi and Leddo's (2024) chemistry research, which observed a 15-point improvement. This study extends the application of self-assessment to algebra education, a field that benefits from critical thinking and understanding. It is worth noting that while the improvement in the middle schoolers' scores

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with self evaluation was comparable to the improvement in high schoolers, their overall scores were lower. This may be due to the advanced content or due to the middle schoolers' younger age, lengthening their learning process.

The notable 28.4% improvement observed in this study suggests that self-assessment may offer unique advantages in algebra education. Algebra, with its emphasis on critical analysis and interpretation of real life scenarios, allows students to engage deeply with content, facilitating the application of algebraic equations in real life. This process promotes a more nuanced understanding of math and algebra. The structured nature of self-assessment enables targeted reflection, improving students' ability to connect algebra concepts.

The implications of these findings are significant for educational practices. Traditional math instruction often relies on passive learning methods, which may not effectively address individual learning gaps. Self-assessment empowers students to take an active role in their learning journey, fostering autonomy and self-regulation. This approach aligns with the goals of formative assessment, which emphasizes continuous feedback and adjustment to improve learning outcomes. By integrating self-assessment into algebra curricula, educators can create a more interactive and personalized learning environment.

Psychologically, the use of self-assessment techniques has been shown to enhance students' self-efficacy and confidence in their academic abilities. Participants in the self-assessment groups generally report a greater sense of control over their learning process and an increased ability to critically evaluate historical sources and arguments. 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 historical information and construct well-informed perspectives. Such skills are essential not only for academic success but also for informed citizenship.

From a broader perspective, implementing self-assessment strategies in algebra 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 self-assessment with CSA and remediation's effects on middle students' knowledge of other subjects and even on that of elementary school students. Investigating the integration of self-assessment with other instructional strategies, such as collaborative learning and technological instruction, could provide insights into creating comprehensive educational approaches. Additionally, examining the impact of self-assessment

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on diverse populations can inform inclusive teaching and learning practices that address the needs of all learners.

In conclusion, this study reinforces the effectiveness of self-assessment in algebra education and highlights its potential to transform traditional teaching methods. By enabling students to actively engage with mathematical content and reflect 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 the past and its implications for the present and future.

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