Sixth Graders Investigate Models and Designs through Teacher-Directed and Student-Centered Inquiry Lessons: Effects on Performance and Attitudes

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Abstract

Science inquiry has been found to be effective with students from diverse backgrounds and varied academic abilities. This study compared student learning, enjoyment, motivation, perceived understanding, and creativity during a science unit on Models and Designs for 38 sixth grade students (20 male, 18 female; 1 Black, 1 Hispanic and 36 White). The unit began with a very teacher-centered approach, then became increasingly student-centered, employing more inquiry with each lesson set to determine the effects of student-centered instruction on performance and attitudes. Pretest-posttest data with specific questions tied to each lesson set were collected, as well as repeated measures attitude surveys administered at the conclusion of each of the six sets of lessons. The surveys included ratings of lesson enjoyment, student motivation, perceived understanding, creativity designed into the lesson, and perceived self-creativity on a scale of one to ten, along with open ended responses of reasons for the ratings. Results indicate a trend of improving knowledge retention as student-centeredness and inquiry increased until the last lesson set, which a few students found too challenging. Additionally, reported levels of enjoyment, motivation, and creativity increased as the instructional approaches became more student-centered until the challenge became too great for some students, causing a small dip in the upward trend. Greater experience with science inquiry may assist students in extending their confidence, inquiry leadership, and achievement.

Key Words

Student-centered instruction, science inquiry, creativity, motivation, models and designs, elementary students.

Introduction

High quality science education is an international priority to solve environmental problems and encourage economic growth (National Science Board, 2007). Globally, governments have recognized the contributions that a full, rich, science education can provide for citizens (Minner, Levy, & Century, 2010). An important component of student-centered science education is inquiry. Many educational policy doctrines have advocated for inquiry-based science education in recent years, including the National Research Council (NRC; 2011). State level curriculum standards, including the state in which the current study occurred (Iowa), have now come to emphasize inquiry. The Iowa Core Curriculum (2009) explicitly states that students must be "actively investigating: designing experiments, observing, questioning, exploring, making and testing hypotheses, making and comparing predictions, evaluating data, and communicating and defending conclusions" (p.1). The Next Generation Science Standards (NGSS) (NGSS Lead States,

2013) emphasize student inquiry through multiple investigations driven by students' questions producing deep understanding of important scientific ideas.

Studies have shown school science inquiry has the potential of enhancing students' higher order learning skills, such as metacognition and argumentation (Dori & Sasson, 2008; Kaberman & Dori, 2009). Evidence indicates hands-on, inquiry-based science instruction helps students develop positive attitudes and increases their motivation to learn science (Hofstein & Mamlok-Naaman, 2007). The body of evidence is growing that suggests engaging students in inquiry-based modeling activities can help students learn content effectively and build subject matter expertise (Kenyon, Schwarz, & Hug, 2008). The current study was undertaken to determine students' enjoyment, motivation, perceived learning, perceived creativity, and measured content learning trajectories when students experienced a continuum of lessons related to the nature of science that began as completely teacher-directed and progressed to increasingly student-directed activities. This experiment may be able to document pedagogical concepts that are often agreed-upon but undocumented such as the very engaging nature of student-centered activities and the possibility that too much student responsibility in the activity can result in frustration and dissatisfaction.

Literature Review

Despite this momentum advocating for inquiry-based methods in the science classroom, there is limited published research on elementary teachers implementing highly student-centered inquiry in their classrooms. The current study aims to extend the literature through an investigation that examined student learning, enjoyment, motivation, perceived understanding, and creativity during a spectrum of teacher-directed to student-directed science activities. These exercises included opportunities to build scientific models and culminated in students creating a toy based on science principles they had investigated. The recent professional literature on science inquiry, scientific modeling, student motivation, and creativity are briefly reviewed in this section to provide background for the current study.

Support for Inquiry-Based Science

Scientific inquiry refers to "the systematic approaches used by scientists in an effort to answer their questions of interest" (Lederman, Antink, & Bartos, 2014). p. 289-290). These approaches include process skills such as observation, classification, inference-making, prediction, questioning, data analysis, and data interpretation, but extend beyond mere process skills to combing these with scientific content knowledge, reasoning, and critical thinking (Lederman et al., 2014).

The National Research Council's framework for K-12 science education emphasizes the need for students to actively engage in scientific practices to deepen understanding of core ideas (Keller & Pearson, 2012). Among the authors' recommendations were eight essential science or engineering instructional practices that were implemented in the current study: (1) Asking questions and defining problems; (2) Developing and using models; (3) Planning and carrying out investigations; (4) Analyzing and interpreting data; (5) Using mathematics, information and computer technology, and computational thinking; (6) Constructing explanations and designing solutions; (7) Engaging in argument from evidence; and (8) Obtaining, evaluating, and communicating information (National Research Council, 2011).

The National Research Council has long advocated for inquiry-based science instruction, defining it as: "the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work" (NRC, 1996, p.23). This approach, "rooted in constructivist thought, seeks to create opportunities for learners to engage in science, gaining in-depth understanding, and building on their previous ideas" (Meyer & Crawford, 2011, p. 529). Reforms aim to move science education away from just learning about science to actually doing science through inquiry in an active classroom setting. In inquiry science, students are doing the thinking and, eventually, the learning, while asking their own questions to guide that learning (Meyer & Crawford, 2011). The National

Science Education Standards state, “Learning science is something that students do, not something that is done to them” (National Research Council, 1996, p. 2).

Along with the push for policy reform have come a number of studies that demonstrate the positive effects of inquiry-based science teaching and learning (McNeill & Pimentel, 2009). Inquiry-based science instruction has been found to be effective with students from varied backgrounds and academic abilities. A study (Meyer & Crawford, 2011) indicated that the use of inquiry-based activities, when coupled with explicit scientific guidance in the nature of science, afforded greater opportunities for students of racially and ethnically underrepresented backgrounds to better understand scientific concepts. An investigation focused on middle school students with behavioral and emotional disabilities (McCarthy, 2005), reported overall results indicating students in the hands-on instructional program performed significantly better than the students in the textbook–focused condition. A report concerning inquiry-based science in Qatar (Areepattamannil, 2012) had a positive effect on achievement, as well as interest in science.

