

Improving Science Scores of Middle School Students with Learning Disabilities through Engineering Problem Solving Activities

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Abstract

This study evaluated the differential effects of three different science teaching methods, namely engineering teaching kit (ETK), explicit instruction (EI), and a combination of the two methods (ETK+EI), in two sixth-grade science classrooms. Twelve students with learning disabilities (LD) and/or attention deficit hyperactivity disorder (ADHD) participated in this study. The dependent variables included students' performance on daily quizzes covering the material taught in that day's lesson and students' performance on a pretest and two posttests covering the steps of the engineering problem solving process. Using a multiple probe across science units design, we demonstrated that both the ETK and EI interventions alone increased the participants' quiz scores, with the combined method (ETK+EI) producing slightly better results in most participants. Students' understanding of the engineering problem solving process also improved after being exposed to the ETK method. Limitations, suggestions for future research, and practical applications are discussed.

Improving Science Scores of Middle School Students through Engineering Problem Solving Activities and Explicit Instruction

The principles of science allow a deeper understanding of the physical world surrounding us. The application of this knowledge to solve real world problems forms the basis of engineering. For students to be successful in the 21st century, they must be able to make connections between science, technology, engineering, and math (STEM) principals. It is, therefore, important for teachers to create a learning environment that exposes students to scientific concepts and problem-solving skills through K-12 science curriculums to adequately build students' science knowledge and skills. Current education policies and practices, such as No Child Left Behind (NCLB, 2002), have placed emphasis on higher level instruction that is reinforced through an increase in teacher accountability and is measured with high-stakes standardized end-of-year assessments in content areas including science. These test results are often analyzed to determine the percentage of students performing below basic level, at basic, proficient, or at advanced level. According to the 2005 Nation's Report Cards in science assessments (Grigg, Lauko, & Brockway, 2006), less than 30% of all fourth, eighth, and twelfth grade students achieved at or above proficiency level, a trend that has persisted since 1996. This lack of growth in science achievement for all students indicates a dire need for more effective science instruction in K-12 schools.

With increasingly diverse science classrooms, teachers are further charged with differentiating their instruction to meet the needs of all students. For example, students with a learning disability (LD) or an attention deficit hyperactivity disorder (ADHD) face unique challenges due to their difficulty with information processing, retention, and other learning deficits. Steele (2007) outlines some of the specific challenges students with LD or ADHD face. Specifically, these students often have difficulty in visual processing, deficits in auditory processing, a lack of motor processing skills, and memory deficits. These challenges can affect a student's ability to analyze tables, graphs, or diagrams, to follow step-by-step directions or to understand materials presented solely in lecture formats, to perform specific laboratory tasks, and to memorize key facts that link with higher-level analytic questions (Steele, 2007). Additionally, receptive and expressive language deficits can further hinder students' ability to communicate clearly using newly attained vocabulary from science lessons. The problems associated with the inability to focus on the teacher or the given assignment can also lead to incomplete written work or laboratory experiments (Steele, 2007). Due to these issues, teachers often find it difficult to effectively provide scientific pedagogy to students with LD or ADHD.

In response to the aforementioned challenges students with LD or ADHD face, teachers need the skills and expertise required to teach a diverse classroom (Biddle, 2006; Grumbine & Alden, 2006). Steele (2007; 2008) outlines possible solutions that teachers can implement in the science classroom to make students more successful. First, teachers can make the material more specific to the students' interest. This allows students to connect what they are learning to previous experiences while gaining their interests. Second, varying teaching methods and activities will facilitate students' access to the material and concepts through different mediums including visual and auditory presentations, hands-on activities, and technology simulations. Third, teachers should model different learning strategies including (a) organizing information into graphic organizers, (b) utilizing the "key questions" often presented at the start of a unit in science textbooks to help make predictions, (c) creating mnemonic devices to help remember the order of events or key facts, and (d) reviewing relevant vocabulary words before beginning each lesson (Steele). Although these suggestions seem promising, empirical research on how to best teach science to students with LD or ADHD is currently limited.

Science Instruction

Most research addressing science instruction in K-12 classrooms has compared the efficacy of three different methods that combine some aspects of Steele's (2007) suggestions for teaching science including (a) the "textbook" approach, (b) explicit instruction, and (c) hands-on, inquiry based instruction. The textbook approach, also called the traditional approach, relies heavily on teacher lectures, students' note taking, and concepts and activities outlined in the classroom textbook. In this approach, the teacher guides instruction while the students passively participate (McCarthy, 2005). Explicit instruction, also referred to as direct instruction, differs from the traditional approach by requiring the educator to teach in small steps, guide students through initial practice with the skills, and provide students with several different levels of practice (McCleery & Tindal, 1999). This approach is also teacher directed, but it allows for more active student involvement. The hands-on, inquiry learning differs from both the textbook approach and explicit instruction in that the teacher facilitates instruction by providing opportunities for the

students to ask questions, explore the material through student-designed experiments, and draw conclusions based on their results (McCarthy, 2005).

