

Incorporating Student Self-assessment and Remediation into Classroom Instruction Greatly Improves Educational Performance in Elementary School Math Students

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ABSTRACT

In previous papers, we have shown that students can be taught to self-assess their own knowledge and knowledge gaps and, by relearning the subject matter with an eye to filling in those knowledge gaps, can improve their performance on tests by an average of 15 to 25 percentage points. These previous studies involved the researchers in the self-assessment interventions, either by managing the instructional process or assisting with the creation of the instructional materials and/or post-tests. In order for an educational intervention to be scalable, it needs to be administered solely by the educators without outside help. Additionally, for the intervention to be attractive to the educational community, it should be free/low cost and minimally disruptive to how teachers conduct their classes. In the present study, a teacher of 40 4th grade math students in Hyderabad, India taught her students arithmetic operations the way she normally does. After her customary formative test, she gave half the students our self-assessment template for math and told the students to fill out the template each day. A few days later, the teacher gave the students her usual final exam on the unit. Those who did not receive the template showed no improvement in performance between formative assessment and post-test. Those who did receive the self-assessment template, on average, improved their performance by 16.5 percentage points from formative to final exam and scored 18.5 percentage points higher on the final exam than those who did not receive the self-assessment template. Both of these differences were statistically significant. Results suggest that incorporating self-assessment and remediation into normal classroom instruction can lead to significant improvements in educational performance with minimal disruption to classroom teaching. Moreover, the results also indicate that without the self-assessment and remediation method,

teachers may find a point in which their continued teaching produces no further gain in student learning, something that can be overcome by adding self-assessment and remediation.

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 a query-based 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; Challagulla and Leddo, 2025).

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. 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. 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 posttest 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 posttest 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 (Prakash and Leddo, 2025e). Then, Prakash and Leddo (2025f) 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.

Following this, Prakash and Leddo (2025g) tested whether self-assessment and remediation would work with elementary school students. This research showed that elementary school students using self-assessment and remediation for math scored an average of 83% on a posttest while those who simply reread the material scored an average of 70%. They also showed that using self-assessment and remediation raised elementary students' reading scores by an average of 20.5 percentage points (Prakash and Leddo, 2025h).

All of the above results were conducted with American students and students in K-12. Sathiyamoorthy and Leddo (2025) investigated whether self-CSA plus remediation would boost performance in college students in Scotland. Here, the testbed was college psychology. Students using self-assessment scored 15 percentage points higher than those who simply reread the material. This study was followed up by one testing whether self-assessment and remediation would raise physics scores of 8th grade students in China (Chen and Leddo, 2025a). In that study, those students using self-assessment and remediation scored 23 percentage points higher than students who did not. Chen and Leddo (2025b) followed up that study with 2nd grade reading students in China and found that those using self-assessment and remediation scored 15 percentage points higher on a post-test than those who did not. Challagulla, Challagulla and Leddo (2025) found that elementary school students in India who used the self-assessment method scored 22% higher on a reading post-test than those who did not.

The studies done in the US and other countries all involved a similar format in which the experimenters administered the instructional sessions and/or prepared the instructional materials and post-test to be used. This is appropriate to establish experimental control when exploring a new topic and engaging in systematic replication. However, for the self-assessment and remediation technique to be useful in the classroom, it must also work when incorporated into a classroom's normal mode of operation without the participation of the experimenters.

The goal of the present study is to conduct such an investigation in which students use the self-assessment and remediation technique while attending their normal classes and taught the normal lessons by their teachers.

METHOD

Participants

40 male and female 4th grade students from Manchirevula Government School in Hyderabad, India were selected to participate in this study. All the students were only a few days into their math unit focusing on three-digit multiplication, division, addition and subtraction. None of the Participants had prior knowledge regarding this unit.

Materials

The educational content for the students was provided by the school, based on its syllabus.

The Participants in the self-assessment condition were also given a model script, translated to Telugu, so that they could use it to teach themselves how to self-assess. The script illustrates the process of self-assessment for adding two-digit numbers. The script is shown below in English.

Script for Self-Assessment:

“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 you want to be able to solve problems like these, you 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 you 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 you would use

in a strategy. So if you are adding two-digit numbers, you need to know how to add two 1-digit numbers. Finally, you 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."

The post-test given to all Participants to display their knowledge was provided by the school. The test was also part of the school's original lesson plan.

Procedure

After the teacher gave the initial arithmetic instruction, she gave a 10-question formative test to see where the students were in their learning. This test was part of the normal teaching process and was not done specifically for this study. After the formative test was given, the class of 40 was split into two 20-student groups, and the teacher explained how to use the template to the students in the self-assessment group. Both groups were then taught by the teacher as they normally would, but the self-assessment group implemented the template at the end of each week to review the topics. The students wrote down what they learned after reviewing their knowledge based on their self-assessment, the teachers checked this at the end of the week to keep the students accountable. This process went on for 3 weeks. The teachers used the results of the self-assessment to help them teach the students better, giving them more clarity in the topics where they were struggling. It is worth mentioning that these results were used to help all 40 students, not just the students using the template. At the end of the unit, the teacher provided the students with a final exam, which also served as a post-test for this study. The post-test contained 10 questions about three-digit multiplication, division, addition and subtraction. Each student took a different test to ensure that cheating would not occur.