A study (Taylor, Therrian, Kaldenberg, Watt, Chanlen, & Hand 2012) has been conducted with students with disabilities that indicated the efficacy of the Scientific Writing Heuristic approach for teaching science, a form of inquiry that emphasizes the use of strategic writing exercises following both teacher and student frameworks to enhance understanding in science laboratory experiences (Akkus, Gunel, Hand, 2007). Use of this protocol by students with disabilities has the potential to increase achievement on standardized assessments because of the focus on big ideas rather than rote memorization of facts (Taylor et al., 2012). An investigation using inquiry-oriented defining exercises (Dawkins, 2014), found that many students experienced a sense of connection to their learning, as well as enjoyment, during this type of activity. The current study offers a repeated measures study that examined student performance and attitudes throughout a continuum from very teacher-centered to very student-centered, including a final toy construction project, allowing investigators to determine the optimal instructional approach for the unit on models and designs.

Scientific Modeling

Much of the instructional focus for the current study centered on the creation and revision of scientific models to explain unknown structures and processes. Various beneficial aspects of scientific modeling have been emphasized by different researchers. Scientific modeling has been defined as “an instructional approach in which learners engage in scientific inquiry whose focus is on the creation, evaluation, and revision of scientific models that can be applied to understand and predict the natural world” (Schwarz, 2009, p. 722). Other investigators (Akerson, Townsend, Donnelly, Hanson, Tira, & White, 2009) noted that scientific modeling involves integration of several fundamental process skills used in science inquiry such as observing, questioning, hypothesizing, predicting, collecting, analyzing data, and formulating conclusions. Models are representations that characterize and simplify a system to make its central features explicit (Gobert & Buckley, 2000). Over the past 50 years, scientists have worked to document and understand the role models play in science (Mathews, 2007), contending that understanding of nature and science occurs through analogy, metaphor, and model. A meta-analysis of the effects of using similarities and differences, such as analogies, comparisons, and metaphors during instruction (Apthorp, Igel, & Dean, 2012), determined that these strategies positively influence student achievement.

Often, a model is a visual representation or explanation of an object or process that is not easily observable. The model may be smaller than the actual object or it may be an enlarged version. The job of the model is to communicate information about that object or process, serving as a basis for further inquiry and discourse. A “model is to be a representation that abstracts and simplifies a system by focusing on key features to explain and predict scientific phenomena” (Schwarz, Reiser, Davis, Kenyon, Acher, Fortus, Shwartz, Hug, & Krajcik, 2009, p. 633). Models can be divided into two categories: conceptual models and physical models. A conceptual model is an idea that takes the form of a description, explanation, or drawing that is yet to be completely understood. A physical model is a three-dimensional construction designed to explain or represent how something works. The physical model allows manipulation and testing in a way that a conceptual model cannot, permitting students to formulate hypotheses and adjust their understanding of the object or process.

Models can be used in the classroom in a variety of ways, including as instructional tools and authentic assessments (Akerson et al., 2009). When students were given a reason for creating models, other than "doing school" and given a chance to discuss models with peers, those students reported a benefit to their learning and understanding (Schwarz, 2009). When students are able to engage in scientific modeling, they notice patterns, constructing and revising representations. These become useful for predicting and explaining, helping students to enhance their scientific knowledge and encouraging them to think more critically (Kenyon, Schwarz, & Hug, 2008).

Student Motivation and Creativity

Motivation is the force within a student that initiates and directs behavior, explaining differences in intensity of behavior (Govern & Petri, 2004). When one is motivated to perform a task, one is more likely to complete that task, as well as performing it with greater quality. The question, then, is what motivates a person in a specific domain?

A three part study (Grant, 2011) suggested that people experienced greater motivation when functioning in positive social atmospheres and that intrinsic motivation was tied to higher levels of creativity. Published studies addressing the science motivation of elementary students are less common than for secondary students. In a study involving elementary students (Cavas, 2011) determined that primary students' motivational levels had a considerable impact on their science attitudes and achievement in science. In another investigation (Sevinç, Özmen, & Yiğit, 2011), stimulating learning environments motivated primary students towards science learning, and may lead to opportunities for students to carry out self-study and form their own learning strategies. Student motivation for science seems to decline after elementary school, but a researcher (George, 2006) also found that students were motivated when they perceived the science as useful and were provided with opportunities to participate in authentic science learning activities.

Creativity is regarded as a desirable trait, one to be nourished, and enhanced in all students (Johnson, 2009). However, few scientists have paid much attention to creativity until recently (Sawyer, 2012). Developing the creative minds of students recently has been at the forefront of educational and societal change because today's careers require innovation and creative approaches. Jobs that don't require creativity are being automated, or are being moved to low wage countries (Sawyer, 2012). Therefore, creativity and motivation, along with enjoyment and perceived understanding, were attitudes examined in the current study to determine how the level of student-centeredness of a lesson set might impact these attitudes.

Method

The current study was designed to compare student learning, motivation, perceived understanding, and creativity during a science unit on Models and Designs for sixth grade students. The six sets of lessons that comprise this unit offered a range of learning activities from very teacher-directed to very student-directed inquiry. The most student-centered of the lessons involved the design and construction of student made models and toys. The authors hoped that an effect could be seen on student science content retention, perceived learning, enjoyment, motivation, and creativity as the amount of student direction increased. The following research question guided this study: How does level of student-centeredness affect student performance and attitudes of lesson enjoyment, perceived motivation, perceived understanding of science, and perceived creativity allowed by the lesson set-up and perceived creativity exhibited by the student.

Next Generation Science Standards

This unit addresses multiple standards in the Next Generation Science Standards: MS-ETS 1-1 Define the criteria and constraints of a design problem with sufficient precisions to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions; MS-ETS 1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem; MS-ETS 1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria; and MS-ETS 1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved (NGSS Lead States, 2013).