Four recent studies examined and compared the efficacy of various forms of these aforementioned methods for teaching science. McCleery and Tindal (1999) compared the effects of explicit, rule-based instruction with the hands-on approach on students' ability to explain and apply the scientific problem-solving process. Fifty-seven sixth grade students, including 14 students with LD, received a combination of these two teaching conditions in three different groups. Group 1 received instruction that incorporated specific rules for performing various tasks into the explicit instruction and combined this with hands-on activities. Group 2 received a similar combination of techniques without the explicit instruction of science concepts. Group 3 received hands-on activities without any explanation of the concepts covered. The results indicated that the students who received a combination of explicit, rule-based instruction with the hands-on approach performed better on the final assessment. Similarly, McCarthy (2005) compared the effects of the textbook approach with hands-on, inquiry learning on science achievement for 18 middle school students with serious emotional disturbances. Group 1 received the textbook approach and Group 2 received instruction using hands-on activities. The results of this study indicated that Group 2 scored better on the hands-on assessment and short answer assessment than Group 1. Both groups performed similarly on the multiple-choice assessment. The author suggests that these results most likely derived from the fact that the students who received the hands-on instruction were more engaged utilizing diverse mediums during the class time than the students who passively participated in the textbook instruction.

Finally, Klahr and Nigam (2004) and Dean and Kuhn (2006) used similar methods to compare the efficacy of the explicit, direct instruction to hands-on, discovery learning. Both studies included 40 to 45 fourth grade students randomly divided into three groups. Group 1 received science instruction in the form of discovery learning, Group 2 received direct instruction, and Group 3 received a combination of discovery learning and direct instruction. Klahr and Nigam empirically demonstrated that direct instruction was more effective than discovery learning based on students' science performance. However, in examining the results over a 6-month time period, Dean and Kuhn found that the group who received only discovery learning instruction performed the highest on assessments at the conclusion of the study. The extent to which different science instructional approaches can lead to greater maintenance and generalization warrants further investigation.

Although each of these studies focused on different combinations of the three major teaching paradigms, they all concluded that implementing explicit instruction combined with hands-on activities yielded the most positive results. However, these studies indicated a need for further research to verify which method, combination of methods, and parts of the methods are the most effective and efficient for science instruction for students with LD and ADHD.

Engineering Problem Solving

Current assessments of educational opportunities and career paths for students indicate that there is a decline in the number of students pursuing engineering careers (Apedoe, Reynolds, Ellefson & Schunn, 2008; Brand, Collver, & Kasarda, 2008). This is more so for students with LD or ADHD who are severely underrepresented in science, technology, and engineering fields

(Alston, Bell, & Hampton, 2002). This may be attributed to a lack of efficient instruction and exposure to K-12 curriculums that discuss engineering concepts involving the application of knowledge to solve real-life problems (McCarthy, 2005). Additionally, the demand for the new generation of students to function in our increasingly technological and global society further challenges teachers to expose students to the concept of engineering by applying own understanding of math, science, and technology to solve real-life problems (TeachEngineering, n.d.). By incorporating applied engineering concepts into K-12 curriculums, teachers can provide students with applied, interdisciplinary units that require the combination of creative problem solving and application of knowledge to address real-life problems. These engineering teaching kits (ETKs) can likely motivate students to pursue a degree and career in engineering (Olds, Harrell, & Valente 2006).

According to the TeachEngineering (n.d.), the engineering problem solving process involves the following steps: (a) problem identification, (b) research of existing solutions, (c) applying knowledge of relevant fields to brainstorm solutions, (d) designing a solution, (e) testing the solution including data collection and data analysis, (f) reiterating the process as needed, (g) determining the social and ethical impacts of the design based on specified design constraints and criteria, and (h) implementing the design. Explicitly instructing and engaging students in the science and engineering steps will allow students to apply their understanding of the material while differentiating instruction and assessment through the multi-disciplinary units.

Current research on the efficacy of incorporating K-12 engineering applications in the science classroom is limited. Olds et al. (2006) discuss the implementation of an ETK in middle school classrooms aimed at informing students about what engineers do, engaging students in the engineering design process, and exposing students to real-world problem solving issues. Specifically, this ETK included a series of lessons and activities involving designing a functioning prosthetic arm. In the activities, the students followed the engineering design process while applying creativity and problem solving skills. The authors argue that based on the change in pretests and posttest scores, the students increased their understanding of the concepts addressed. However, this study lacked an experimental design; therefore, empirical conclusions about the effectiveness of a science ETK is not possible.

Clearly, the current literature lacks empirical research that examines effective methods for teaching science and engineering to students with LD or ADHD. The purpose of this study was to determine the effects of three different science-teaching methods on the performance of basic Earth science and the engineering problem-solving process of middle school students with LD and/or ADHD. These three treatments include: (a) explicit instruction (EI), (b) ETK, and (c) a combination of the two methods (ETK+EI). Specifically, this study was designed to evaluate (a) the differential effects of EI and ETK+EI on the science quiz scores of students with LD and/or ADHD (Class A), (b) the differential effects of ETK and ETK+EI on the science quiz scores of students with LD and/or ADHD (Class B), and (c) the differential effects of ETK or EI and ETK+EI on the pretest and posttests on the engineering problem solving process of students with LD and/or ADHD.

Method

Participants and Setting

The participants for this study were 12 sixth grade students in two science classes (i.e., Class A and Class B) in a suburban, private K-12 school in the southeast, United States. All participants were Caucasian males with LD and/or ADHD as defined by the state guidelines and were between the ages of 12 and 13. Class A had seven students; of whom, two were diagnosed with LD (Students A1 and A3) three were diagnosed with ADHD (A2, A6, and A7), and one had both LD and ADHD (A5). One student with ADHD was removed from the study due to extended absences. Class B had six students, including two students with ADHD (Students B4 and B5) and four students with LD (B1, B2, B3, and B6). All students diagnosed with LD had a significant learning deficit in written expression or reading comprehension. The participants were selected based on regular attendance, parental consents, and low science achievement.