RESULTS

The Participants' responses to both the formative and final exams were scored by the teacher as part of her normal classroom grading. All test scores are out of 10 possible points. The test scores were shared with the researchers, so they could evaluate the effectiveness of the self-assessment technique. Average scores from the formative and final tests are shown in Table 1, broken down by condition.

Table 1: Formative and Final Test Scored Broken Down by Condition

	Formative Test	Final Test
No self-assessment	4.95	5.25
Self-assessment	5.45	7.10

It appears, at first glance, that the average formative test scores in the self-assessment group were higher than those in the no self-assessment group. While this could potentially create less room for improvement when using the self-assessment template, it turns out that the difference in formative test scores between the no self-assessment and self-assessment groups was not statistically significant, $t < 1$.

The next analyses that were done were to determine whether students improved their performance between the formative test and the final test. For the no self-assessment group, such improvement, if any, would result from the additional instruction provided by the teacher and the additional practice they received from homework and classroom activities. For the self-assessment group, such improvement would result from the additional instruction, practice given by the teacher, and the self-assessment and remediation they did. The data showed that, on average, no self-assessment students' scores increased an average of .30 between the formative test and the final test. This increase was not statistically significant, suggesting that no self-assessment students showed no improvement as a result of additional teaching and practice. Moreover, seven of the 20 students had scores that actually decreased between formative test and final test.

For the self-assessment group, the average difference between the formative test and the final test was 1.65 points. This improvement was statistically significant, $t(19) = 11.00$, $p < .0001$. Unlike in the no self-assessment group, no student in the self-assessment group had a lower score on the final test than on the formative test. In fact, every student showed improvement, except one who scored 9 out of 10 on both tests, suggesting a ceiling effect.

The next analysis examined whether the increase of 1.65 correctly answered questions between final test and formative test for the self-assessment group was statistically higher than the .30 increase for the no self-assessment group. This difference, too, was statistically significant, $t(38) = 4.12$, $p = .0002$. The final analysis was a direct comparison of final test scores between the two groups, comparing the means of 7.10 and 5.25 for the self-assessment and no self-assessment groups, respectively. This difference was statistically significant, $t(38) = 3.81$, $p = .0005$.

DISCUSSION

This study aimed to evaluate the effectiveness of Cognitive Structure Analysis (CSA) in helping elementary school students in India self-assess and remediate knowledge gaps in mathematics. The findings demonstrate that CSA-trained students significantly outperformed their peers, with the experimental group scoring an average of 18.5 percentage points higher than the control group. These results align with earlier research, such as Prakash and Leddo (2025g), who reported a 13.5 percentage point improvement in elementary school math in United States students using CSA to self-assess.

The present study is noteworthy in comparison to our previous research in the area of self-assessment and remediation. First, and most importantly, in our previous studies, we the experimenters were involved in the experiment, either by conducting the actual study with the Participants and/or creating the instructional materials and tests that were used in the study. Given that any educational intervention has value only if it can be turned over to educators and have them incorporate that intervention into their daily teaching, preferably with minimal disruption, the present study is a demonstration that self-assessment can, in fact, be incorporated into a classroom and still produce large educational gains. Moreover, the burden on the teacher is virtually non-existent. What could be easier than handing the students a sheet of paper, asking them to fill it out and then checking once a week to make sure they do?

Second, the present study represents the first of our studies where the self-assessment process was used on an ongoing basis rather than as a one-time intervention. Ideally, self-assessment would be something that students do regularly (even if not every day). While a firm conclusion cannot be reached from just this study, the fact that the present study found an 18.5 percentage point improvement in performance for those who used self-assessment compared to those who did not, whereas in Prakash and Leddo (2025g), there was just a 13.5 percentage point improvement, may suggest that extended use of the self-assessment and remediation process may lead to larger educational gains than just a single use. More research in this area would be beneficial.

The third noteworthy finding is that, after the formative test, additional instruction by the teacher did not result in improved student performance on the final exam. In fact, 35% of the students actually showed lower performance on the final test than on the formative test. On the other hand, when adding self-assessment and remediation, students receiving the same instruction as those in the no self-assessment condition showed a statistically-significant 16.5 percentage point improvement in performance with all but one student improving performance (that student plateaued at 90% on both exams).

While it is not clear from the present study whether the improvement in performance in the self-assessment condition students was due to the self-assessment alone or the combination of self-assessment plus additional teacher instruction, it is useful to note that, on average, improvement in the present study did not occur without self-assessment and, in our previous studies, students did show comparable improvement as in the present study without additional teacher instruction and with only self-assessment and remediation. Regardless of whether the teacher's instruction was necessary to produce the educational gains observed in the self-assessment condition students between the formative test and final tests, the self-assessment and remediation activities by the students were necessary to show a higher average performance on the final exam. It is important to note this, since often when new educational interventions are offered to the educational community, there is often pushback based on the claim that teachers are too busy to take on new activities. If the present study's results are illustrative of a widespread phenomenon, the implication is that additional instruction reaches a point of diminishing returns such that a small portion of the teacher's time is better used by introducing the self-assessment technique to students and ensuring that students use it. In terms of return on investment of time spent, this minor investment of time yields far bigger increases in student performance than investing 100% of a teacher's time in teaching alone.

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