Participants and Teacher

The study included 38 sixth grade students of ages 11 or 12 years. This group of 20 males and 18 females consisted of 1 Black, 1 Hispanic, and 36 White students. The students were members of two science classes taught by the same instructor at an elementary school in a small city in Iowa, USA. The percentage of students receiving free or reduced-cost lunch at the school was 54 percent. This study was approved by the investigators' overseeing university human subjects committee and the school district. All participating students and their parents were fully informed of the study and provided signed consent for their data to be included in the study.

The teacher (first author of this article) had over 13 years of experience as an elementary teacher at the time of this study and had been teaching science to sixth grade students for many years. He had taught all of the science lessons to both classes of sixth graders that year. The teacher had many years of experience teaching hands-on inquiry science with a positive attitude and he was enrolled in a doctoral program focused on science education. In general, his instructional units in science contained both teacher-directed and more student-centered lessons. He had just completed an endorsement in Education of the Gifted and wanted to infuse more creativity and student invention in his lessons. The current topic of models and designs seemed to be an appropriate situation for implementing an investigation.

Design

The study had a repeated measures design with specific questions on the pretest-posttest tied to the various modules of the science unit. The student attitude survey was administered after each of the modules so that student attitudes could be compared across the modules.

The study involved the use of the Models and Designs unit created for the Full Option Science System (Lawrence Hall of Science, 2000). The main purposes of this unit of were to provide students with an understanding of scientific modeling and to engage students in structured design, construction, and testing of models. Students had many opportunities to design, exchange ideas, and manipulate real materials in an effort to create meaningful products. Students began to understand the modeling process in the first few lesson modules. They worked through black boxes and learned about conceptual versus physical models. They then took these skills to a higher level while trying to design a contraption that mimicked one the teacher had created. However, this contraption, called a Hum-Dinger, could only be heard, not seen or examined internally. The last module of this FOSS kit exposed students to a structured design process as they designed, tested, and redesigned small go-carts that performed various movements. An additional inquiry module was added to engage students in examining many toys based on simple machines or other science concepts and to challenge them to create a new or similar toy themselves.

For the purposes of this study, these modules were manipulated somewhat to make the first lesson very teacher-directed, then, transitioning to more and more student-centeredness as the modules progressed. The additional final module was designed and implemented by the investigators to provide experience with reverse engineering and designing a toy. This module was intended to be the most student-centered, giving the students ample freedom in how they accomplished the goal. To complete this task, students partnered with two classmates of choice. Each group was then given a container with several different toys. All of the toys had moving parts so that the toys "did something" that could be explained by one or more scientific principles. Students initially chose three of the toys from the container to study. They observed the toys and researched them using the Internet and a set of books provided by the teacher so as to scientifically describe how the toys worked. Such things as simple machines (especially gears, screws, and levers) centripetal forces, stop-motion animation, and basic dynamics of flight were encountered as students worked to explain their selected toys.

After this phase, the students chose one scientific concept they had described, working to design a toy using this same concept. They needed to determine the materials that would be required (from a list of possible materials provided by the teacher), to describe the way those materials would be combined, and then to build and test the prototype until they had a working toy. Students eventually presented their toy to the rest of the class and explained the science behind how it worked. Table 1 provides an outline for the sequence of lessons and intended outcomes.

Table 1. *Design of the Study Showing Increasing Student-Centered Nature of Science Activities*

Module	Teacher or Student-Centered	Main Activity of Lesson Set	Intended Outcomes
Pretest	-	Pretest administered to all students	Baseline for current student knowledge
1	Highly teacher-directed	Reading information about science models from science texts or articles.	Students read for information and define assigned vocabulary or concepts.
1	-	Students respond to survey and rate their perceptions of enjoyment, learning, and creativity.	
2	Teacher directed	Lessons on black boxes in science.	Students investigated and created conceptual and physical models of an actual black plastic box that contained marbles and cardboard pieces.
2	-	Students responded to survey and rate their perceptions of enjoyment, learning, and creativity.	
3	Teacher-directed, but included student choices and input	Make a contraption that hums and then dings when a string is pulled, using given materials.	Students used their own ideas to create a box that hums and dings.
3	-	Students responded to survey and rate their perceptions of enjoyment, learning, and creativity.	
4	Teacher-directed, but included student choices and input	Make a go cart that rolls down a ramp	Students made a model go-cart and learned essential for a working go cart. Students also began to map their design processes
4	-	Students responded to survey and rate their perceptions of enjoyment, learning, and creativity.	
5	Mostly student - directed	Devised a go-cart challenge of students' choosing.	Students generated their own challenge for their go-cart model and then accomplish it.
5	-	Students responded to survey and rate their perceptions of enjoyment, learning, and creativity.	
6	Student-centered	Students chose a toy from a given set and explain the science behind it.	Students analyze the toy for scientific principles or simple machine actions
6	Student-centered	Students created their own toy that shows scientific properties or principles.	Student designs a toy using choice of many given materials that shows same scientific principles
6	-	Students responded to survey and rate their perceptions of enjoyment, learning, and creativity.	
Posttest	-	Posttest given to all students	

Instrumentation

Two main instruments were used to gather data over the course of this study. One was a criterion-referenced pretest-posttest intended to gauge student learning from a baseline to the end of the unit, and the other was a repeated-measures survey that students took at the conclusion of each the six sets of lessons. The identical pretest-posttest was designed by the investigators so that each multiple choice, matching, or short-response question corresponded to a specific lesson set and addressed its intended outcomes. [The test items will be shown in the Results section.] Students took this assessment before any classroom instruction occurred, and then again after all work on the entire unit had been completed. The repeated attitude survey was intended to gather specific information about each of the lesson sets. Students rated their perceptions of the lessons just-completed (regarding enjoyment, motivation, perceived understanding, creativity designed into the lesson and self-perceived creativity) on a scale of one to ten with “1” meaning “not at all” and “10” meaning “very much.” Students were asked to supply two written reasons for their rating of each aspect (open-ended responses).

Analysis

Pretest and posttest scores of participating students were entered into a spreadsheet for calculation of means and standard deviations. Student ratings on the attitude surveys were subjected to the same treatment. Student reasons given for attitude ratings were written onto a spreadsheet and sorted into categories using the constant comparative method in which similar ideas were grouped into categories and categories evolved as each new idea was considered and placed (Dye, Schatz, Rosenberg, & Coleman, 2000).