The instruction at the school is specially designed for students with LD and ADHD. At the time of the study, there were 264 students attending the school, 12% of the student body was receiving financial aid, and 2% described their ethnicity as “other than Caucasian.” In both science classes, there was one special education teacher, who was also the primary experimenter. Both classes met four times each week for 45-min periods. The classroom was arranged with a whiteboard at the front of the room, three tables seating two students arranged in a horseshoe shape, and a LCD projector installed on the ceiling.

Experimenter

The primary experimenter and primary data collector was a state-endorsed highly qualified and certified special education teacher of the two participating science classes. At the time of the study she had 5 years of experience teaching middle school math and science to students of all abilities. She had a bachelor degree in mechanical engineering with experience in the engineering problem solving process. During the study, she was seeking a master’s degree in special education. The director of the school assisted in collecting procedural integrity data and interobserver reliability data.

Dependent Variables and Measurement

There were two dependent variables in this study that were measured using a permanent product recording method. The first dependent variable was the students’ ability to correctly answer questions relating to material covered from the McDougal Littell Science *Earth’s Surface* (Trefil, Calvo, & Cutler, 2005) textbook including three units: (a) technology used to view Earth and the Earth’s systems (unit 1), (b) weathering and soil formation (unit 2), and (c) minerals (unit 3). This was measured using a written assessment asking the students to answer 10 short questions requiring one- or two-word responses (e.g., “What is one example of something that is in the biosphere?”). All questions covered the material taught on that day. For baseline and maintenance data collection, questions were randomly chosen across quizzes used during interventions within the same unit. Students were given 5 min to complete a quiz at the end of each class period. The experimenter read aloud all quizzes to ensure students received the required accommodations. On some days, the students received up to two assessments on two different units in order to simultaneously collect baseline and intervention data across units.

The second dependent variable was the students' ability to correctly answer 10 questions about the engineering problem solving process in 5 min three times throughout the study (i.e., beginning of the baseline [pretest], following the first EI or ETK condition [posttest 1], and at the conclusion of the study [posttest 2]). These questions measured the students' understanding of: (a) the engineering design process, (b) possible careers in engineering, (c) required coursework for students pursuing engineering, and (d) possibilities for students who complete an engineering degree. The experimenter developed the questions based on the components of the engineering design process as well as the goals of engineering (i.e., to apply knowledge of math, science, and technology and creativity to design a solution for a defined problem). Items for the three assessments addressed the same material but were worded differently and randomly sequenced.

Interobserver Reliability

Interobserver reliability was measured for 32% of all unit quizzes and 33% of engineering quizzes across participants and experimental conditions by a trained adult volunteer using an answer key. An item-by-item method was employed to calculate the interobserver reliability by dividing the number of agreed items by the total number of questions (i.e., 10) and multiplying by 100. The results indicated a mean 99.1% agreement (range 80%-100%).

Social Validity

Social validity data were collected at the conclusion of the study. All participants completed a 15-item questionnaire that required the participants to rank each of the 12 items on a scale of 1 to 5 with 5 being strongly agreed and 1 being strongly disagreed. The areas included the degree to which the participants viewed engineering as important, they learned about what engineers do, and whether they liked and learned best from guided notes, brainstorming sessions, group work, class discussion, and/or explicit instruction. The last three items of the questionnaire were open-ended questions that asked the participants to describe the type of instruction in which they learned the most, the least, and their overall learning experience with science and engineering. The experimenter read these questions aloud to the entire class.

Experimental Design and Procedures

Two separate experiments were concurrently conducted in two different classes in this study. For Class A, we examined the differential effects of an ETK and the combination of ETK and explicit instruction (EI). For Class B, we examined the effects of EI compared to the effects of ETK+EI. This was designed to yield results that would help determine which method, or a combination of methods, was the most beneficial. For both experiments, the experimental design was a single-subject multiple probe (Horner & Baer, 1978) across three science units (unit 1: earth, unit 2: soils, unit 3: minerals). For both experiments, there were four conditions of baseline, intervention A, intervention B, and maintenance.

Baseline. During this phase, students received no science instruction. Baseline data were collected to determine students' pre-knowledge of the science contents.

Intervention A (ETK) for Class A. The ETK instruction for Class A consisted of a series of activities that were either adapted from the Engineering Teaching Kits from the TeachEngineering Resources for K-12 (TeachEngineering, n.d.) or developed by the experimenter. The lessons and activities published on the TeachEngineering website were peer-

reviewed and classroom tested. The activities chosen or developed for this study met the following criteria: (a) provided students access to the material from the McDougal Little Science *Earth Surface* textbook while including at least one aspect of the engineering design process, (b) were age and grade-level appropriate, and (c) were implemented in one 45-min class period.

The experimenter spent the first 5 min of class by presenting the students with the engineering design process worksheet and defining engineering problem of the day. The experimenter then spent 15 min providing students with background information needed to solve the problem and the opportunity to brainstorm possible solutions as well as defining expectations for the tasks to be completed. This information was dictated by the ETK that had been selected for that day to cover the relevant material. The students then spent 15 min completing the daily worksheet as they conducted the associated engineering activity. During this time, the experimenter circulated throughout the room to ensure that students stayed on task. Students were allowed to ask questions about the procedures during information collection, but the experimenter did not explicitly instruct the students on data analysis or the engineering process. The next 5 min were spent meeting as a class to discuss results and ideas. In the last 5 min of class, the students turned in their completed work and completed the daily quiz.

