Spring 2019

Project-Based Learning with Student-Developed Models in the NGSS Curriculum

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Thesis Submitted in Partial Fulfillment of the Requirements for the

Degree of Master of Arts in Education

California State University, Monterey Bay

May 2019

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Abstract

The Next Generation Science Standards (NGSS) were implemented to increase students' scientific literacy, shifting the focus from teacher-centered to student-centered learning (NGSS Lead States, 2013). One result of this shift has been the increased use of project-based learning where learners can discover their own knowledge through a series of problem-solving tasks and projects. Student-developed models (i.e., three-dimensional models) is an application of project-based learning that has shown to increase students' science literacy in higher grades (Bell, 2010; Krajcik & Merritt, 2012). This study investigated the effectiveness of utilizing student-developed models among middle school students to create a deeper understanding of key concepts (i.e., analyzing and interpreting data, constructing explanations, and engaging in arguments from evidence) to improve scientific literacy. The study used a quantitative nonequivalent two-group pretest-posttest quasi-experimental design. The treatment group participated in designing, testing, and redesigning a student-developed model car made from various household materials. The control group participated in standard science instruction (i.e., laboratory experiments, online interactives, and note taking). After a four week learning sequence for Newton's Laws of Motion, the data was analyzed using independent and paired t-tests. The data concluded a statistically significant difference for the treatment group when compared to the control group. Future studies should measure motivation, as the engagement from the treatment group could have been a determining factor in the founding results.

Keywords: Next Generation Science Standards, Scientific Literacy, Project-Based Learning, Student-Developed Models, Three-Dimensional Models

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Literature Review

The Next Generation Science Standards (NGSS) provides a shift in science instruction from teacher-centered to student-centered, supporting the idea of discovery learning. Prior to the development of the NGSS, middle school students often exhibited low scientific literacy and difficulty connecting daily science content to larger scientific phenomena (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). Recent reforms in science education build on educational theories, such as discovery learning, to encourage students to construct their own knowledge in an inquiry-based process (Krajcik & Merritt, 2012). This inquiry-based pedagogical approach can be facilitated through project-based learning.

Project-based learning is a form of discovery learning that allows students to work collaboratively to solve real-world problems. Due to the implementation of the NGSS, the construction of knowledge from project-based learning, becomes a promising tool that may help increase students' scientific literacy (NGSS Lead States, 2013). Student-developed models (i.e., three-dimensional models) can serve as a product, when paired with project-based learning, to help explain key scientific concepts (i.e., analyzing and interpreting data, constructing explanations, and engaging in arguments from evidence). Therefore, through student-developed models, students may develop a deeper understanding of scientific phenomena, which may suggest an increase in scientific literacy (Krajcik et al., 2014). Ultimately, modern science educational practices stem from the transition of how science is taught within the classroom.

Science Classroom Instruction

As times change, so do teaching practices within the classroom. Traditional methods of teaching science consisted of memorization and regurgitation of facts. Given this type of approach, students often had a difficult time grappling with scientific concepts, which became evident in student work (Eisenhart, Finkel, & Marion, 1996). Science classes were teacher-centric, with teachers dispensing knowledge to a passive student audience, rather than teachers being facilitators of learning (Wise, 1996). Such classroom practices included chalk and talk methods; limited collaboration and group learning; and the improper alignment between objectives, activities, and assessments (Kubicek, 2005). Furthermore, traditional teaching methods placed a higher emphasis on test results, rather than the understanding of concepts. This has been a long standing concern in the educational field. For example, Dewey (1910) foreshadowed the limitations to science education by generalizing that the collection of final knowledge through tests is an inadequate measure of what a student knows. Therefore, students need numerous learning opportunities and modalities to demonstrate academic achievement. Multiple opportunities to indicate learning are needed across the curriculum, but are critical when discussing scientific literacy.

The importance of science literacy. Scientific literacy is defined conceptually by the National Research Council (2011) as the knowledge and understanding of science concepts and processes required for decision making, participation, and productivity. In the twenty-first century, students are expected to learn content through a multitude of platforms to meet various learning needs. Modern methods in education include the significance of collaborative learning, problem-based learning, skill building, and a technology-driven classroom (Kubicek, 2005). In a middle school science class, students analyze and interpret data tables, graphs, and other forms of evidence, which requires more than the memorization of facts. The development of scientific literacy, in meaningful contexts, can engage students in active inquiry and problem solving. Therefore, the use of problem-solving within a science class, can further support students' engagement in increasing scientific literacy (Council of Ministers of Education, Canada, 1997). In addition to student engagement, discovery learning may increase scientific literacy through students drawing their own conclusion to a scientific phenomenon using problem-solving skills.

Discovery learning in instruction. Bruner (1961), believed that the purpose of education is not to impart knowledge, but to facilitate a student's thinking and problem-solving skills. Therefore, teachers who facilitate the learning process allow students the chance to discover knowledge for themselves. The skills that students learn through discovery learning can then be transferred to a range of situations, inside the classroom and in the public domain. Furthermore, discovery learning, also known as inquiry learning, is gaining an increase in support throughout science education. Teachers are increasingly becoming interested in student learning through engagement, exploration, explanation, elaboration, and evaluation (NGSS Lead States, 2013). Current reforms in science instruction reflect ongoing development and implementation of curricula aligned to the NGSS. Through inquiry learning, the NGSS aligned curriculum is aimed to increase students' scientific literacy across all disciplines of science.

Next Generation Science Standards

The NGSS provides a way to teach science, through inquiry learning, with increased rigor. The NGSS uses discovery learning to teach students scientific content and develop scientific skills in the context of real-world phenomena (NGSS Lead States, 2013). That is, the NGSS aligned curriculum focuses on a deeper understanding of scientific literacy, not only memorization of facts, where students can apply their scientific knowledge beyond the classroom. Students are able to link science practices to daily challenges by planning and carrying out investigations, asking questions, developing and using models, and designing engineering solutions (NGSS Lead States, 2013). As a result, students are able to form deeper connections within the content and learn standards through an inquiry-based process (i.e., a lab investigation or a three-dimensional model) to develop physical representations of their newly-found knowledge. Thus, the framework of the NGSS aligned curriculum was created to help students formulate a deeper understanding of grade-level content (Krajcik et al., 2014).