Results

Pretest-Posttest

Table 2 presents students’ pretest and posttest scores. Overall scores on the pretest were low at 13.4%, but posttest scores averaged 87.2%, indicating that students learned much during the course of the unit. The effect size, Cohen’s *d*, calculated for the difference between pretest and posttest scores was 5.19, which is interpreted as a very large effect of the lessons.

As lessons progressed and student-centeredness increased, posttest scores showed a trend toward greater student achievement. This trend, though, may have been affected by the distance of lessons from the posttest; content learned later and closer to the test may have been better-remembered. The only exception to this trend was lesson set 6, at which student scores dipped somewhat, likely having to do with the challenging aspect of explaining the science of a real world toys and then creating a toy that utilized the same concept. Figure 1 shows the overall positive trend and downward turn during the last module graphically. A paired *t*-test calculation that examined the large difference of mean student scores from questions addressing Modules 1 and 2 compared to mean student scores from questions related to Modules 4 and 5 resulted in a *p*-value of 0.002. Cohen’s *d* effect size was calculated to be 0.92, a large effect size. A paired *t*-test calculation of mean student scores from the first three modules compared to mean student scores from the last three modules, in this case, including the downturn of Module 6, resulted in a *p*-value of 0.06 still showed a small effect size with Cohen’s *d* equaling 0.27.

The data indicate that some student-centeredness is better than none, but that it is possible to go too far if students are not ready to take on the responsibility or do not have sufficient background to support their independent work. Even a small amount of student centeredness seems to make a significant difference and one can go pretty far in this direction before there is a sign of problems in a practice-oriented unit like this one. This finding is useful for informing science instruction and curriculum development.

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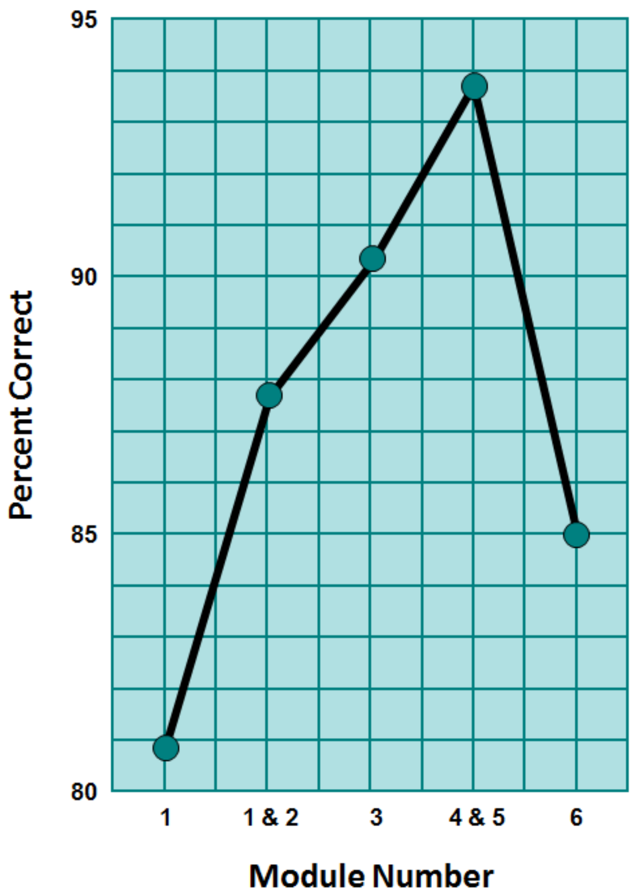

Figure 1. Graph showing the upward trend of improving content scores until Module 6.

Student Attitude Ratings and Reasons

Table 3 presents mean student ratings for lesson set enjoyment, motivation, perceived learning, designed-in creativity of the lessons, and student-perceived creativity. Except for highly teacher-directed lesson set 1, students generally gave high ratings, in the range of 7.8-9.2, on a scale of 1-10. Lesson 1 had overall lower ratings for all 5 attitude categories and paired t-tests between the mean student ratings from Lesson 1 and the average of the means for Lessons 2-6 indicated a statistically significant difference with p-values < 0.0001. Cohen's *d* effect sizes were very large for enjoyment, set-up creativity, and self-creativity; effect sizes were large for motivation and perceived learning. All effects favored the more student-centered lessons.

Table 2. *Pretest and Posttest Results*

Item #	Question	Module in which concept was taught	Pretest Scores (Percent correct)		Posttest Scores (Percent correct)	
			This Question	This set	This Question	This set
1	What is a model?	1	33.3 (32)	22.2 (21)	80.6 (35)	80.9 (27)
2	Give two examples of a model and explain why each is a model.	1	18.1 (27)		78.5 (36)	
3	A situation in which scientists agree is called _______.	1	5.6 (23)		91.7 (28)	
4.	Define a physical model and a conceptual model.	1 & 2	6.3 (20)	4.1 (8)	90.3 (26)	87.8 (21)
5	What is a scientific black box?	1 & 2	8.3 (22)		93.1 (24)	
6	Name three real world examples of black boxes.	1 & 2	0 (0)		83.8 (30)	
7	Which of these is NOT a model?	1 & 2	11.1 (32)		91.7 (28)	
8	A person who uses scientific knowledge to design useful things is called _______.	3	13.9 (35)	4.2 (6)	83.3 (38)	90.3 (19)
9	Write out the five step scientific design process.	3	3.1 (5))		91.7 (19)	
10	What do you think is the most important part of the scientific design process? Why?	3	5.6 (23)		83.3 (38)	
11	Which of these has NO effect on how far a rubber-band powered go-cart will travel?	4 & 5	58.3 (50)	32.6 (25)	91.7 (28)	93.8 (18)
12	How much further can a go-cart travel if its wheel circumference is doubled?	4 & 5	22.2 (42)		88.9 (32)	
13	A rod on which a wheel turns is call the _____.	4 & 5	30.6 (47)		97.2 (17)	
14	When building a self-propelled go cart, the energy to propel the cart 2 meters comes from ____	4 & 5	19.4 (40)		97.2 (17)	
15	Describe a simple children's toy that moves. Explain the science behind how it works.	6	9.7 (22)	21.9 (18)	91.0 (28)	85.0 (20)
16	Match each toy to an explanation of how it works.	6	30.1 (23)		81.0 (25)	
Overall mean score			13.4 (9)		87.2 (18)	

