The Pedagogy of Teaching STEM

by

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Abstract

STEM education implementation comes into every classroom. STEM lessons use various levels of inquiry learning methods. Inquiry methods of teaching vary in the amount of teacher direction. It is a struggle for teachers to provide a good lesson if their students do not fully understand the standard or goal of the lesson. Free inquiry teaching methods allow students to freely explore a topic without much background information provided by the teacher. Guided inquiry teaching methods include the teacher as a guide to help students to understand the background information and goal of the lesson. While both approaches have benefits, how much background information should students in grades three to five be given to guide them to learn as much as possible? STEM lessons using both methods of inquiry teaching were used to discover which way helped the students to understand the experiences. Students who participated in the guided inquiry method of teaching had a better understanding of the concepts in the lessons.

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Chapter I: Introduction

Identify the Issue

STEM is the process of connecting learning to Science, Technology, Engineering, and Math. There are numerous STEM projects available for use in the classroom, such as creating a boat out of tinfoil and discovering how many pennies it will hold, building towers with marshmallows and toothpicks, and building paper plate hover cars.

When students work on STEM projects, they appear to be engaged in the activity. Their conversations and facial expressions usually show joy and excitement. Though different strategies are used by the students to create the STEM project, the final product shows their understanding of the project. During work time, when students understand the teacher's expectations, they talk about what they are doing. Conversations and questions help students create increasingly complex plans. Creating a project can be valuable, but projects that do not connect to what they are learning cause students to miss out on deeper learning within the project (MacEwan, 2013).

Teachers should guide students to understand the STEM principles in their projects. Playing to learn is valuable for students' growth at all levels, but they have to do more than play (Rieber, Smith, & Noah, 1998). Play provides a way for students to grow in their knowledge about how objects work. Teachers bring knowledge of why or how something works. They are guiding the students to more in-depth knowledge about the project or helping students to apply their learning to other studies.

Teachers often complete a STEM project and cheer because the result matches the picture in the book or on the internet. They may not have connected the project to a learning goal or a standard. Teachers need to guide students to use their play to identify how that play relates to science, technology, engineering, and math (Education, 2016).

Importance of the Project

In recent years increasing numbers of teachers are looking for STEM projects to demonstrate that their students are doing STEM. Completing STEM projects to fulfill a requirement set by principals or school boards is not the reason to have students complete STEM projects. Students of these teachers might be missing out on the next level of completing the STEM project. Those teachers are not connecting the science, technology, math, and engineering skills to the projects their students are completing. The discourse, engagement, and deep learning are missing from a project that is only done to fulfill a requirement to have STEM lessons (Honey, Pearson, & Schweingruber, 2014). It is essential to find a way to provide both the fun of the STEM project and the connected learning standard or skill to create in-depth learning that benefits a student's educational growth.

STEM jobs keep America competitive in the world market (U.S. Department of Education, 2015). Inventions are the way to stay ahead of other countries. Students are not filling those jobs because they are not well prepared in the fields of science and math. The government is providing many incentives to prepare teachers to better prepare students. STEM Innovation Network is giving money to institutions of higher education to provide teacher training in STEM fields, and the National STEM Master Teacher Corps provides money to have the best science and math teachers improve STEM lessons. These are just two examples of how the government views STEM teaching and the need for quality STEM teachers (U.S. Department of Education, 2015).

Once government and education identified a need for STEM education, teachers began to create STEM projects that connect to math and science. The connections and learning that engage and push students might encourage students to follow STEM careers. They will not be able to do that if teachers only create fun projects and do not connect them to the standards or learning goals.

The Project Purpose or Goal

The goal of this project is to discover if students develop a deeper understanding of a concept in a STEM project if an instructor uses guided inquiry for the lesson rather than free inquiry, which would consist of merely handing out the instructions to the project without any additional guidance.

Chapter II: Literature Review

Introduction

Literature for STEM education is rich with methods and reasons to incorporate STEM education into elementary school classrooms. This literature review will focus on how STEM came to the forefront in education, what the concerns are for teachers using STEM education, and what makes a strong STEM lesson.