The framework of the NGSS integrates three main aspects: Disciplinary Core Ideas, Science and Engineering Practices, and Crosscutting Concepts. Disciplinary Core Ideas are the scientific standards to understand for a given science discipline. Science and Engineering Practices are the processes that scientists use to understand information learned from observations or experiments. Lastly, Crosscutting Concepts are portable skills that can be used in other content courses or across science disciplines (NGSS Lead States, 2013). Krajcik and colleagues (2014) suggest the blending of these three dimensions, which allows students to make deeper connections, with the increased probability to solve problems and explain scientific phenomena. Ultimately, the integration of Disciplinary Core Ideas, Science and Engineering Practices, and Crosscutting Concepts explains the needed change of science instruction from teacher-centered to student-centered, where students can discover the "*how?*" and "*why?*" of science.

Student-Centered Learning

When a classroom operates with student-centered instruction, students and teachers share the focus of learning; interacting equally. Students learn from one another through the discussion of concepts and by working cooperatively on activities (Henry, Henry, & Riddoch, 2006). Furthermore, students become more interested in learning activities when they can interact with their peers and participate actively (Henry, Henry, & Riddoch, 2006; Krajcik & Merritt, 2012).

The development of the NGSS aligned curriculum creates the opportunity for students to take responsibility of their own learning by asking questions and completing tasks independently.

Student-centered learning provides a chance for greater exploration and investigation of scientific concepts (i.e., analyzing and interpreting data, constructing explanations, and engaging in arguments from evidence). The curricula aligned to the NGSS is organized into a coherent sequence of learning, and the standards allow students the opportunity to grapple with relevant questions to solve real-world problems (Holthuis, Deutscher, Schultz, & Jamshidi, 2018). Therefore, with the implementation of the NGSS, students' answers shift from only asking "*what?*" to wondering "*how?*" and "*why?*", providing the possibility to engage deeper in conceptual thinking. Ultimately, a student-centered science classroom becomes less like a traditional classroom when students can participate in hands-on learning, through the use of projects, to help increase scientific literacy (Holthuis, Deutscher, Schultz, & Jamshidi, 2018).

Project-Based Learning

Project-based learning is an effective framework to demonstrate student-centered learning in a NGSS aligned classroom. Project-based learning can be defined as a student-driven, teacher-facilitated approach to learning, which teaches a multitude of strategies critical for success in the twenty-first century (Bell, 2010; Blumenfeld et al., 1991). In using project-based learning, students develop a question to answer a scientific concept, and are guided through the inquiry process under a teacher's supervision.

Students are able to solve real-world problems, through project-based learning, because project-based learning is the basis of the curriculum and not a supplementary activity to support knowledge (Bell, 2010). Most projects include reading, writing, and mathematical calculations to support a justifiable answer to the developed question. In this case, through the framework of project-based learning, students not only follow the procedural steps of the scientific method, but strive for a deeper understanding of the content by asking new questions and creating artifacts (Blumenfeld et al., 1991). Using project-based learning, students work collaboratively to research, design, test, and redesign models that reflect their knowledge. The creation of models provides an opportunity for students to engage deeply with the target content, which can affect long-term retention through hands-on learning.

Models in Science

Modeling is a core practice in science, which supports scientific literacy (Schwarz et al., 2009). Models can vary from a drawing that is changed or expanded upon, a handmade three-dimensional representation, or a computer simulation to explain a unit of study that cannot be observed due to scale, time, safety or budget costs (Schwarz et al., 2009). Scientists use models to process, organize, and redefine their thoughts while synthesizing new information about the phenomena of study. Model development through the current implementations of the NGSS aligned curriculum provides students the chance to explore deeper into scientific phenomena to answer a question (NGSS Lead States, 2013).

Models should synthesize concepts in a unique way for students to be able to retain content knowledge to increase scientific literacy. In traditional teaching methods, models were constructed with predetermined supplies to create a three-dimensional representation to help explain a structure (i.e., the construction of a DNA strand or a replication of the solar system). However, models using the NGSS aligned curriculum goes beyond explaining structure and is intended to demonstrate key concepts (i.e., analyzing and interpreting data, constructing explanations, and engaging in argument from evidence) to explain and predict scientific phenomena (Krajcik & Merritt, 2012). Furthermore, Schwarz and colleagues (2009) state that if a model cannot account for evidence, then the model should not be used as a tool to explain a phenomenon. Thus, Science and Engineering Practices in the NGSS aligned curriculum allows students to use evidence to explain scientific discoveries by designing, testing, and redesigning models.

Student-Developed Models

A student-developed model is defined conceptually by Schwarz and colleagues (2009) as a three-dimensional model (i.e., an artifact) to demonstrate scientific knowledge through an investigative process. Three-dimensional models, such as artifacts, can include physical representations of a system, process, or design (Krajcik & Merritt, 2012). Constructing drawings or diagrams to represent systems or events that explains a scientific concept, provides students with a tangible product of their learning. The NGSS expects students to construct and revise models based on new evidence to predict and explain a scientific phenomenon (Krajcik & Merritt, 2012). The shift from researcher-developed models to student-developed models changes the way that science is learned within the classroom.