During this phase, the daily lessons were planned to address at least one step in the engineering design process. Due to the depth of this process and the time it would take to have the students complete the entire lesson, the entire engineering design process could not be implemented in one 45-min class period. However, at the end of the three science units, the students had been exposed to all steps of the engineering design process. For example, one lesson in the soil unit required students to focus on defining various problems that could occur with soil (e.g., not enough nutrients for plants to grow or poor composition that would easily erode in rain fall). The next lesson required the students to research existing solutions to the defined problem. In the third lesson, the students had to brainstorm possible solutions that would work better based on what they had learned about the properties of soil. Each of these lessons focused on one aspect of the engineering design process; but across lessons, students had the opportunity to build upon their previously knowledge to master the entire engineering design process.

Intervention A (EI) for Class B. The explicit instruction for Class B consisted of a series of activities developed by the experimenter that included the required components of explicit instruction (i.e., model-lead-test). Similar to Class A, daily activities chosen for this study meet the following criteria: (a) provided students with access to the material from the McDougal Littell Science *Earth Surface* textbook (Trefil et al., 2005), (b) were age and grade-level appropriate, and (c) could be implemented in one 45-min class period.

The experimenter spent the first 4 min of class introducing the topic. The next 36 min were separated into three 12 min segments. In each segment, the experimenter modeled the guided notes for the lesson. Guided notes were premade notes with blank spaces that the students completed. These notes were projected on the whiteboard so the experimenter could fill in the correct answers while soliciting student responses. The experimenter then led the students through the practice problems. Finally, the experimenter tested the students with the relevant independent practice. During this time, the experimenter circulated throughout the room to ensure that students stayed on task and explicitly instruct the students if questions arose. For

example, while the students were answering questions about the different properties of minerals following guided notes on this topic, the experimenter would guide the students to the correct answer by leading questions. Then, the experimenter would reinforce the concepts by asking the students questions about what was just discussed. In the last 5 min of each class, the students turned in their completed work and completed the daily quiz.

Intervention B (ETK+EI) for Classes A and B. The intervention B for both classes combined the ETK with EI in basic Earth science and the engineering problem solving method. During this phase, the experimenter spent the first 5 min explicitly instructing students about the engineering design process and defining the engineering problem of the lesson. The next 5 min were spent with the students brainstorming possible solutions to the problem. The experimenter then spent 10 min presenting relevant background information using the “model-lead-test” method. Following this, the students had 15 min to complete the related engineering activity in a group. As the students conducted the activity, the experimenter circulated the room and asked probing questions (e.g., “What if the design constraints required the engineer to choose a mineral that had a hardness greater than 5?”) to monitor students’ understanding. The final 5 min were spent taking the daily quiz.

Maintenance. The maintenance phase began when the students had completed the material covered in each unit. Maintenance of these skills was measured using the same format as the daily quizzes with randomized selection of questions across lessons within that unit. Instruction on the specific unit during the maintenance phase was unavailable.

Procedural Reliability

Procedural reliability was established through the use of three pre-made checklists to ensure that each intervention was implemented correctly. Each checklist corresponded to the type of instruction that was implemented: ETK instruction (13 items), EI instruction (22 items), and ETK+EI instruction (18 items). The director of the middle school employed procedural reliability measurements by conducting observation sessions during 30% of the intervention sessions to determine the extent to which the experimenter conducted the instructional procedures correctly. The director chose the observed sessions randomly, blind to the experimenter. The procedural reliability was calculated by dividing the number of components completed correctly by the total number of components possible and multiplying this by 100. The procedural reliability indicated a mean of 98.9% with a range of 92.3% to 100%.

Results

Science Quiz Scores

Differential effects of ETK and ETK+EI for Class A. Students A1 through A6 received the ETK instruction, followed by the ETK+EI instruction in a staggered format across the three science units, therefore allowing the experimenter to evaluate the additive effects of ETK+EI over the ETK instruction. During the baseline condition, the quiz scores for all participants were equal to or lower than 3.0 across all units with the exception of one data point of the Minerals unit for participant A4, A5, and A6 (see Figure 1). During ETK, all participants made improvements in quiz scores for all units with the class mean scores of 7.46, 7.39, and 6.57 for

Earth, Soil, and Minerals units, respectively (see Table 1, upper panel). A visual analysis of the graphs indicates that there were no overlapping data points between the baseline and ETK conditions, except unit 3 for participants A4 and A6, suggesting that ETK had a clear positive effect on students' quiz scores. During the ETK+EI condition, all but participants A5 and A6 slightly improved their mean quiz scores when compared to those during the ETK instruction, with the class mean of 7.92 for Earth unit, 8.67 for Soil unit, and 9.29 for Minerals unit. However, such improvement was not conclusive for all participants based on visual analyses of the data. During the maintenance condition, the majority of participants in Class A remained at a level of correct responses similar to that during ETK+EI, with the overall class mean of 8.88, 8.39, and 8.78 across the three units.