Note: Standard deviations shown in parentheses

Table 3 *Mean Student Attitude Ratings*

Lesson Set	Enjoyment	Motivation	Understanding	Set-up Creativity	Self-creativity
Lesson Set 1 Black Box Reading	5.7 (2)	5.8 (3)	6.1 (2)	5.7 (3)	4.9 (3)
Lesson Set 2 Modeling Black Boxes	8.9 (1)	8.2 (2)	7.8 (2)	8.3 (2)	8.5 (2)
Lesson Set 3 Hum-dingers	9.0 (2)	8.8 (2)	8.1 (2)	9.2 (1)	9.0 (1)
Lesson Set 4 Go-Carts	9.2 (1)	8.1 (2)	8.1 (2)	8.8 (2)	7.8 (2)
Lesson Set 5 Go-Cart Tricks	9.2 (1)	8.6 (2)	8.1 (2)	8.8 (2)	8.0 (2)
Lesson Set 6 Toy Project	8.6 (2)	7.8 (2)	8.1 (2)	8.7 (2)	7.9 (3)
Mean of Lesson Sets 2-6	8.9 (1)	8.2 (2)	8.0 (2)	8.7 (1)	8.2 (2)
Comparing Lesson Set 1 to the Mean of Lesson Sets 2-6: Cohen's *d*	1.95	1.13	0.99	1.37	1.43
Effect Size Interpretation	Very Large	Large	Large	Very Large	Very Large

Note: Standard deviations shown in parentheses

Table 4 provides reasons given by students for ratings of lesson enjoyment. As noted in the results presented in Table 3, students scored their enjoyment of lesson 1 significantly lower than the other lessons, though its mean score of 5.7 was in the neutral zone. The most frequently-occurring reasons for lesson enjoyment (although these were not noted for all lessons) across the lessons were: hands-on lessons, fun and liking for science, the mystery of determining the unknown, student choice, enjoyable challenges, and pride in accomplishment.

Students had more reasons for low enjoyment ratings for lesson set 1 than any other lesson set. They noted that they did not enjoy all the reading about science and found it boring and difficult to answer the questions, though they were intrigued with the idea of the mystery and figuring out the unknown. There were few low ratings for lesson sets 2-6 and therefore few reasons given for lack of enjoyment. Throughout all six lesson sets, many students commented in class that they found all the lessons to be fun, and that they generally had a positive outlook on science. Additionally, students often stated that the hands-on natures of lesson sets 2-6 stimulated their enjoyment.

Table 4. *Reasons Given by Students for Ratings of Enjoyment of Lessons*

Reason Given for Enjoyment Rating	Lesson Set 1 Black Box Reading	Lesson Set 2 Modeling Black Boxes	Lesson Set 3 Hum-dingers	Lesson Set 4 Go-Carts	Lesson Set 5 Go-Cart Tricks	Lesson Set 6 Toy Project
Mystery of figuring out the unknown	8	9	0	1	0	0
Interesting topic	5	2	0	0	0	1
New learning	4	0	3	0	0	0
Fun, I like science	5	3	4	9	6	12
Teacher helped me	1	0	0	0	0	0
I like to write	1	0	0	0	0	0
Group work was fun	0	2	4	5	4	0
Hands-on activity	0	16	13	9	5	8
Made conceptual model	0	4	0	0	0	0
Enjoyable challenge	0	0	5	12	0	1
Allowed to be creative	0	0	6	5	4	2
Pride in accomplishment	0	0	4	11	1	0
Be like a scientist	0	0	1	0	0	1
Choice	0	0	0	0	19	4
Excited to get started	0	0	0	0	0	1
Naturally creative	0	0	0	0	0	1
Reason Given for Low Enjoyment Rating	**Lesson Set 1 Black Box Reading**	**Lesson Set 2 Modeling Black Boxes**	**Lesson Set 3 Humdingers**	**Lesson Set 4 Go-Carts**	**Lesson Set 5 Go-Cart Tricks**	**Lesson Set 6 Toy Project**
I don't like reading	7	0	0	0	0	0
Boring	6	0	0	0	0	1
Hard questions /difficult	4	0	2	0	3	0
Want hands on	2	0	0	0	0	0
Too much writing	1	0	0	0	0	0
Lack of success	0	0	0	0	2	0
Negative group experience	0	0	0	0	2	4
Didn't like outside of school requirements	0	0	0	0	0	1
Not interested in topic	0	0	0	0	0	1

Table 5 gives student reasons for motivational rating of the lesson sets. As noted before, student motivation in lesson 1 was significantly lower than ratings in other lesson sets. Students gave lack of interest, dislike of reading, and a preference for hands-on learning as reasons for this lower rating. Overall, the sense of accomplishment and solving of a mystery were often listed as reasons for positive motivation for lesson sets 2-5. In the more student directed lesson sets 3-6, a common reason given for high motivation was that they students were so interested in what they would do that they couldn't wait for science class.