According to the NGSS aligned curriculum for middle school grades, students benefit from developing and using models to make connections to science phenomena (NGSS Lead States, 2013). Furthermore, middle school students start to think more abstractly than in lower grades, which suggests that creating models (i.e., artifacts) can be a starting point for students to express their knowledge (Wadsworth, 1996). It is essential for students to construct models that explain phenomena, show evidence within their models, and explain possible limitations of the created models (Krajcik & Merritt, 2012). Therefore, by designing models, students engage in scientific processes while taking ownership of the information learned. Student-developed models (i.e., a three-dimensional model) not only provides the understanding of a structure but the *"how?"* and *"why?"* a phenomenon is happening. With proper iterative process of construction and revision (i.e., redesign), the utilization of models, will provide explanation to larger scientific concepts. Through models, middle school students may form a view of science as an effective method of inquiry, serving as a productive twenty-first century skill and leading to higher scientific literacy (Krajcik et al., 2014).

Models provide scientists and engineers with tools for thinking, to visualize and make sense of phenomena, and develop possible solutions to design problems (National Research Council, 2011). The use of student-developed models has been proven to increase the understanding of science content in higher grades (Bell, 2010). In middle school, student-developed models (i.e., a three-dimensional model car), paired with the NGSS aligned curriculum, can support cooperative group work, incorporate twenty-first century skills, and increase the retention of scientific literacy.

Cooperative group work can be an effective strategy for improving achievement, motivation, and social interactions in science (Holthuis, Deutscher, Schultz, & Jamshidi, 2018). In addition, the use of small groups in science is recommended to showcase student-centered learning because students take part in an authentic reflection of the scientific process in a real-world context (Woods-McConney, Wosnitza, & Donetta, 2011). Furthermore, the creation of student-developed models, in a small group setting, can have a positive impact on the achievement of students and can help support the practice of twenty-first century skills.

When constructing models, students participate in twenty-first century skills such as collaboration, communication, creativity, and critical thinking, which are skills that all learners need for success in school, the work place, and life (NGSS Lead States, 2013). Student-centered learning, through the development of models, promotes social learning which helps students become proficient with twenty-first century skills. Middle school students use twenty-first century skills in the process of designing, testing, and redesigning models to help increase the connection from daily lessons to the understanding of phenomena. Twenty-first century skills paired with student-developed models allows students to brainstorm ideas, act as good listeners, and develop the skill for critical thinking (Krajcik et al., 2014). Bell (2010) states that student-developed models promotes effective communication, negotiation, and collaboration skills as students work together to create solutions to real-world problems. Ultimately, student-developed models paired with the incorporation of twenty-first century skills, could promote an increase in scientific retention.

The retention of scientific literacy can be evident in student-developed models. Instead of short-term memorization strategies, student-developed models provide opportunity for students to engage in the content at a deeper level, which will strengthen long-term retention through the application of hands-on learning. Apart from achievement in test scores, retention in scientific literacy can be measured through Performance Expectations, which are statements that describe students' proficiency of standards in the NGSS aligned curriculum (NGSS Lead States, 2013). Performance Expectations statements are not the memorization of isolated terms, but focus on students applying ideas to explain phenomena (Krajcik et al., 2014). Middle school students that are able to meet and/or exceed the standards for Performance Expectations within a unit of study, would suggest a form of mastery for the Disciplinary Core Ideas, Science and Engineering Practices, and Crosscutting Concepts. The understanding of science content, in relation to the Performance Expectations, should improve scientific literacy among middle school students.

Method

The purpose of this study was to explore how designing, testing, and redesigning three-dimensional models, through the application of project-based learning, can improve middle school students' science literacy. In alignment with the NGSS curriculum, students utilized twenty-first century skills (i.e., collaboration, communication, creativity, and critical thinking), to determine whether the application of project-based learning led to an improvement in the understanding of scientific phenomena. Furthermore, the study considered whether student-developed models (i.e., a three-dimensional model car) provided a deeper understanding of scientific concepts through discovery learning. The potential growth in the understanding of scientific concepts was analyzed with the measurement of achievement in test scores.

Research Question

The research question for this study was: Do student-developed models create a deeper understanding of key concepts (i.e., analyzing and interpreting data, constructing explanations, and engaging in arguments from evidence) to improve middle school students' scientific literacy?

Hypothesis

Building on research by Bell (2010) and Krajcik and colleagues (2014), the researcher hypothesized that student-developed models would create a deeper understanding of key concepts (i.e., analyzing and interpreting data, constructing explanations, and engaging in arguments from evidence) and increase middle school students' scientific literacy. Creating models (i.e., artifacts) is a useful tool that allows middle school students to start thinking more abstractly (Wadsworth, 1996). Therefore, incorporating student-developed models (i.e., a three-dimensional model car) in science education may help students express their knowledge through critical thinking and increase problem-solving skills (Krajcik & Merritt, 2012). The hypothesis was tested using a quantitative nonequivalent two-group design where the potential growth in the understanding of scientific concepts was analyzed with the measurement of achievement in test scores.

Research Design

This study used a quantitative nonequivalent two-group pretest-posttest quasi-experimental design. The sample consisted of two different 8th grade science classes from the same middle school. One class was the treatment group that participated in designing, testing, and redesigning of student-developed models (i.e., a three-dimensional model car). The other class was the control group that participated in standard science instruction (i.e., laboratory experiments, online interactives, and note taking) in a transitioning NGSS aligned course. Both the treatment and control group took a nine question NGSS aligned pretest prior to the instruction of the unit (Accelerate Learning Inc., 2018). The treatment and the control group participated in the unit through the same learning sequence of the NGSS 5E lesson design: engagement, exploration, explanation, elaboration, and evaluation (NGSS Lead States, 2013). At the end of the unit, the treatment and control group took a nine question NGSS aligned posttest (Accelerate Learning Inc., 2018). The posttest consisted of the same questions as the pretest, but the questions were in a random order to ensure that students did not memorize the answers based upon the initial sequence of the questions. The change in test scores, analyzing students' pretest and posttest, determined if student-developed models increased scientific literacy when compared to standard instruction (i.e., laboratory experiments, online interactives, and note taking).