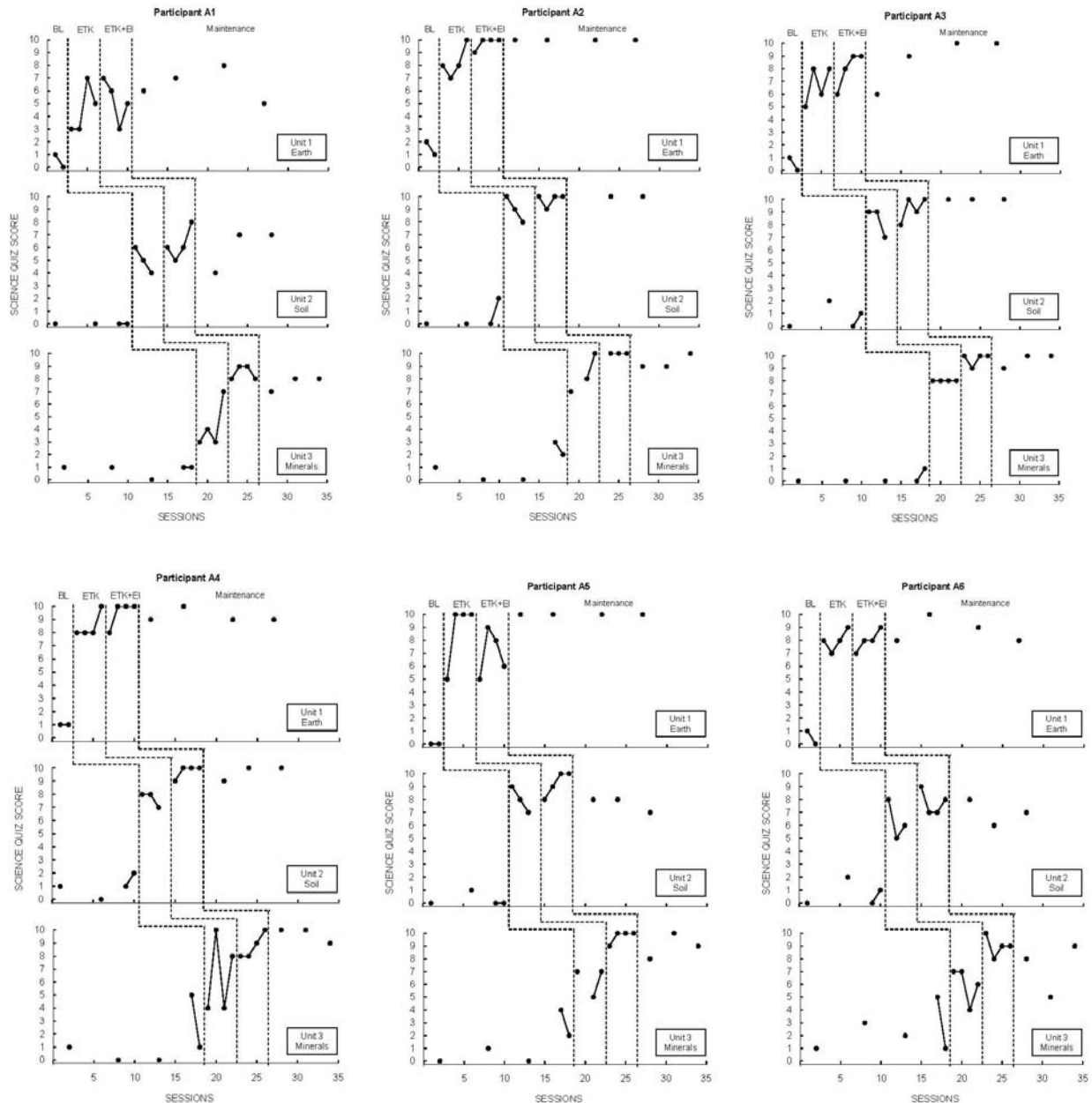


Figure 1. Participants' science quiz scores across experimental conditions in class A.

Table 1

Participants' Mean Scores on Science Quizzes across Three Units and Experimental Conditions in Classes A and B

<i>Class A</i>												
Stud.	Unit 1: Earth				Unit 2: Soil				Unit 3: Minerals			
	BL	ETK	+EI	Maint.	BL	ETK	+EI	Maint.	BL	ETK	ETK+	Maint.
A1	0.50	4.50	5.25	6.50	0.00	5.00	6.25	6.00	0.80	4.25	8.50	7.67
A2	1.50	8.25	9.75	10.00	0.50	9.00	9.75	10.00	1.20	8.33	10.00	9.33
A3	0.50	6.75	8.00	8.75	0.75	8.33	9.25	10.00	0.20	8.00	9.75	9.67
A4	1.00	8.50	9.50	9.25	1.00	7.67	9.75	9.67	1.40	6.50	8.75	9.67
A5	0.00	8.75	7.00	10.00	0.25	8.00	9.25	7.67	1.40	6.33	9.75	9.00
A6	0.50	8.00	8.00	8.75	0.75	6.33	7.75	7.00	2.40	6.00	9.00	7.33
Class Mean	0.67	7.46	7.92	8.88	0.54	7.39	8.67	8.39	1.23	6.57	9.29	8.78