Table 5. *Reasons Given by Students for Motivation Rating of Lessons*

Reason Given for Motivation Rating	Lesson Set 1 Black Box Reading	Lesson Set 2 Modeling Black Boxes	Lesson Set 3 Hum-dingers	Lesson Set 4 Go-Carts	Lesson Set 5 Go-Cart Tricks	Lesson Set 6 Toy Project
Interesting topic	7	2	0	0	0	1
Confident in ability	2	0	0	2	1	2
Learning new things	2	1	1	0	2	0
Fun, I like science	2	7	6	4	1	6
Like to read	1	0	0	0	0	0
Teacher helped me	1	0	0	0	0	0
Challenging	0	2	7	6	7	3
Accomplish/solve mystery	0	13	5	14	7	0
Hands-on	0	5	3	1	0	3
Positive Group work	0	4	4	2	0	1
Couldn’t wait for science	0	0	4	4	15	3
Drawing	0	1	0	0	0	0
Thinking like scientists	0	1	0	0	0	0
Freedom of thought	0	0	2	0	1	2
Plenty of materials to use	0	0	0	0	0	1
Successful	0	0	0	0	0	1
Reason Given for Low Motivation Rating	**Lesson Set 1 Black Box Reading**	**Lesson Set 2 Modeling Black Boxes**	**Lesson Set 3 Hum-dingers**	**Lesson Set 4 Go-Carts**	**Lesson Set 5 Go-Cart Tricks**	**Lesson Set 6 Toy Project**
Not interested	11	1	0	0	0	6
Don't like to read	4	0	0	0	0	0
Prefer hands-on work	4	0	0	0	0	0
Don’t like writing	2	1	0	0	0	1
Want more teacher help	1	0	0	0	0	0
Don’t understand	0	1	0	0	0	0
Not structured enough	0	0	3	0	0	0
Ready to move on	0	0	0	2	0	0
Lack of success	0	0	0	2	2	0
Fun, but not educational	0	0	0	2	0	0
Lack of success	0	0	0	0	2	0
Negative group experience	0	0	0	0	1	1
Don’t like using computers	0	0	0	0	0	1
Hard	0	0	0	0	0	1

Table 6 shows student reasons given for perceived understanding of science concepts. Again, as in previous attitude ratings, students gave more negative reasons for lesson set 1, citing that they did not understand the content as well because they only read about the modeling process without any concrete examples of the models. In fact, in lessons 2 and 3, students frequently remarked that concrete models helped their understanding of models. Starting in lesson set 3, students cited the process of designing something as aiding their understanding.

Student comments often showed a spike in frequency when each concept was addressed. For instance, lesson set 2 allowed students to actually participate in the modeling process, leading to many comments about its aid in understanding. Lesson set 3 introduced, then allowed students to use, the design process, which then led to a spike in comments indicating that it helped in understanding. These concepts were addressed and used in later lessons; but, the spike occurred when they were first addressed. Because students were only asked to provide two reasons for their attitude ratings, the ideas most prevalent in their current thinking were written.

Table 6. *Reasons given by Students for Rating of their Understanding of the Science Concepts in the Lessons*

Reason Given for Higher Understanding Rating	Lesson Set 1 Black Box Reading	Lesson Set 2 Modeling Black Boxes	Lesson Set 3 Hum-dingers	Lesson Set 4 Go-Carts	Lesson Set 5 Go-Cart Tricks	Lesson Set 6 Toy Project
Understood content	16	4	4	17	18	14
Somewhat understood the content	1	0	0	1	0	5
Already knew it	1	0	0	0	0	0
Concepts are fun	1	2	0	0	0	0
Models helped understanding	0	20	10	0	2	2
Teacher explanation	0	2	0	0	2	3
Design Process	0	0	15	1	7	0
Uniqueness is okay	0	0	0	1	0	0
Understood with extra research	0	0	0	0	0	6
Reason Given for Lower Understanding Rating	**Lesson Set 1 Black Box Reading**	**Lesson Set 2 Modeling Black Boxes**	**Lesson Set 3 Hum-dingers**	**Lesson Set 4 Go-Carts**	**Lesson Set 5 Go-Cart Tricks**	**Lesson Set 6 Toy Project**
Didn’t understand any concepts	6	0	3	0	0	0
Didn’t understand part	8	1	0	4	2	0
Lack of direct instruction	2	0	0	0	0	0
Overwhelmed	1	0	0	0	0	0
Confusing	0	3	0	3	3	0
Partner Problems	0	1	0	1	1	
Limited choice of toys	0	0	0	0	2	
Lack of success	0	0	0	0	0	1

Table 7 shows reasons given by students for rating creativity of the lessons' design. Students appreciated that freedom of thought was designed into lessons 2-6, allowing for more creativity. In contrast, this reason did not appear in lesson 1, in which students commented that the readings were not creative. Students also recognized that the creativity that was allowed when the teacher built in time for model design and creation.

Table 7. *Reasons given by Students for Rating Creativity of the Lessons Set-up or Design*

Reason Given for Higher Lesson Creativity Rating	Lesson Set 1 Reading about Black Boxes	Lesson Set 2 Modeling Black Boxes	Lesson Set 3 Hum-dingers	Lesson Set 4 Go-Carts	Lesson Set 5 Go-Cart Tricks	Lesson Set 6 Toy Project
Freedom in answers	7	0	0	0	0	0
The concept is creative	2	0	10	0	0	0
Partner or Group work	1	3	1	2	1	0
Freedom in thought	0	14	17	29	25	18
Actual model creation	0	10	4	0	3	4
Hands-on activity	0	3	0	2	0	0
Fun activity	0	3	0	0	1	1
Chance to be a scientist	0	1	1	0	0	1
Adequate materials	0	0	0	1	0	0
Success	0	0	0	1	0	0
Allowed to be creative	0	0	0	0	0	7
Reason Given for Lower Lesson Creativity Rating	**Lesson Set 1 Black Box Reading**	**Lesson Set 2 Modeling Black Boxes**	**Lesson Set 3 Hum-dingers**	**Lesson Set 4 Go-Carts**	**Lesson Set 5 Go-Cart Tricks**	**Lesson Set 6 Toy Project**
No creativity	6	0	0	0	0	0
Not hands-on	2	0	0	0	0	0
Questions were hard	1	0	0	0	0	0
Don't like to read	1	0	0	0	0	0
Didn't feel creative	0	2	0	0	2	0
Lack of success	0	0	0	2	1	1
Group Issues	0	0	2	0	0	1
Didn't have unlimited materials	0	0	1	0	0	0
Not enough time	0	0	0	0	1	0
Limited choice of toys	0	0	0	0	0	1

Table 8 gives reasons for rating self-creativity during lessons. Nine students remarked that they were not creative in lesson 1 because there was no opportunity for creativity. Again, on the positive side of self-creativity, students remarked that the lessons 2-6 led to creative, free thoughts, something they appreciated. They also felt confident in their creativity, especially in lessons 3-6, in which creativity was required.