Independent variable. The independent variable in this study was the creation of student-developed models (i.e., a three-dimensional model car) in the learning sequence of the NGSS 5E lesson design (NGSS Lead States, 2013). For this study, a student-developed model was defined conceptually by Schwarz and colleagues (2009) as a three-dimensional model (i.e., an artifact) to demonstrate scientific knowledge through an investigative process.

Dependent variable. The dependent variable in this study was the growth of scientific literacy. For this study, scientific literacy was defined conceptually by the National Research Council (2011) as the knowledge and understanding of science concepts and processes required for decision making, participation, and productivity. To measure the potential growth of scientific literacy, the treatment and control group took a nine question NGSS aligned test from an online science educational platform titled STEMscopes (Accelerate Learning Inc., 2018). See Appendix A.

Setting & Participants

The setting for this study was a middle school, comprised of 7th and 8th grade students, that is located in Central California. The school site has a student demographic of 98.5% Hispanic or Latino, 0.7% Caucasian, 0.6% Filipino, and 0.2% African American; with a total student population of 1,051. The middle school is labeled as a Title I School, where 93.2% of the student population is classified as socioeconomically disadvantaged and qualifies for the Free and Reduced Lunch Program (Educational Data Partnership, 2018). On district-wide documentation forms, less than 9.2% of students identify as English Only with 48.9% of students labeled as English Language Learners (ELLs).

The sample for this research was selected through purposeful convenience sampling. The researcher taught the treatment and control group; therefore, the participants were readily accessible during the time of the study. The sample was representative of the target population, with a majority of the middle school site displaying the same student demographics with similar scientific literacy. The sample consisted of 53 students. In the treatment group, 26 students participated in designing, testing, and redesigning of student-developed model cars. Concurrently, in the control group, 27 students participated in standard NGSS aligned instruction (i.e., laboratory experiments, online interactives, and note taking). The treatment and control group participated in the same learning sequence of the NGSS 5E lesson design.

Treatment group. The treatment group consisted of 26 students; 53% are female and 47% are male. All students are between the ages of 13-14. The ethnicity of the treatment group is 100% Hispanic or Latino. Educational subgroups are 38% ELLs, 19% are enrolled in the college readiness Advancement Via Individual Determination (AVID) course, and 8% have an Individualized Educational Plan (IEP).

Control group. The control group consisted of 27 students; 44% are female and 56% are male. All students are between the ages of 13-14. The ethnicity of the control group is 100% Hispanic or Latino. Educational subgroups are 36% ELLs, 14% are enrolled in the college readiness AVID course, and 18% have an IEP.

Measures

To measure scientific literacy, the treatment and control group took a nine question NGSS aligned test from an online science educational platform titled STEMscopes as both a pretest and posttest (Accelerate Learning Inc., 2018). See Appendix A. The nine question NGSS aligned test covered the 8th grade curriculum standards for Newton's Laws of Motion (Accelerate Learning Inc., 2018). The nine question test assessed knowledge using the three-dimensions of the NGSS aligned curriculum: Disciplinary Core Ideas, Science and Engineering Practices, and

Crosscutting Concepts (NGSS Lead States, 2013). The test consisted of one short answer question, seven multiple choice questions, and one Claim-Evidence-Reasoning question (see Appendix A). The Claim-Evidence-Reasoning question was graded using the Claim-Evidence-Reasoning rubric, which is modified from the California Science Test (see Appendix B).

The treatment and the control group took the test electronically. The test was designed to take approximately twenty to twenty five minutes of class time. The multiple-choice questions were self-graded upon submission. The researcher and another trained science teacher graded the one short answer question and the Claim-Evidence-Reasoning question using the provided rubric (see Appendix B).

Validity. To ensure validity, the test measuring the growth in scientific literacy was aligned with the NGSS curriculum for Newton's Laws of Motion for 8^{th} grade content. The test questions were developed by STEMscopes and aligned with current science standards that are incorporated on the California Science Test (Accelerate Learning Inc., 2018). Therefore, both content and construct validity were established for the measure.

Reliability. To ensure reliability, the NGSS aligned test was graded using the rubric from STEMscopes (Accelerate Learning Inc., 2018). A study conducted by Rice University Center for Digital Learning and Scholarship (n.d), showed a statistically significant relationship ($p < 0.05$) between STEMscope tests and NGSS aligned state tests. The one short answer question was graded upon students' capability of correctly solving the mathematical calculation. The seven multiple-choice questions were graded automatically upon submission, using the provided answers from STEMscopes (Accelerate Learning Inc., 2018). Lastly, the Claim-Evidence-Reasoning question was graded upon the Claim-Evidence-Reasoning rubric to provide high test-retest reliability (see Appendix B). The researcher and one other science teacher, trained in using the rubric, graded the pretest and posttest. The researcher and another science teacher graded 20% of the same short answer questions and the Claim-Evidence-Reasoning statements to ensure inter-rater reliability.

Intervention

The intervention is based off the work of Bell (2010) and Krajcik and colleagues (2014). The creation of models (i.e., a three-dimensional model car) provides an opportunity for students to engage deeply with the target content, which can affect long-term retention through hands-on learning. In addition, Krajcik and Merritt (2012) suggest that student-developed models consists of key concepts (i.e., analyzing and interpreting data, constructing explanations, and engaging in arguments from evidence) to explain and predict scientific concepts. In the study, the treatment group designed, tested, and redesigned a student-developed model car to increase their understanding of key concepts for Newton's Laws of Motion. The intervention focused on students designing a three-dimensional model car, out of various household materials, to test, redesign, and retest to meet NGSS Performance Expectations for the unit (NGSS Lead States, 2013). The student-developed model car was aligned with the NGSS 5E lesson design. Over the timespan of four weeks, the intervention started with a pretest, following the creation of a three-dimensional model car to explore Newton's Laws of Motion, and concluded with a posttest comprised of the same questions in a randomized order.