STEM and Education

STEM is the acronym for Science, Technology, Engineering, and Math. The term originated in the 1990s when the National Science Foundation (NSF) wanted a short way to talk about the four disciplines. NSF started with the acronym “SMET” (Science, Math, Engineering, Technology) but felt that it was too close to smut. The term STEM solved the problem. However, the STEM lessons were not part of the curriculum until the discussions began about India and China bypassing America in the global economy by *outSTEMming* the United States of America (Sanders, 2009). Now the race to increase science, technology, engineering, and math graduates was on for America.

STEM education became part of the educator's world. Those who believed in the idea of STEM education thought that it could contribute to problem-solving skills, critical thinking, and analytical thinking as well as real-world connections to the curriculum (Brown, Brown, Reardon, & Merrill, 2011). The colleges were creating STEM education graduate programs, and high schools were adding STEM classes. Teachers were encouraged to increase the rigor of the math and science programs within the schools. Elementary schools were encouraged to add STEM lessons to their programs. While STEM programs gained a place in the school curriculums, some problems remained.

Students entering STEM degree programs were leaving because they were dissatisfied, or it was too much work (Rhodes, 2017).

Concerns about STEM Education

Not all teachers have embraced STEM education. Some feel STEM is taking away or minimizing English/language arts, the arts, and foreign languages (Runge, 2018). Those teachers think that a well-rounded program could prepare students for STEM professions as well as or better than a program that focuses only on those disciplines that are included in STEM (Schroth, n.d.). Another group of teachers felt that they did not have the background knowledge or materials that they needed to teach STEM education. One group did not want to add another class to their schedules (Brown, Brown, Reardon, & Merrill, 2011).

Confusion about what to do with STEM is still present in education. Elementary teachers struggle with the time a true inquiry lesson may require to reach the solution or goal for the presentation. Reading and math classes are still part of the school day, and they also demand a designated amount of time (Callahan, et al., 2013). Time constraints within the school may make it difficult to allow for the discourse, engagement, and deep learning they want to see in a STEM lesson. It is often difficult to see the growth at the time of the experience, but usually, in a lesson later in the year, the new growth in learning will appear.

Research has found that collaboration by nonverbal conversations was part of the deep learning that administrators wanted to see in lessons teachers created (Francisco, Gomoll, Hmelo-Silver, Šabanović, & Tolar, 2017). Nonverbal conversation happens when students connect with another student without telling one another what they need.

They understand what is required and work together to reach the final goal of the project. Questions on how to achieve that level of learning are a constant concern for teachers who are attempting to teach STEM education lessons. Many teachers feel insecure in their knowledge to answer the questions students might ask during the experience. This uncertain feeling may be why teachers create and use STEM lessons but do not always connect the lesson to any specific learning standard (Haverly, 2017).

Value of Good STEM Lessons

It is vital to get intentional about STEM lessons (MacEwan, 2013). Teachers need to prepare and study the concepts for the STEM lesson. They need to find the standards and base the goals of the STEM lesson on that standard. While students are working on the STEM project, teachers should encourage and ask questions to guide the students in deeper learning in that STEM lesson. Students complete their work and discuss the knowledge they have acquired; they make the connections and confirm the deep learning that has occurred in their collaborative group. Teachers need to be involved in those discussions to help students to be aware of their knowledge and fill in any gaps in the learning they have done. When the STEM lessons are integrated, and active learning happens, students may be motivated to continue into STEM fields and improve their math and science interest and performance (Moore, Roehrig, & Stohlmann, 2012).

Six characteristics create a good STEM lesson: focus on real-world issues and problems, use the engineering design process, hands-on inquiry and open-ended exploration, teamwork, rigorous math and science content in learning, and multiple right answers with failure reframed as a part of learning (Jolly, 2014). STEM should not be a stand-alone process. Instead, it should incorporate a variety of disciplines in an inquiry style lesson (Riley, 2016).