Table 8. *Reasons given by Students for Rating Self-Creativity during Lessons*

Reason Given for Higher Self-Creativity Rating	Lesson Set 1 Black Box Reading	Lesson Set 2 Modeling Black Boxes	Lesson Set 3 Hum-dingers	Lesson Set 4 Go-Carts	Lesson Set 5 Go-Cart Tricks	Lesson Set 6 Toy Project
Clever enough to complete	5	0	0	0	6	0
Naturally creative	3	0	0	0	3	4
Led to creative, free thoughts	2	10	18	14	6	7
Easy & Fun	1	5	0	1	0	0
Models helped understanding	0	4	2	1	1	0
Good group work	0	1	3	0	0	2
Felt confident, creative	0	5	12	10	1	8
New concept	0	1	0	0	0	0
Challenging	0	0	0	0	3	0
Spent extra time	0	0	0	0	1	0
Found new ways to solve problems	0	0	0	0	0	4
Forced to be creative	0	0	0	0	0	1
Reason Given for Lower Self-Creativity Rating	**Lesson Set 1 Reading about Black Boxes**	**Lesson Set 2 Modeling Black Boxes**	**Lesson Set 3 Humdingers**	**Lesson Set 4 Go-Carts**	**Lesson Set 5 Go-Cart Tricks**	**Lesson Set 6 Toy Project**
No opportunity for creativity	9	0	0	0	0	0
Lack of interest	1	0	0	0	0	1
Too much writing	1	0	0	0	0	0
Lacking creative skill	0	3	0	4	5	4
Group problems	0	0	0	2	4	2
Ran out of time	0	0	1	2	0	0
Pre-determined goal was limiting	0	0	0	1	0	0
Too many ideas	0	0	0	1	0	0
Confusing at times	0	0	1	0	0	0
Not much color	0	0	1	0	0	0
Lack of Success	0	0	0	0	4	3

Student-Made Toys

During lesson set 6, students investigated toys based on simple machines or other science principles, writing explanations of the science behind their operation and creating a toy of their own that illustrated the same ideas. A large variety of toys was made. Figure 2 shows several example student-made toys including kaleidoscope, rain stick, jumping acrobats, pecking hens, musical tone cups, and spin tops.

This module was the most student-centered, transferring responsibility for learning entirely to the student. Many students appreciated the choice and opportunity for creativity, but others were overwhelmed with the challenge. Some toys chosen by students exhibited principles difficult to recreate and the chance for student failure was real. Some students were frustrated with the high level of challenge and some final products did not show the targeted scientific principles. This caused arguments within groups and showed in the attitude data as "negative group experiences."

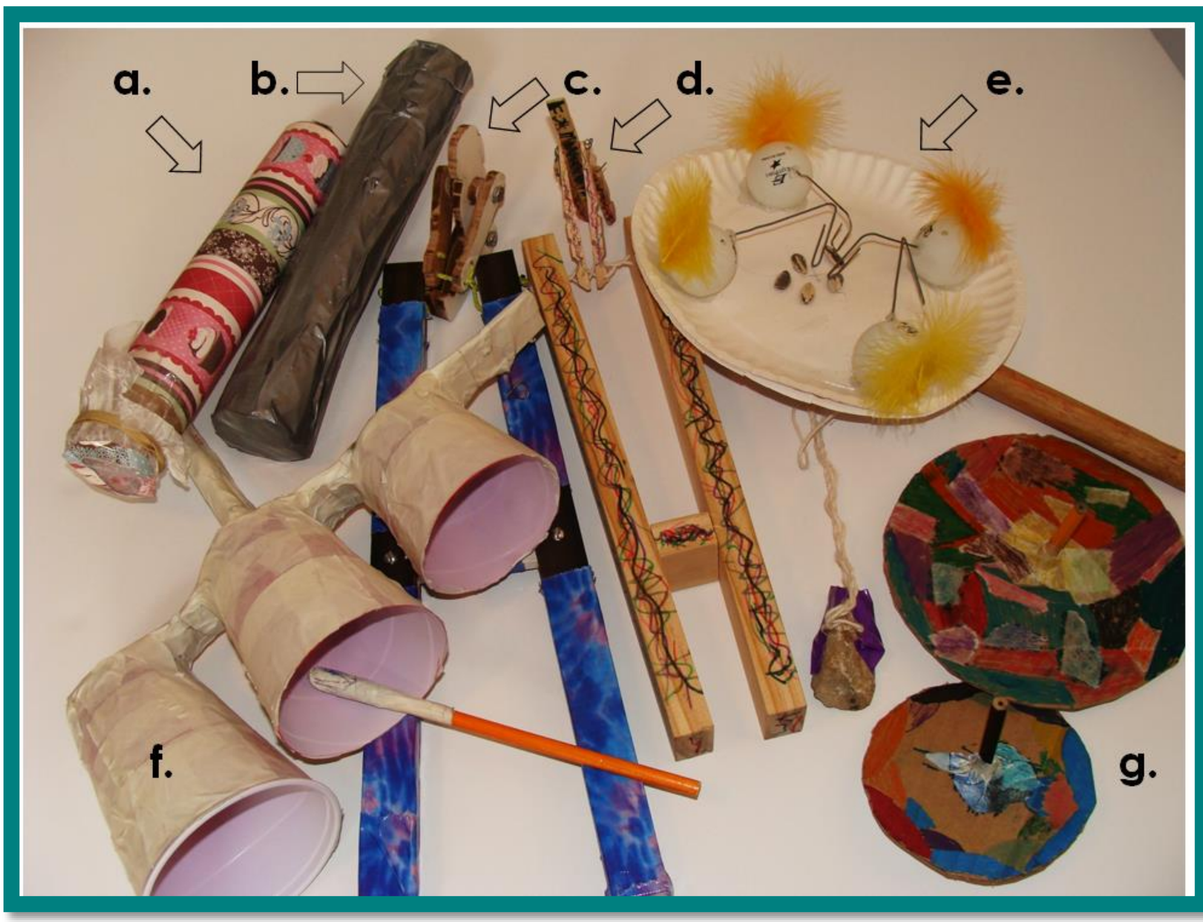

Figure 2. Example student-made toys: a. kaleidoscope covered with wrapping paper; b. rain stick covered in duct tape; c. blue tie-dyed design jumping acrobat; d. jumping acrobat of natural wood decorated with marker; e. pecking hens toy with weight attached to strings below that pulls on hens as rotated; f. musical instrument tone cups of different sizes and pitch; and g. two decorated spin tops.