Procedures

The treatment and control group started the unit by taking the nine question NGSS aligned pretest to determine a baseline of knowledge for Newton's Laws of Motion (Accelerate Learning Inc., 2018). Within the four week unit, three learning sequences following the 5E lesson design were conducted. In the first learning sequence, students created a Google Slides presentation of a model car that is propelled by gravitational potential energy. Students then designed a three-dimensional model car to represent the model car described in their online presentation. After collecting data for Newton's First Law of Motion, students included a graph and an explanation of the relationship between the position/distance of their model car to potential energy. In the second learning sequence, students created an explanation of the relationship between the mass and speed of their model car. Students collected data by redesigning and testing their model car with various added masses, affecting the acceleration and speed. For Newton's Second Law of Motion, students were able to calculate speed, graph data points, and identify the relationship between distance, time, and acceleration. In the third and final learning sequence, students redesigned their model car to make their car move faster and withstand a wall collision without damaging a raw egg. After collecting data for Newton's Third Law of Motion, students created an explanation of acceleration and mass to the force of an object. The study lasted for four weeks, one week dedicated for each of Newton's Laws of Motion, with days in between to redesign student models. The final lesson included the nine question NGSS aligned posttest, where the difference in test scores were analyzed to determine if an increase in scientific literacy was present in the treatment group (Accelerate Learning Inc., 2018).

Fidelity. To ensure fidelity, a second science teacher observed the treatment group and another (third) science teacher observed the control group; both observations were on three separate days of the study, one day for each of Newton's Laws of Motion (see Appendix C) for a total of 20% of the study. The teacher that observed the treatment group saw days in the learning sequence dedicated to designing, testing, and redesigning a student-developed model car. The teacher that observed the control group saw days in the learning sequence where students were participating in standard science instruction (i.e., laboratory experiments, online interactives, and note taking). The observations indicated 100% fidelity to the intervention. In addition, the two science teachers that performed the observations graded 20% of the short answer questions and the Claim-Evidence-Reasoning questions from the nine question NGSS aligned pretest and posttest (Accelerate Learning Inc., 2018). Overall agreement between inter-raters was 100%

Ethical Considerations

The study followed the three core principles of educational research from the Belmont Report. The Belmont Report discusses the respect for persons, beneficence, and justice. In this study, no harm came to the students in the sample. Students in both the treatment and control group gained an understanding of the scientific content through the creation of student-developed models or the standard science instruction. This study provided very low risk to all participants in an educational setting. All student information remained anonymous and was kept confidential during and after the study.

Validity threats. Extraneous variables that could have affected the validity of the study included the structure of learning sequence and the bias from the researcher. The structure of the learning sequence was taught by one teacher, the researcher, for the treatment and control group. The treatment group was the only 8th grade science class designing, testing, and redesigning student-developed models to understand the content of Newton's Laws of Motion. During the time of data collection, for this study, was the first application of student-developed models for the lesson sequence on Newton's Laws of Motion. If modifications to instruction were needed, modifications were made during the time of the study. The control group, received standard science instruction (i.e., laboratory experiments, online interactives, and note taking), like every other 8th grade science class at the school site. The lesson sequence for control group has been taught in previous years, with modifications made from year-to-year to ensure a smooth transition between lessons.

Similar classes, for the treatment and control group, were chosen to limit the extraneous variable of bias from the researcher. The treatment and control group have similar demographics (i.e., amount of ELLs, students enrolled in AVID, and students with an IEP), which could potentially result in the same growth of scientific literacy in both the pretest and posttest scores. The middle school site for the study has a rotating bell schedule, ensuring that the treatment and control groups were taught at different instructional hours of the day, which may have also affected the bias of the researcher.

Data Analyses

All data was entered into the Statistical Package for the Social Sciences® (SPSS®) for Windows, version 24.0.0 (SPSS, 2016). No names or identifying information was included in the data analysis. Before the analyses was conducted all data was cleaned to ensure no outliers are present (Dimitrov, 2012). After cleaning the data, independent samples t-test (treatment and control group) and dependent samples t-test (pretest and posttest) were conducted to determine the significant difference in science literacy between the two means scores on the nine question NGSS aligned test from STEMscopes (Accelerate Learning Inc., 2018). Further, before interpreting the analytical output, Levene's Homogeneity of Variance was examined to see if the assumption of equivalence has been violated (Levene, 1960). If Levene's Homogeneity of Variance was not violated (i.e., the variances were equal across groups), the data was interpreted for the assumption of equivalence; however, if the variances were not equal across groups the corrected output would be used for interpretation.

Results

Two independent samples t-test were conducted on the whole sample ($n = 53$) for both the pretest and posttest assessment scores. Results for the pretest were: Levene's Homogeneity of Variance was not violated ($p > 0.05$), meaning the variance between groups was not statistically different and no correction was needed and the t-test showed non-significant differences between the mean scores on the pretests between the two groups $t(51) = 1.182$, $p > 0.05$. The similarity in variance after the pretest conclude that the two groups, treatment and control, are comparable (see Table 1). Results for the posttest were: Levene's Homogeneity of Variance was violated ($p < 0.05$) meaning the variance between groups was statistically different and the second line of data were used between the mean scores on the posttest between the two groups $t(51) = 3.260$, $p < 0.05$ with a significance level of 0.01. The difference in variance after the posttest conclude that the two groups, treatment and control, are not comparable and there was a statistically significant difference between the mean scores.

Table 1

Results of Independent Samples T-Tests

	Mean	SD
Pretest		
Treatment	7.35	1.96
Control	6.59	2.62
Posttest*		
Treatment	9.92	2.45
Control	7.37	3.19

Note. SD = Standard Deviation. * = $p < 0.01$

After determining the differences between pretest and posttest assessment scores between groups, two paired t-test were run for both the treatment and control group to determine if participants mean scores from pretest to posttest were significantly different within each group (see Table 2). Results for each group were as follow: treatment group, t (25) = -6.312, $p < 0.05$ with a significance level of 0.001; control group, t (26) = -1.606, $p > 0.05$. This infers that the treatment and control group produced growth in their content knowledge from pretest to posttest. The treatment group started the study with a pretest mean score of 7.35 and concluded the study with a posttest mean score of 9.92, to exhibit a mean score difference of 2.57. The control group started the study with a pretest mean score of 6.59 and concluded the study with a posttest mean score of 7.37, to exhibit a mean score difference of 0.78. Additionally, the negative t value also stipulates that an increase in mean scores were achieved from pretest to posttest, with a higher difference in mean scores from the treatment group.