<i>Class B</i>												
	Unit 1: Earth				Unit 2: Soil				Unit 3: Minerals			
	BL	EI	+EI	Maint.	BL	EI	+EI	Maint.	BL	EI	ETK+	Maint.
B1	0.00	5.50	8.75	8.75	0.50	7.67	9.25	8.67	0.80	6.00	8.00	6.00
B2	0.50	5.50	8.25	8.75	0.00	6.33	8.50	7.00	0.00	5.75	9.50	7.33
B3	0.00	5.00	8.75	8.75	0.50	7.00	8.25	8.00	0.80	5.25	7.00	7.00
B4	0.00	9.50	8.00	9.50	0.25	9.33	9.50	9.00	0.20	7.50	10.00	9.33
B5	1.00	7.50	7.50	8.50	0.25	8.33	9.25	8.50	1.20	7.25	9.33	8.33
B6	0.50	7.25	8.00	8.50	0.75	8.67	9.25	9.00	1.40	6.25	9.50	8.33
Class Mean	0.33	6.71	8.21	8.79	0.38	7.89	9.00	8.36	0.60	6.35	8.77	7.60

Differential effects of EI and ETK+EI for Class B. In contrast to Class A, students B1 through B6 received the EI instruction, followed by the ETK+EI instruction allowing the experimenter to evaluate the additive effects of ETK+EI over the EI instruction. During the baseline conditions, all students' data remained low and stable with only two data points (i.e., for participants B5 and B6 on the Minerals unit) that were above 2.0 correct answers. During EI, all participants achieved clear improvement in quiz scores (see Figure 2) for all units with the class mean scores of 6.71, 7.89, and 6.35 for Earth, Soil, and Minerals units, respectively. A visual analysis of the graphic displays shows that there were no overlapping data points between the baseline and EI conditions across all units, except for participant B3. This suggests that EI contributed to the improvement of students' quiz scores for all units. During the ETK+EI condition, all participants except B4 and B5 slightly improved their mean quiz scores when compared to those during the EI instruction, with the class mean of 8.21 for Earth unit, 9.00 for Soil unit, and 8.77 for Minerals unit (see Table 1, lower panel). However, such improvement was clearer for participants B1 and B2 than others according to visual analyses of the data. During the maintenance condition, the majority of participants in Class B remained at a level of scores similar to that during ETK+EI, with the overall class mean of 8.79, 8.36, and 7.60, respectively.