Discussion

Results of the study indicate that students retained more science content from the more student-centered lessons, had more positive attitudes toward those lessons, and recognized more creativity in the lesson designs and their own performance. Similar to Dawkins (2014), students reported that they enjoyed their learning and felt connected to the learning process. Overall, this points to the conclusion that students can thrive in an environment of student-centered, inquiry-based experiences.

From lesson set 2 on to lesson set 6, students appreciated the active, hands-on nature of the lessons. Each of these lesson sets included increasing student-led investigation that went beyond just reading about the science, although that was still an important component of the comprehensive science unit. This study provides further evidence for the idea that students who are active participants in their learning, such as students in the meta-analysis conducted by Apthorp, Igel, and Dean (2012), retain more content. Apthorp and colleagues noticed that effect sizes were much larger when the control condition of a study engaged participants in highly teacher-directed text-based activities, a finding similar to that in our study.

Our students recognized that they were more involved in their learning, an important metacognitive aspect for a fully engaged learner. Metacognition is one of the aspects Rule (2006) recognized as being a component of authentic learning, The four components of authentic learning (Rule, 2006), also addressed by inquiry activities in the current study, are: engagement of learners in the real-world work of professionals (using models and designing toys); inquiry activities that practice higher-level thinking skills and metacognition (using, analyzing, and creating models); small group discussions among a community of learners (group work); and student empowerment in their work through choice (humdinger construction, go-cart tricks, new toy).

Once students were allowed to be active and figure things out on their own, as well as to begin to ask their own questions, they remarked time and again about their appreciation of the freedom of thought they were allowed. They preferred to have some options in how they figured things out, and to not always be told exactly what to do or how to do it. Results are similar to the findings of Meyer and Crawford (2011) who found that students felt successful when they were doing their own thinking, learning, and questioning. This positive effect was amplified when students had a real mystery to solve or phenomenon to explore. Instead of just reading about how to do something or being told how something works, students approached a problem as a mystery to be solved, thus engaging in the an authentic, scientific problem-solving process. They could formulate their own theories, test them out, then reject or accept them accordingly. Not only does this teach students science content, it also teaches them science process.

In much the same way that students instantly recognized their ability to do science and have some freedom of thought, they also recognized and appreciated the allowances for creativity that were built into the later lesson sets, especially sets 4-6. According to the data gathered, students want to be creative and to control how their work is conducted. Modules 5 and 6 were especially full of creative options and students recognized and appreciated these aspects, as evidenced by the high rating and accompanying comments on the student surveys for those two lesson sets. Grant (2011) suggested that people experienced greater motivation when functioning in positive social atmospheres and that intrinsic motivation was tied to higher levels of creativity. The results of this study also indicate that, for many students, when they had a positive group experience, they reported higher levels of motivation and creativity. Additionally, the overall findings suggest that the majority of students felt motivated by the more student-centered work, and also saw themselves as more creative during those lessons.

The small dip in student performance, enjoyment and motivation during lesson 6 indicates that balance that must be accomplished between enough student-centeredness and too much autonomy and challenge. Although overall results were still favorable, the attitude ratings for lesson set 6 were not quite as high as lesson sets 2-5, except in the areas of self -perception of understanding and creativity. Lesson set 6, the “Toy Project” was designed to be the most student-centered, with the least amount of teacher-direction imposed. Final products, as well as the process to arrive at the final product, were very wide open and could differ greatly from group to group. Some students noted that lack of success, negative group experiences (differing opinions), and some requirements outside of school time limited their enjoyment and motivation. This may be related to individual personality and interactive preferences. While it appears that the vast majority of students enjoy active learning with some flexibility, not all enjoy a great deal of freedom and responsibility in science class. A balanced approach of active, student-centered instruction, closely monitored by the teacher seems to have elicited the most favorable learning conditions for the largest number of students. Alternatively, this final inquiry lesson required the most responsibility for learning that students had encountered; more opportunities to plan and conduct inquiry investigations may better prepare students for challenges of this type.

Conclusion

This study indicated that student performance on the posttest increased as the level of student-centeredness increased. Student enjoyment and perceived understanding of science also showed an increasingly positive trend as student-centeredness increased. Students recognized when they participated in science inquiry, appreciating the freedom of choice in their investigations.

Implications for practice

Results from this study indicate that inquiry is needed in science classrooms. Reading is an essential support to scientific investigation, but should not be the focus. Active, engaged upper elementary students who were allowed choice in what they investigated or how they proceeded displayed more positive attitudes toward their learning and retained learning better. When students were allowed to be creative, they recognized and took advantage of the opportunity.

Suggestions for Further Research

In the current study, there was no time to add totally student centered lesson set with students generating the project idea (in the final project, the idea of reproducing a toy was decided by the teacher), because of school curriculum and scheduling constraints. However, a natural next step would be to ask for student input in creating the driving question for the lesson. For instance, students may ask to invent something completely new and hold an invention convention. An example might be to find a gadget that they could improve. This would be similar to the toy project, lesson set 6, but more open with complete student choice in selecting the item. Another possibility would be to restrict the invention to being made of recycled materials.

This unit on Models and Designs was primarily a science *process* unit, as opposed to a science *content* unit. The unit contained content for students to learn, but that content focused on the scientific process of modeling and design, which can be applied to most scientific investigations. Further research could be conducted to determine if similar favorable results are obtained with a more content-oriented unit, such as human body systems emphasizing the form and function of organs and systems. Reading about functions of cells, organs and bones of the body might be addressed in teacher directed parts of the unit. Student-centeredness could be continually increased in subsequent lessons until students were devising their own questions to test the effects of different stimuli on specific body components or systems.

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