Table 2

Results of Paired T-Tests

	Mean	SD
Treatment Group*		
Pretest	7.35	1.95
Posttest	9.92	2.45
Control Group		
Pretest	6.59	2.62
Posttest	7.37	3.19

Note. SD = Standard Deviation. * = $p < 0.001$

Discussion

The NGSS changed the delivery of science instruction to tailor the expanding learning needs of students, with an increase in rigor, to support practices of the twenty-first century. The shift in instruction, from teacher-centered to student-centered, allows the opportunity for learners to grapple with scientific concepts under the guidance of their instructors (Wise, 1996). The increase in scientific literacy, which is the knowledge and understanding of science concepts and processes required for decision making, participation, and productivity, is a goal embedded within the NGSS aligned curriculum (national Research Council, 2011; NGSS Lead States, 2013). Project-based learning, a form of inquiry, can demonstrate the productivity of hands-on learning in a NGSS aligned classroom, where students are able to think more abstractly. An important scientific practice in middle school grades is the development and use of models to help support scientific literacy (Schwarz et al., 2009). In order to predict and explain a scientific phenomenon, the NGSS expects students to construct and revise models based on evidence to gain a deeper understanding of content knowledge (Krajcik & Merritt, 2012). Student-developed models (i.e., three-dimensional models) provides middle school students the chance to participate in cooperative group work, succeed in the use of twenty-first century skills (i.e., collaboration, communication, creativity, and critical thinking), and increase the likelihood of retaining scientific literacy (NGSS Lead States, 2013).

This study was conducted to determine if using student-developed models (i.e., a three-dimensional model car) would increase scientific literacy, through the application of project-based learning, in a NGSS aligned course. Based on the research of Bell (2010) and Krajcik and colleagues (2014), the hypothesis for the study stated that using student-developed models would create a deeper understanding of key concepts (i.e., analyzing and interpreting data, constructing explanations, and engaging in arguments from evidence) and increase middle school students' scientific literacy. The two groups, treatment and control, engaged in the same pretest prior to the start of the study to indicate a baseline knowledge for Newton's Laws of Motion. The treatment group received the intervention which comprised of students designing, testing, and redesigning a student-developed model car made from various household materials to participate in laboratory experiments to gain content knowledge for Newton's Laws of Motion. The control group received standard science instruction (i.e., laboratory experiments, online interactives, and note taking) that included pre-determined materials by the instructor to gain content knowledge for the same subject matter. At the end of the four week study, one week dedicated to each of Newton's Laws of Motion with time in between to redesign student models, both the treatment and control group engaged in the same posttest, which consisted of the same questions in a randomized order.

According to the research of Bell (2010) and Krajcik and colleagues (2012) it was expected from this study that the treatment group would have a higher mean score on the posttest because student-developed models were proven to increase the understanding of science content in higher grades when compared to standard science instruction (i.e., laboratory experiments, online interactives, and note taking). During the study, it was determined that there was significant difference between the treatment and control group on the posttest with a significance level of 0.01 (see Table 1). Meaning, at the start of the study the treatment and control group were comparable with no significant difference in the mean scores for the pretest; however, by the end of the study, the treatment group that participated in the intervention was not comparable to control group with the difference in mean score variance after the posttest. That is, on average, the treatment group made greater gains on post assessment than the control group. Therefore, middle school students that engaged in project-based learning with an emphasis on student-developed models increased their scientific knowledge, as found in similar studies with higher grades (Bell, 2010).

The use of student-developed models, incorporated with the NGSS aligned curriculum, gave the treatment group a greater difference in mean scores, resulting in a statistically significant difference (see Table 1). This study presented that student-developed models can be an effective tool for middle school students to increase scientific content when compared to standard science instruction (i.e., laboratory experiments, online interactives, and note taking). Furthermore, previous studies have concluded that students who are able to create a tangible artifact to help explain concepts can demonstrate in increase in scientific literacy (Krajcik & Merritt, 2012). Nonetheless, this study showed that middle school students gained more scientific content for Newton's Laws of Motion through the use of student-developed models; however, this cannot correlate to the level of understanding for the content, which cannot be captured through a multiple choice test. In addition, there could be other possible limitations that may have affected the performance levels of students from pretest to posttest in the treatment and control group.

Limitations & Future Directions

Various limitations could have impacted the outcome of the study including the time frame, the type of sampling, and the number of participants. The time frame of the study, which was conducted over four weeks, could pose as a limitation. The study consisted of one week dedicated for each of Newton's Laws of Motion, with days in between to redesign student models. However, if the study was longer, the treatment and control group could have engaged in the learning sequence longer; potentially, increase the mean scores for both groups. Another limitation for the study was the type of sampling that was conducted. The type of sampling was purposeful convenience sampling because the researcher taught the treatment and control group, making the participants readily accessible during the time of the study. Lastly, the sample size for the study was small, with 26 students in the treatment group and 27 students in the control group. Although the sample size was representative of the student population at the school site, it may not be a true representation of all middle school students in 8th grade and therefore results should be generalized with caution.

Previous studies confirm that student-developed models increase the retention of scientific literacy (Krajcik et al., 2014). However, future studies should be conducted to investigate the effectiveness of these practices to provide further evidence that the results from this study are indeed accurate and the statistical difference did not happen by chance. For future studies, the time of the intervention conducted should be increased to a longer time frame than four weeks. Also, random samples, larger than 53 students, should be used to gather a greater scope of the targeted population. Furthermore, the researcher noted that level of engagement from all students in the treatment group, including a sense of accomplishment, from creating student-developed models. In proceeding studies, a measure to test student motivation can be included to see if that was a factor that lead to an increase in mean scores between the two groups tested.