Inquiry lessons use methods such as guided research, document analysis, and question and answer sessions. Students are encouraged to ask questions to support them through the investigation process (Guido, 2017). STEM has added another dimension by including an art component. Science, technology, engineering, art, and math (STEAM) work together to help students in their investigation process. Susan Riley (2016) states that a STEAM lesson is not just about 3-D printing and Lego Labs. It is an intentional connection between naturally aligned STEM and arts standards.

STEM pedagogy is trans-disciplinary, offering students the ability to use project-based learning to address real-world problems. Connecting learning to several disciplines is done by the teacher using questions and facilitating the content learning rather than sharing information to help the students complete the STEM project. How do you get the inquiry lessons to have unity and focus? One way to get unity and focus is to plan the inquiry lesson around a focused problem the children need to address. Planning of the inquiry lesson gives direction and also provides control to students as they are working to find a solution to the problem (O'Neill, Togioka, Yamagata, & Yamagata, 2012).

A successful inquiry lesson happens when a teacher provides students with the opportunity to draw on their strengths and background knowledge. It gives teachers more chances to see the strengths of their students. Teachers usually are leaders and provide the information students need to thrive. STEM lessons may take teachers out of their comfort zone to help students to grow in problem-solving and critical thinking (O'Neill, Togioka, Yamagata, & Yamagata, 2012).

Summary

STEM came to the forefront of education to help students become better problem solvers and make science, math, engineering, and math instruction stronger. Teachers recognize the need for STEM lessons, but often do not receive training in all of the disciplines of STEM. Anxiety and stress caused by a lack of training in the STEM disciplines may cause teachers to make weak connections in their lessons to the standards and concepts of science, math, engineering, and technology. Suitable STEM lessons use an inquiry style of teaching with the teacher as a guide rather than the sage on the stage.

Chapter III: Implementation

Introduction

The goal for this field study was to discover whether students in grades three, four, and five achieved a deeper understanding of the main idea of a STEM lesson from a guided inquiry style of teaching or a free inquiry style of teaching.

Guided inquiry required more teacher involvement in the STEM lesson. The teacher provided background knowledge and information to help the students. A discussion at the end of the project would also be part of the guided inquiry method of teaching. The free inquiry style of teaching put more responsibility on the students to discover and complete the project without predetermined background knowledge from the teacher.

Procedures, Artifacts, and Results

Participants. The test subjects were students in grades 3-5 at St. John's school in Lake City, Minnesota. There were 17 students in the classroom. Four students were in grade 5, six students in grade 4, and seven students in grade 3. The genders represented in the classroom were 25% male and 75% female. When looking at the ethnicity of students in the classroom, 75% were Caucasian, 12.5% Hispanic, and 12.5% Asian.

Students were divided randomly into groups A and B for the study. Using two groups provided a way to view the students interacting in two different STEM projects with both styles of inquiry instruction. Since groups of eight or nine students would be considered large for an inquiry approach, the groups were randomly subdivided again into small groups of four or five students each and identified as Groups A1, A2, B1, and B2 in the field study.

During the first STEM activity (Paper Airplanes), group A1 and A2 followed the free inquiry approach and group B1 and B2 used the guided inquiry approach. During the second STEM activity (Fulcrum and Lever), group B1 and B2 followed the free inquiry approach, and group A1 and A2 followed the guided inquiry approach. Each group participated in each inquiry approach to decide if the differences in children's learning are based on the students or the instructional method. Teachers from other grades kept the groups that were not completing a STEM activity at the time in a different classroom to ensure that the groups did not share what they did in their lessons.

STEM Projects. The field study contained two STEM projects. The first one worked with paper airplanes and focused on engineering as well as production. The second project guided students to understand that a lever worked better based on the location of the fulcrum.