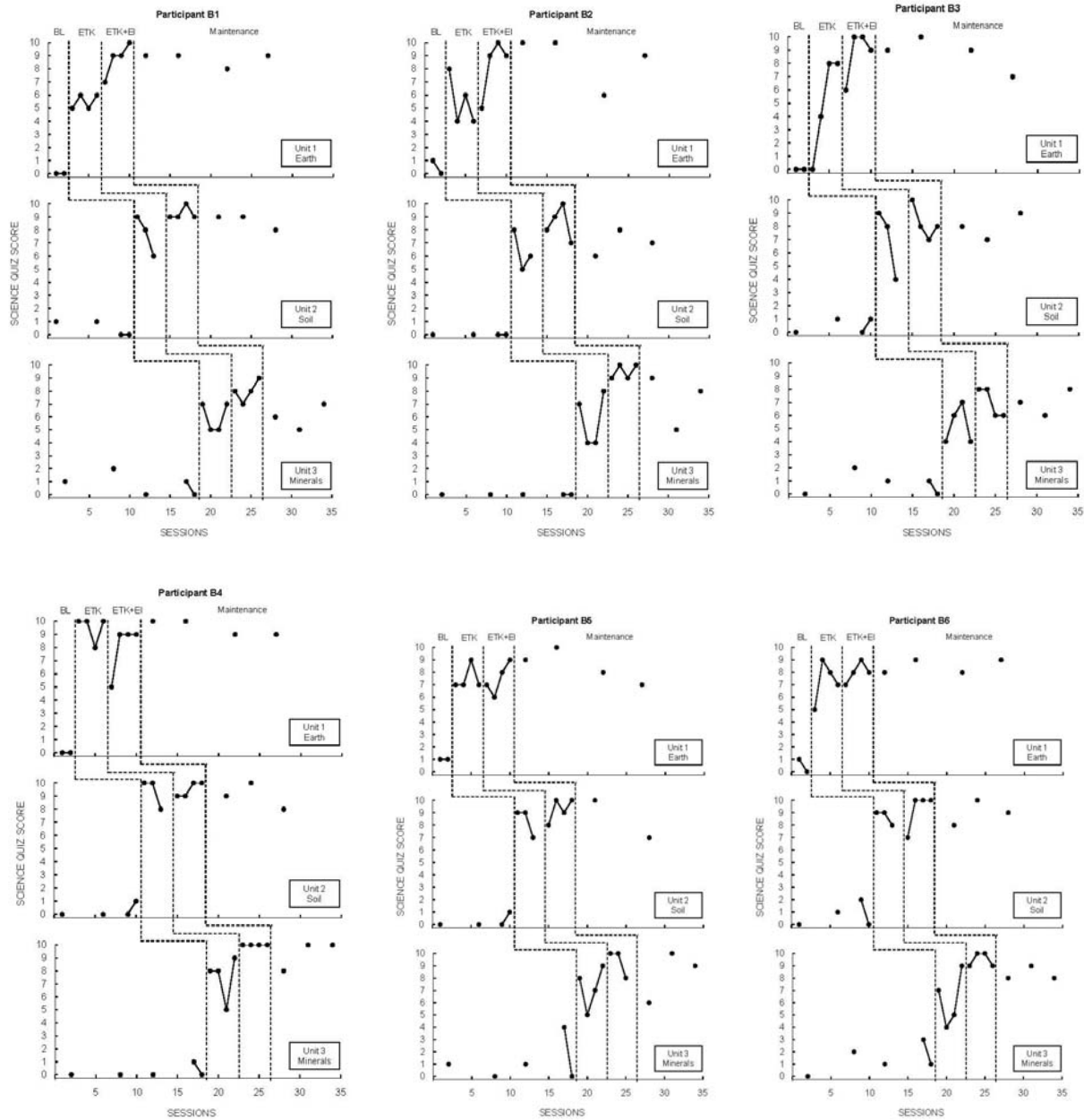


Figure 2. Participants' science quiz scores across experimental conditions in class B.

Engineering Problem Solving Knowledge

Class A. The pretest data collected for Class A indicated that participants A1 through A6 answered zero to two questions correctly, with the class mean of 0.8 correct responses on the engineering problem solving knowledge test. In the first posttest, all participants except A1 improved their accuracy in the engineering problem solving process, with a range of 2.0 to 7.0 correct and a class mean of 4.0 correct after receiving four sessions of ETK instruction. On the second posttest, all participants in Class A improved their score by at least 3 correct answers (see Figure 3).

Class B. Similar to Class A, the pretest results for participants in Class B indicated that majority of the students did not have a clear understanding of the engineering design process. Participant B6 received the highest number of correct responses of five among his peers. At the end of the initial four sessions of EI instruction (i.e., Earth unit), three of the six participants in Class B scored lower on the first posttest when compared to their pretest scores. On the second posttest, the five participants who completed the test all scored higher by at least 30% more than the pretest and first posttest, with a class mean of 9.2 correct responses (see Figure 3).

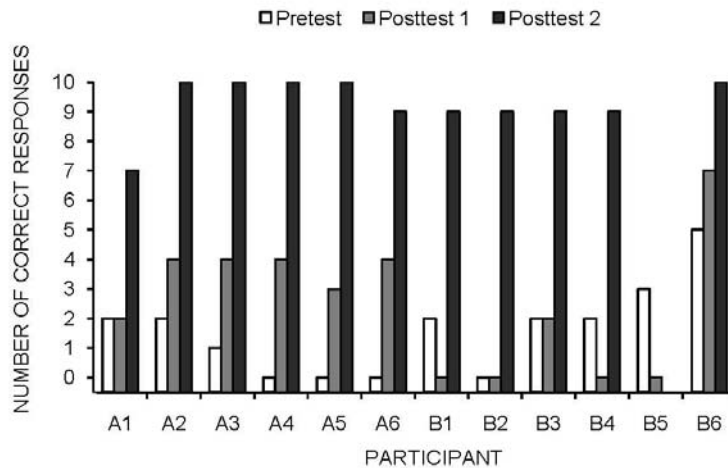


Figure 3. Number of correct responses on the pretest and posttests of the engineering design process.

Social Validity

Class A. Overall, the data from the social validity questionnaire indicated that the participants in Class A agreed or strongly agreed that learning about engineering is important. They also agreed that guided notes, class discussion, learning problem-solving process, and explicit instruction helped with their understanding of science and engineering concepts, and that they better understood what engineering entails. Furthermore, three of the six participants in Class A strongly agreed that working in groups helped their learning. The activity students disliked the most was working in groups. For the open-ended questions, most students responded that they had positive experiences with the engineering based activities and guided notes. For example, participants A1, A3, A5, and A6 all listed “activities” as a part of instruction that helped them learn the science concepts the best. Three students expressed that guided notes did not help them as much as the activities. When asked about their learning in science and engineering concepts, five of the six participants in Class A responded positively. For instance, participants A1 and A3 both expressed that they want to become engineers when they get older. Student A5 expressed dislike of the engineering concept by indicating “I didn’t like engineering because other things interest me more.”

Class B. The data for Class B indicated that students agreed or strongly agreed that guided notes, class brainstorming sessions, and explicit instruction helped them better understand the concepts in class. Additionally, five out of the six students agreed or strongly agreed that they understood

what engineering is. Five students agreed or strongly agreed that working in groups to solve an engineering problem helped them better understand the material. Out of these four students who responded to the open-ended questions, all indicated that they thought the engineering based activities helped in their learning of the concepts. Only one student, B1, expressed dislike of the guided notes. When asked to describe their learning in science and engineering concepts, two out of the four students, responded “great” and “fun.”

Discussion

The purpose of this study was to determine the differential effects of three different science-teaching methods (i.e., ETK, EI, and ETK+EI) on the basic Earth science performance and the engineering problem-solving process of 12 middle school students with LD and ADHD. The results of this study showed that both ETK and EI alone helped students gain an understanding of the science concepts when compared with the baseline condition. Additionally, the combined method of ETK+EI produced further improvements for most students on their quiz scores when compared to the individual interventions. Participants’ understanding of the engineering design process also improved as a result of being exposed to the ETK instruction. This study extends previous research in empirically investigating the effects of multiple science instructional methods for students with LD and ADHD, by specifically integrating engineering problem-solving process in the instruction.