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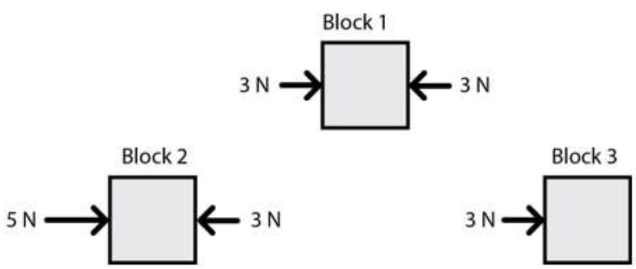
Appendix A

NGSS Aligned Test from STEMscopes

Newton’s First Law of Motion

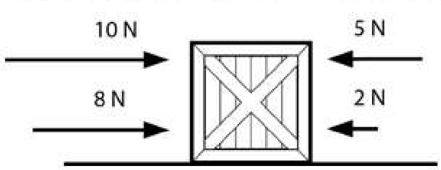
The illustration shows the forces in Newtons (N) acting on three different blocks.



Which boxes will move under these conditions?

A	Blocks 1 and 2
B	Blocks 2 and 3
C	Blocks 1 and 3
D	Blocks 1, 2, and 3

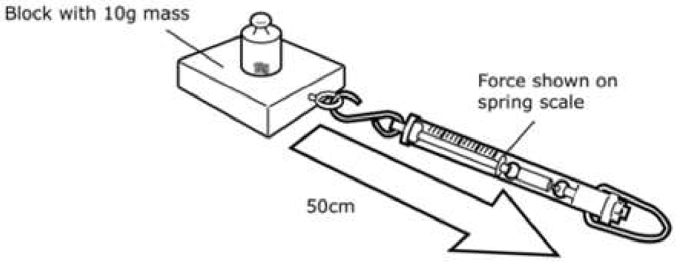
The illustration shows all the forces in Newtons (N) acting on a box.



The sum of all the forces acting on the box results in a force acting on the box–

A	to the right with a strength of 11 Newtons.
B	to the left with a strength of 7 Newtons.
C	to the right with a strength of 25 Newtons.
D	to the left with a strength of 6 Newtons.

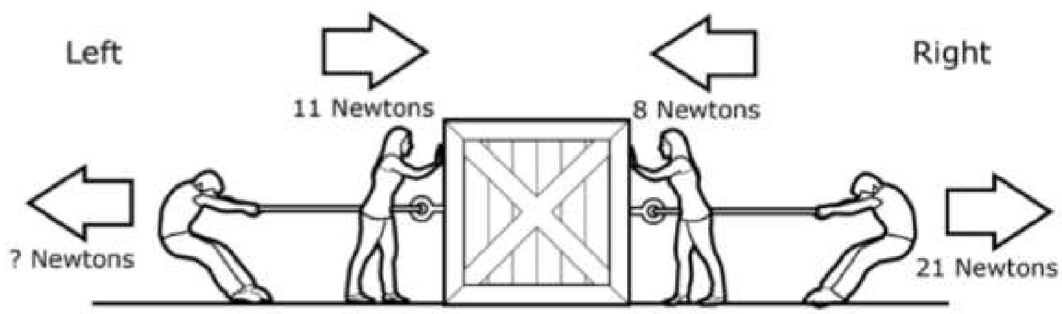
Students are investigating how mass affects the force needed to move an object. They attached a wooden block to a spring scale and placed a 10 g mass on top of the block and pulled it 50 cm across the table.



Which of the following changes to their setup would result in a larger force reading on the spring scale?

A	Sliding the block 60 cm
B	Attaching a larger spring scale
C	Using a 20 g mass
D	Using a circular piece of wood

A diagram of forces being applied to a box by four people is illustrated below. If the net force acting on the box is 10 N to the right, what is the magnitude of the force applied by the boy pulling to the left?