The Next Generation Science Standard (NGSS, 2013) 3-5-ETS1-1 Engineering Design guided the first STEM project. The standard was to “Define a simple design problem reflecting a need or want that includes specified criteria for success and constraints on the materials, time, or costs.” The STEM lesson selected to meet this standard was “Defining an Engineering Design Problem with Paper Airplanes” (Science Buddies, 2019). In the lesson students were asked to create a paper airplane design in 15 minutes with very few materials (paper, scissors, tape) and then mass produce a total of 12 airplanes in 5 minutes. The learning objectives of the lesson were to identify the criteria and constraints in the problem and explain why it is important to specify criteria and constraints for an engineering problem.

The second STEM project, Using a Lever, guided students to discover the load a lever can lift based on the location of the fulcrum. The project aligns with the Next Generation Science Standard (NGSS, 2013) 3-5-ETS1-3 Engineering Design. In this standard students "Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved." The STEM lesson selected to meet the standard was "Give It a Lift with a Lever" (Science Buddies, 2018). The lesson made use of a ruler, plastic bag, pennies, a pencil, and a bar of soap. The objective of the lesson was to discover how moving the fulcrum affected how many pennies were needed to lift the bar of soap.

Paper airplane project development. Students were excited to begin the Paper Airplane STEM project. They shared positive comments about how fun it would be and that they couldn't wait to start. The teacher shared the constraints. Each group would have 15 minutes to create a paper airplane that was easy to build again, flew straight, and far. Each group received 16 pieces of paper, books, and other resources. Because Group A's STEM lesson was using a free inquiry method of teaching, the teacher observed the students at work but did not guide them in the process. However, when students asked a question, the teacher answered the question.

The students in Groups A1 and A2 worked as separate teams to complete the pretest together to see if they understood the project, but filled in the answers to their pretest questions separately (see Appendix A). Then they worked for 15 minutes on their paper airplane plans for the project in their small groups.

Group A1 tested paper airplane designs, ran out of paper, but reused folded paper to find the paper airplane that flew in a straight line the farthest distance. Group A2 appeared to be insecure and frustrated as they tried to discover a paper airplane that would be best. Group A2 complained about the resources and said that they didn't even know how to fly a paper airplane. The teacher intervened by demonstrating one style of a paper airplane and how to fly it. Students worked for the entire 15 minutes, trying to design the best paper airplane.

Small groups, A1 and A2, met with their small group members and chose the plane they thought would be best. The students used an assembly line style to create the final twelve airplanes for the flight test within a five minute time limit. The members of each group A1 and A2 flew each plane and charted the results (see first two columns of Appendix B).

Groups B1 and B2 received the same information concerning the time limits and constraints of the project. Using the guided inquiry method, the teacher discussed the limitations and suggested that students think about how to create a paper airplane. Within their small groups, students completed the pretest (see Appendix C).

The teacher demonstrated how to create one type of paper airplane. Students looked at various resources. Group B1 used a how to fold paper airplanes resource sheet. A student in B1 felt he would be good at creating and flying paper airplanes because another student taught him how to make and fly paper airplanes. Students in Group B2 struggled with a student that was controlling and demanding. The teacher intervened in the group by showing them one style of the paper airplane and helped them to learn how to fold that style of a paper airplane. After the teacher's intervention, students in Group B2 seemed to be able to move forward. Students in Groups B1 and B2 met within their groups and chose the paper airplane design they thought would be the best one to fit the criteria given to them at the beginning of the project. Students then used an assembly line method to mass produce 12 paper airplanes for the recorded flights. The members of each group B1 and B2 flew each plane and charted the results (see last two columns of Appendix B).

Paper airplane project results. It is somewhat interesting to note that students that utilized the free inquiry method of instructions happened to create planes that flew a greater distance (212.7 and 227.9 inches) than those in that utilized a guided inquiry method of instruction (130.2 and 158.5 inches) (see Appendix B). Based on teacher observation, how well the planes flew appeared to be related more to prior experience with creating airplanes and working productively together within groups, than to the actual inquiry method of instruction.