Effects of ETK

The results from Class A suggest that using an ETK is an effective teaching method. These results are consistent with previous studies by McCarthy (2005) and Dean and Kuhn (2006) supporting the benefits of hands-on, application based instruction that can allow students to connect with science materials and offer them a multi-sensory approach to learning. In the current study, students received added instruction on the engineering design process during the ETK instruction. This component requires the students not only to become actively involved with the material, but also to apply their creativity to solve real-life problems. For example, in the soil unit, the students had to apply what they know about the properties of soil to assess the soil in their own yards and design a way to make their soil hold water for a pond. This required the students to implement the engineering design process to apply what they learned in previous lessons about soil properties, to test and determine the quality of their soil sample, and to brainstorm ideas to make their soil more viable for the defined design problem. These types of connections between what students have learned and real-life problem solving opportunities make the material more relevant and accessible to the students (Olds et al., 2006).

In addition to the improved science scores, the effectiveness of the ETK instruction is further supported by students’ demonstration of knowledge in the engineering design process as shown on the posttest results. Specifically, none of the students in Class A answered more than two items correctly on the pretest. On the first posttest, five of the six students increased their number of correct responses by two to four responses. Greater improvement was observed on the second posttest when the students had received 24 ETK lessons that covered the entire engineering design process. These results may be attributed to the repetition of the engineering design process and the student involvement in the various steps throughout the ETK and ETK+EI lessons. Contrarily, students in Class B did not improve their engineering problem-solving

knowledge until they received the ETK+EI instruction (i.e., posttest 2). This finding is not surprising as students' knowledge is unlikely to improve until they are directly taught.

Effects of EI

The results from Class B indicate that using EI in isolation is effective in improving students' science achievement. The data show that all students improved their daily quiz scores from baseline to the EI phase across all three science units. These findings are consistent with the study conducted by Klahr and Nigam (2004) indicating that explicit instruction is a beneficial way to teach students science concepts. Although explicit instruction does not allow the students to directly interact with real-life problems or apply their understanding of the material to daily situations, it requires students to actively respond to questions about the concepts explained explicitly. The repetition and systematic use of guided notes may have helped students understand the science concepts. This is supported by Klahr and Nigam, acknowledging that the provision of multiple exemplars and explicit explanations during science instruction can foster better students' understanding of difficult concepts than discovery learning.

Effects of ETK+EI

The purpose of examining the combination of ETK+EI was to determine if the combination of the two teaching methods would allow students to better access and employ the material. The combination of ETK+EI yielded greater improvement in daily quiz scores for most students in both Class A and Class B, when compared to ETK or EI alone. These results are consistent with the findings of McCleery and Tindal (1999), demonstrating that a combination of explicit instruction and hands-on learning experiences produced better student test results. In Class A, students' improvement in quiz scores was not substantial, which indicates that the additive ETK+EI instruction supports a continuation of students' understanding of the material. However, most students in Class B showed greater improvement in quiz scores during ETK+EI condition than those during the EI condition. This possibly suggests that the ETK component of the instruction has a stronger effect than the EI component because the ETK allows the students to use a multisensory approach to interact with the material while connecting the concepts to their every-day lives. Such interpretation needs to be made cautiously because the results are compared across two different classes.

Limitations and Recommendations for Future Research

There were three main limitations in this study that warrant future research. First, the study did not allow us to compare the effects of the ETK and EI alone because Class A and Class B received a respective intervention. Due to the limited number of lessons available within each unit and the nature of the experimental design, it is difficult to structure three conditions where we might compare ETK, EI, and ETK+EI within each class without possible carry-over effects. We chose to investigate the effects of ETK and EI separately in two classes to allow for more rigorous experimental control. Future research should compare the effects of these two interventions alone.

The second limitation concerns the implementation of the daily quizzes. This type of daily quizzing was a novel approach for most participants; thus, the written quizzes may not accurately represent what they know. We employed written assessments because we felt that it would help

prepare students for similar types of testing situations (e.g., standardized tests) in the future. Due to repeated measurement, students also may have become more accustomed to the type of testing, as shown in the slightly increasing scores during baseline for unit 3. Additional research is warranted to determine if different types of assessment would yield similar results.

The third limitation is related to the student demographics. In this study, all students were Caucasian males with LD or ADHD in a private school setting where class sizes were no larger than seven students per class. As a result, subject generalization is limited. Future research needs to determine if a similar study would yield similar results with participants of a more diverse demographic background, such as female students, students with different disabilities, students of different ethnicity, and students attending public schools.

Implications for Practice

Based on the results of this study, it is apparent that students who have been diagnosed with a LD or ADHD benefit from being exposed to a combination of explicit instruction and the applied engineering problem-solving process in the sixth grade science classroom. It is important to provide students with structure, guided notes, and repetition of the material. It may be more important to provide students with the opportunity to not only interact with the material in hands-on experiments, but also apply what they have learned to solve real-life problems using the engineering problem-solving process. The availability of structured and peer-reviewed online sources of engineering teaching kits, such as www.teachengineering.com, makes it more accessible for science teachers to engage students in engineering problem-solving process in daily instruction. These sources provide engineering background for teachers who may not be familiar with engineering concepts. Additionally, most of these ETK lessons require minimal time to prepare and few extra materials. By combining these readily available ETK lessons with teacher resources provided by state science textbooks, teachers can easily include both ETK and EI in science classrooms. This combination will provide students with a multisensory approach to access the content. It will also expose students to what engineering is, hopefully inspiring them to pursue careers in engineering to solve real life problems.

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