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Improving Student Performance by Having Students Assess and Remediate Their Own Knowledge Deficiencies

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ABSTRACT

Previous papers have presented an assessment methodology called Cognitive Structure Analysis (CSA) that assesses a student's knowledge of a subject rather than looking simply at whether students can give the correct answer to a set of questions. The results of these CSA based assessments were reliable in predicting problem solving performance. In Cynkin and Leddo (2023), it was shown that students could be taught to use CSA to self-assess their own calculus knowledge. Dandemraju and Leddo (2024) extended these findings to the subject of chemistry. This present study replicates the previous studies and extends the research question to whether students can effectively remediate their own knowledge deficiencies after self-assessing them. The subject area used was electrochemical cell questions found on the Medical College Admission Test. 18 high school students were taught the concept of electrochemical cells using a YouTube video whose audience was MCAT test-takers. After watching the video, half were taught to self-assess using CSA and told to rewatch the video to fill in any knowledge gaps. The other half were simply told to rewatch the video if they felt there were things they did not understand. Both groups were then given a post-test on the material they just learned.. The results showed that students who were taught to self-assess had an average post-test score of 16.67 out of 20 or 83.4%. Those who were not taught to self-assess had an average post-test score of 13.56 out of 20 or 67.8%. These results showed that students can be taught to self-assess and remediate their own knowledge and knowledge deficiencies, respectively. Implications for education at the societal and individual student levels are discussed.

INTRODUCTION

For as long as education has existed, assessment has been a form of measurement of how much students have learned the content they were taught. The definition of "learning the content" has been operationally defined by the number of correct answers a student has answered on a test.

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According to classical test theory, a major pillar of the assessment methodology assumes that the total number of correctly answered test items indicates the student's level of knowledge (cf., de Ayala, 2009).

A variety of assessment frameworks have been adapted by teachers. These can be categorized by whether students are asked to select the correct answer from a set of answer choices, or asked to construct their own answer. Multiple choice tests require students to select answers from several distractors and are widely used in standardized testing due to its ease of grading (Chaoui, 2011). However, students often score higher on multiple choice tests than they do on constructive response tests as students can increase their scores through guessing (cf. Elbrink and Waits, 1970; O'Neil and Brown, 1997). The second method of assessment used are constructive tests, which require students to enter responses to questions, rather than choose from a preselected group. Students are more likely to reason logically when given constructive tests, making the test more valid when measuring students' actual knowledge (Herman et al., 1944; Frary, 1985).

However, there is a challenge with the key assumption of classical test theory in that correct answers indicate learning. A student who makes a lot of mistakes on a test probably lacks a fundamental understanding of the knowledge tested (unless there was an outside factor affecting the testing environment). However, a student who may get correct answers on a test can have knowledge deficiencies. They could simply be getting lucky by parroting facts or formulas that they do not understand, or guessing correctly on multiple choice exams. The lack of correct answers does not inform the teacher what concepts need to be reiterated and an incorrect answer to a test question may indicate an underlying knowledge deficiency.

Previously, we have reported an assessment methodology called Cognitive Structure Analysis (CSA) that is designed to assess the underlying concepts a student has, so that when a student does in fact make a mistake, the source can be identified and remediated (Leddo et al.,

2022; Ahmad and Leddo, 2023; Zhou and Leddo, 2023; Dandemraju, Dandemraju, and Leddo, 2024). CSA is based on decades of cognitive psychology research that have shown that people possess a variety of knowledge types, each of which is organized and used differently in problem solving. As there are different types of knowledge, the framework is an integration of several prominent and well researched formalisms. These include semantic nets, which organize factual information (Quillian, 1966); production rules, which organize concrete procedures (Newell and Simon, 1972); scripts, which are general goal based critical thinking strategies (Schank and Abelson, 1977; Schank, 1982); and mental models, which explain the principle behind concepts (deKleer and Brown, 1981). This framework is known as INKS, also known as Integrated Knowledge Structure. Developed by John Leddo (Leddo et al., 1990), this framework suggests

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that expert knowledge is organized around these scripts and principles that allow people to construct explanations and make predictions in situations.

In order to identify the root cause of the mistake, we used a query-based assessment framework called Cognitive Structure Analysis (CSA, Leddo et al., 1990)., which incorporates principles from the INKS knowledge representation framework. In recent research, assessments produced by CSA correlated .966 with problem solving performance in Algebra 1(Leddo et al, 2022), 0.63 with problem solving in the scientific method (Ahmad and Leddo, 2023), and 0.80 with problem solving performance in precalculus (Zhou and Leddo, 2023).

The value of CSA as an assessment tool is that it provides educators with a proper means of assessing what concepts students have and are lacking, so that appropriate remedial instruction can be provided. In fact, we have shown that when students are assessed using CSA and the assessed INKS knowledge components that they are deficient in are remediated, they score 10 points or a full letter grade higher than if they are assessed using the traditional "solve the problem and show all work" method and the missed steps are then corrected (Leddo and Ahmad, 2024).

While the previous research shows that CSA is highly diagnostic of what students know and predictive of performance, and student performance can be significantly improved by remediating INKS knowledge rather than missed problem solving steps, the onus of doing so is placed on the teacher, who may have difficulty assessing each of his/her individual students. An alternative paradigm is to teach students to self-assess, diagnose their own learning needs and provide their own remediation. Self-assessment is different than self-explanation (cf. Chi et al., 1989). The latter refers to explanations that people generate about material that they are learning. Self-explanation can help people learn material better. Self-assessment refers to a person's assessment of his/her own knowledge after s/he learns the material.