The learning objectives of the lesson were to identify the criteria and constraints in the problem and explain why it is important to specify criteria and constraints for an engineering problem. After the Paper Airplane STEM project was finished, students completed a post-test (see Appendices D and E). The answers on the post-test indicate that generally students in all four small groups worked under the project constraints and were able to share that they were able to create paper airplanes that met the constraints given at the beginning of the project. The students would have changed how many pieces of paper they were able to use in the practice session, added more resources, and increase the time. Students in both groups realized that constraints are valuable in some situations.

Fulcrum/lever project development. The second STEM project guided students to understand the use of a fulcrum with a lever. The objective of the lesson was to discover how moving the fulcrum affected how many pennies were needed to lift the bar of soap. The teacher used the free inquiry method of teaching when leading group B in the project and the guided inquiry method with group A. A student was moved from Group B2 to Group B1 for the benefit of all students.

The teacher led a short discussion about the ways items can be lifted. Students were given a ruler, pencil, pennies, a plastic bag, and a soap bar. The teacher informed the students they would use the machine they build to elevate the soap bar. The students' goal was to find the best location for the fulcrum (pencil), so the fewest pennies were needed to raise the soap bar. The teacher encouraged students to use their science textbook for ideas on creating the machine.

Both small groups B1 and B2 refused to look at the textbook for about 10 minutes. They struggled with creating the lever to lift the soap bar. Using the textbook was again encouraged by the teacher, and both groups found a similar lever experiment. The students did not connect the two ideas because the materials in the textbook were different than the ones they were given. Student B1b tried to convince his team members to try some of the recommendations in the text. Student B1b studied the book and tried to explain how a lever works because of the force and location of the fulcrum. The rest of the group allowed Student B1b to show them, and they were able to create a lever that worked. Then they used the fulcrum, which changed the number of pennies needed for lifting the soap bar. Group B1 spent time convincing one member they were on the right path to finding how to raise the soap bar, which caused them to run out of time to record their findings.

Group B2 never understood the connection to the essential question shared at the beginning of the project. They were confused by the science book experiment they used for a resource. The experiment in the textbook used clay for portions of the experiment. They did not have clay, and they were not able to discover other ways to make the lever work without the clay. They spent time on how to wrap the pennies into smaller groups. Finally, Student B2c realized they could use a pen as a fulcrum, and they were able to complete the measurements and enter them on the recording sheet (see Table 1).

Groups A1 and A2 were given the same project materials and general instructions as groups B1 and B2. In addition the teacher shared information on how to create a lever and led a discussion on where they might have seen a lever. Because the teacher was using the guided method of inquiry, the entire group talked about related vocabulary, how a lever works, and why a lever is useful. Students then worked in their small groups A1 and A2 to create the lever and complete the project. Students tested the position of the fulcrum and completed the recording sheet (see Table 1).

Table 1
Position of Fulcrum vs Pennies Used to Lift Load

Groups	Distance from fulcrum to the soap bar (load)	Pennies needed to lift soap bar
Group A1	4 inches	44
	3 inches	30
	2 inches	20
Group A2	3 inches	34
	2 inches	24
	1 inch	16
Group B1	4 inches	45
	3 inches	35
	2 inches	20
Group B2	(didn't finish)	(didn’t finish)

Note: Group A used the “guided inquiry” method of instruction and Group B used the “free inquiry” method of instruction. Group B2 ran out of time to report results.

Fulcrum/lever project results. As indicated in Table 1 above, all groups that completed their work were able to come to the conclusion that the load (soap bar) could be lifted with fewer pennies when the fulcrum (pencil) was closer to the load.

After both groups finished the project, all students were brought together to complete a post-test (see Appendices F, G, and H for the complete test and results). See Table 2 below for a summary of results on the post-test by group.

Table 2
Fulcrum Project Multiple Choice Posttest Summary

Questions	% of answers correct by group A1-A2	B1-B2
1. Which piece of playground equipment is an example of a lever?	100%	100%
2. Where should you push on this lever to make it easier to lift the box?	62.5%	55%
3. Where should you place the pencil to make it easier to lift the box?	100%	77%
4. What are some examples of materials you could use to make a simple lever?	100%	55%
5. A door is a type of lever. If a door is already open a little bit, and you want to open it all the way. It will open most easily if you:	62.5%	66%

Note: Group A used “guided inquiry” method of instruction and Group B used “free inquiry” method of instruction.