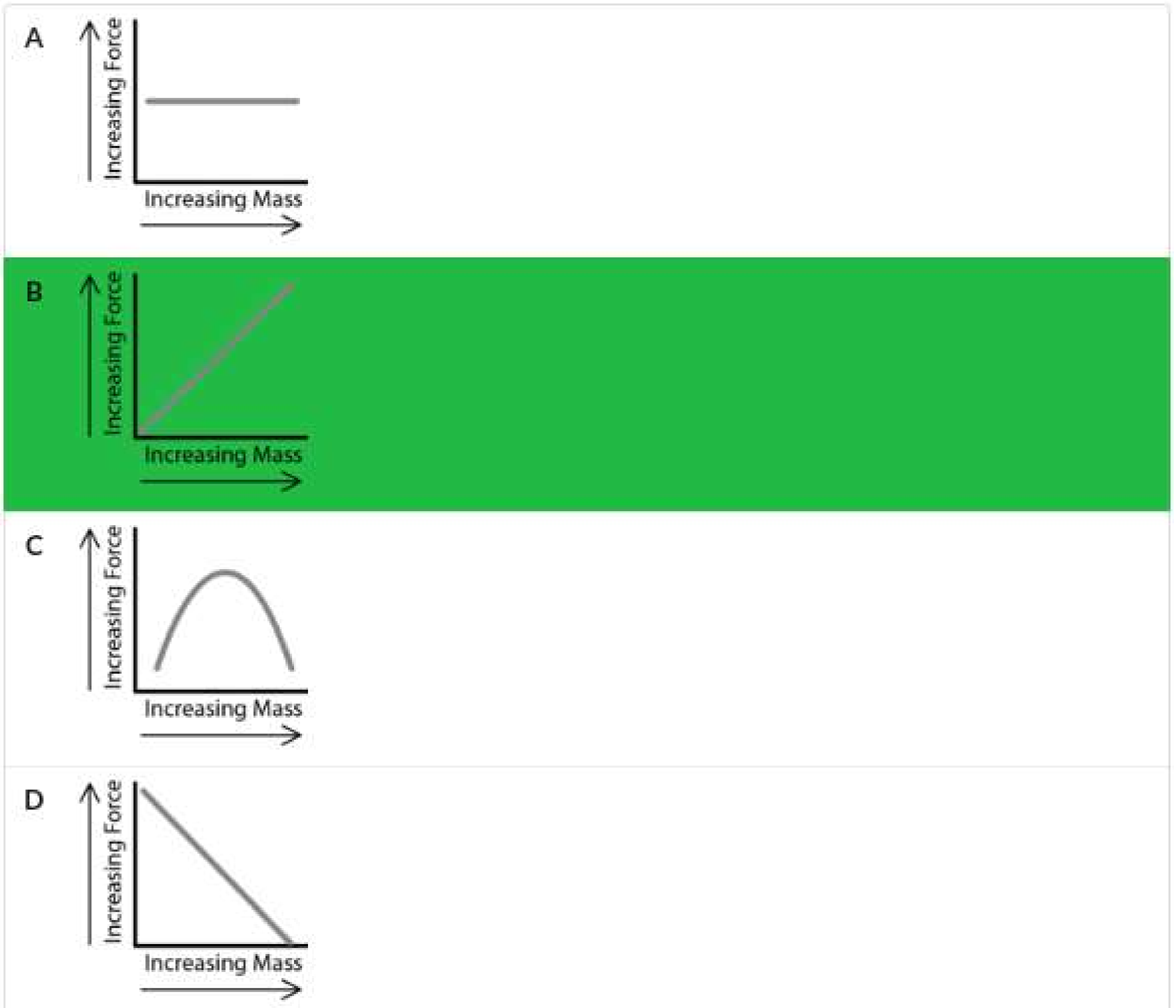


Answer

The magnitude of the force applied by the boy pulling to the left is 14 N.

Newton's Second Law of Motion

Which of the following graphs shows how the mass of an object affects the amount of force needed to move it?



Claim-Evidence-Reasoning

Scenario

Mrs. Roberts' class won a day at the bowling alley for their good behavior all year. When they arrived, Jason picked the green ball that weighed 6 lbs, and Amanda picked the yellow ball that weighed 12 lbs. Amanda was having a hard time getting her ball to roll down the lane. Jason was doing great! He was pushing his ball hard, and it was going straight down the center. He even got a strike twice!

External Data

Prompt

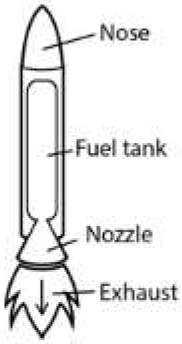
Write a scientific explanation about why Amanda was having a hard time.

Newton's Third Law of Motion

A baseball bat hits a baseball with a force of 100 Newtons. What is the force and its direction exerted by the ball on the bat?

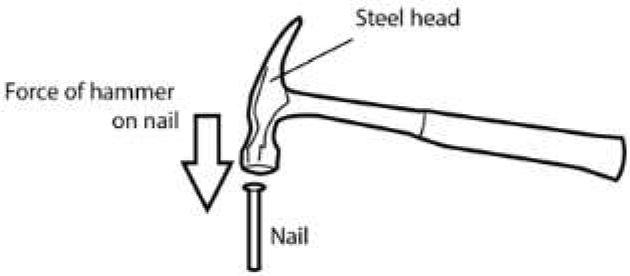
A	100 Newtons, same direction
B	100 Newtons, opposite direction
C	200 Newtons, same direction
D	200 Newtons, opposite direction

The nozzle of a rocket is pointed downward so that as fuel is ignited, the exhaust pushes downward. Why is this arrangement necessary for a rocket to function properly?



A	The rocket is protected from the heat of the exhaust.
B	Burned fuel can be collected on the ground.
C	As fuel is combusted, the rocket pushes the gases backward and the gases push the rocket forward.
D	This allows the rocket to be steered properly.

The head of a hammer is often made of steel. This makes the head heavy, which helps create a strong force for driving nails. Steel is also strong. The head of a hammer must be strong to resist what force?



A	The force of the air resistance on the moving hammer
B	The force of the person using the hammer
C	The force of gravity pulling down on the hammer
D	The force of the nail pushing in the opposite direction

Appendix B

Claim-Evidence-Reasoning Rubric

Claim-Evidence Reasoning Rubric - generic (Based on CAST)

Note: Must be 2 sentences minimum

Points awarded	2	1	0
Claim	Answers the question and is accurate based on data	Answers the question, but is inaccurate based on data	No claim, or does not answer the question
Evidence	Cites data and patterns within the data and uses labels accurately.	Cites correct data from the data source, but not within the context of the prompt. OR Cites incorrect data from the data source, within the context of the prompt.	No evidence, or cites changes, but does not use data from the data source.
Reasoning	Cites scientifically accurate reason, using correct vocabulary, and connects this to the claim. Shows accurate understanding of the concept.	Cites a reason, but it is not inaccurate or does not support the claim or supports an incorrect claim. Reasoning does not use the scientific terminology or uses it inaccurately.	No reasoning, or restates the claim but offers no reasoning.

Appendix C

Fidelity Checklist

<table>
<tr><th colspan="6">Fidelity Checklist</th></tr>
<tr><td colspan="3">Treatment Group Class Observer
▪ Students are designing, testing, and redesigning a student-developed model car made from various household materials.
▪ Students are participating in laboratory experiments with their student-developed model car.</td><td colspan="3">Control Group Class Observer
▪ Students are participating in standard science instruction (i.e., laboratory experiments, online interactives, and note taking).
▪ Students are participating in various laboratory experiments with pre-determined materials.</td></tr>
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