A previous paper (Cynkin and Leddo, 2023), explored whether high school students taking calculus could be taught to self-assess their own knowledge using CSA and in doing so, potentially identify gaps in their knowledge that might be responsible for mistakes that they make or times when they feel stuck when solving problems. Cynkin and Leddo found that students could be taught to assess their knowledge accurately. Dandemraju, Dandemraju and Leddo (2024) extended this work to show that students could also accurately self-assess their knowledge of chemistry.

The previous papers on self-assessment address only half the issue. Of course, students need to be able to accurately assess their knowledge in order to remediate any deficiencies. However, accurate assessment is not the same as remediation, any more than an accurate medical diagnosis

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equals a treatment. The present paper seeks to address the second half of the research question, namely, can students effectively use their self-assessments to remediate deficiencies in their knowledge and in doing so, raise their performance?

This question was investigated in the context of teaching Medical College Admission Test concepts, specifically electrochemical cells.

METHOD

Participants

18 male and female magnet high school students were selected to participate in this study. All students had taken honors chemistry, while some were also taking AP chemistry. This difference provided a wider range of expertise on a potential chemistry topic. None of the participants had knowledge regarding specific topics seen on the MCAT.

Materials

The educational content for electrochemical cells was provided by a YouTube video. The link for the video is shown below.

Electrochemical Cells: https://www.youtube.com/watch?v=PscoxVdwkSk

The Participants in the self assessment condition were also given a model script that they could use to teach themselves how to self-assess. The script illustrates the process of self-assessment for solving equations in Algebra 1. The script is shown below.

Script for Self-Assessment:

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.

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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.

The post-test given to all Participants to display their knowledge is linked below.

https://docs.google.com/forms/d/e/1FAIpQLSeUsjTgHKXkkqJCd0kQ_X8JuDD7Ycan7GKZ5qwjeNF046kPTw/viewform?usp=sharing

Procedure

Participants were randomly assigned to each condition. Instructions were provided on Google Forms, one for each condition. The Google Forms contained the links to the videos, instructions after watching the videos and the post-test. The control group Google Form told the Participants to watch the video. After watching, Participants were told that if they felt there was something in the video that they did not understand, they should go back and rewatch the video. After that, they took the post-test on the Google Form itself. The experimental group Google Form also told the Participants to watch the video. However, after watching the video, experimental group Participants were given the self assessment script and then were asked to create a self assessment based on their understanding of the topic contained in the video. Participants wrote their self assessments on Google Forms. In the self assessment, they were asked to follow the same format as the one found in the script. After the self assessment, they were given the same post-test as the control group. The post test contained questions that were direct recall, situation based, along

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with 1 outlier question that did not cover information from the video, ensuring that cheating did not occur.

RESULTS

The analysis of the Participants' data was conducted by evaluating the number of correct answers on the post test. The analysis of the post test responses showed a range of scores with a mean post-test score of 13.56 out of 20 (67.8%) and 16.67 out of 20 (83.4%) in the control group and experimental group, respectively. The difference in the means was statistically significant, $t = 3.02$, $df = 16$, $p = .008$. Moreover, the individual scores in these groups were noteworthy. In the control group, the highest score was 17, meaning no student would have received an A grade by conventional grading standards. In the experimental group, the lowest score was 14, meaning the lowest grade any student would have received would have been a C under normal grading standards.

Subjectively, Participants in the experimental group reported the self-assessment method to be helpful and expressed interest in utilizing this method of assessment into their current study habits, suggesting this method not only works, but would also be adopted. Meanwhile, the control group did not find any benefit in rewatching the video, as they lacked a visual and written understanding of what they understood and what they did not.

DISCUSSION

This study aimed to assess whether students could successfully self-assess their own chemistry knowledge and remediate any knowledge deficiencies. The results of the study were successful, as the students were able to self assess and remediate the MCAT concept they were introduced to. It was found that self-assessing and remediating knowledge deficiencies led to 15 percentage points or roughly one and one-half letter grades higher on the post-test. These results suggest that teaching students to self-assess and remediate their own knowledge needs could have tremendous benefits at both the societal and individual levels.

At the societal level, for decades, the majority of US students have performed below grade level in core academic studies. Traditionally, it has been the burden of teachers to assess and remediate the needs of their students, a daunting task when teachers can teach over 100 students per day. The present results show that an enormous burden can be lifted from the educational system by having students self-assess and remediate their own educational needs. It is noteworthy that not a single student in the experimental condition scored below 70% on the post-test, meaning no student would have failed the otherwise difficult lesson and test. While these results may not hold up for every student worldwide, it is notable that the lowest score in the experimental group post-test was higher than the average score in the control group post-test.

Moreover, students were able to learn to self-assess and remediate by reading a one-page set of instructions, a process that takes approximately 10 minutes to complete. We are hard pressed to imagine other interventions that can be implemented for free, that can scale to an entire population, and that produces such large and immediate results.

There are additional benefits at the student level. Every day, there are millions of students worldwide who learn a lesson and have the response, “I don’t get it.” Such frustration can be a blow to a student’s self-esteem and love of learning. As members of the educational community, we have seen countless students who view themselves as poor learners or who shy away from certain subjects that they have internalized that they just cannot learn. Teaching them to self-assess and remediate can empower students to master subjects that they otherwise might fail.

Finally, in today’s world, we see self-directed learning on the rise as the Internet offers virtually unlimited opportunities for people to learn. One challenge is that often people may not know how well they have really mastered the material. They might watch a YouTube video and feel that they understood the material but have no way of knowing how much they learned or the level of their understanding (recall that the INKS framework that the CSA self-assessment technique is based on includes knowledge structures representing different levels of abstraction and complexity). In fact, Leddo, Clark and Clark (2021) found that both middle schoolers and adults were unreliable at determining how well they understood what they just learned. The present self-assessment framework provides people with a formal framework to self-assess and remediate, thereby enhancing to people’s self-directed learning.

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