The post-test revealed that 100% of the students in both the guided inquiry group (Group A) and the free inquiry group (Group B) identified a lever from a list of playground equipment choices (question 1). Group A was better at recognizing the best place to push on the lever (question 2) and where the best place was to put the fulcrum (question 3) to make the lever work efficiently. Students in Group A identified all of the levers among the possible choices (question 4). At the same time, the students in Group B, the free inquiry instruction group, generally chose only one potential lever among a list of possible choices (question 4).

Overall, students in the guided inquiry group (Group A) scored a higher percentage correct when taking the post-test. In addition to the post-test results, the teacher led a discussion to determine the overall understanding of the students concerning levers and the position of the fulcrum. The subjective opinion of the teacher is that the students in the guided inquiry group had a better understanding.

Chapter IV: Reflective Essay

Introduction

The goal for this field study was to discover whether students in grades three, four, and five achieved a deeper understanding of the main idea of a STEM lesson from a guided inquiry style of teaching or a free inquiry style of teaching.

Guided inquiry required more teacher involvement in the STEM lesson. The teacher would provide background knowledge and information to help the students. A discussion at the end of the project would also be part of the guided inquiry method of teaching. The free inquiry style of teaching put more responsibility on the students to discover and complete the project without predetermined background knowledge provided by the teacher.

Conclusions

Prior to the start of the project, I was concerned about the methods that teachers used to engage students in STEM projects and the learning that did or did not happen during those projects. I worked on a field study that used the same STEM project but two different methods of inquiry instruction to discover what method created STEM lessons with increased student learning. Both guided inquiry and free inquiry styles of teaching can be appropriate and successful in the correct setting. Using free inquiry appeared to mean that students were handed a sheet of paper or given oral directions and some materials and told to create. I was concerned that this method might not provide the information needed by students in grades three, four, and five to understand the science behind the project entirely. Guided inquiry instruction was the other method used in the field study. This method gave the students the background information and guidance to help them as they created their STEM projects.

The Next Generation Science Standards guided the two STEM projects. The first STEM project's focus was on engineering. Students were asked to create an airplane in 15 minutes that would be easy to reproduce and would also fly straight and fast. The second STEM project worked with levers and identifying the best location for the fulcrum.

The first thing I should have looked at was group structure. Students in all of the groups needed to review the responsibilities and ways to act in a group. Lack of social-emotional instruction and strong will of one student stressed both the group and the students. Group interaction may have prevented the group and the student from learning together. Other groups seemed to work well but still would have benefitted from large group instruction on how to work in a group.

The paper airplane project showed the importance of background knowledge. Students that did not know how to build a paper airplane created many versions that could not fly. Eventually taking time to show them how to create a paper airplane did not waste their time; it helped them to learn about constructing paper airplanes. At the end of the project, all students were able to build a paper airplane that flew, and they were able to fly them as well. The time spent in teaching one another and teacher input on how to create the airplane created a successful project no matter which inquiry method was used. However, it was apparent to me that students stayed on task better and generally accomplished more in a shorter period of time when utilizing the guided inquiry method of instruction.

The fulcrum/lever project focused on discovering how moving the fulcrum affected how many pennies were needed to lift the bar of soap. Once again it was evident to me that the guided inquiry method of instruction, where the teacher provided background knowledge at the beginning of the project, allowed the groups to work on the project more efficiently and with less friction within the group. Group B1 and B2, the free inquiry groups, spent an inordinate amount of time trying to decide what to do. In fact, group B2 ran out of time to complete the project.

Recommendations

STEM lessons are essential and helpful for students to establish deeper learning about the topic or objective in the STEM lesson. It is vital to guide the students by providing background knowledge and information that helps them to be successful in the STEM lesson. In the paper airplane lesson, students would have been able to accomplish the goals and spend more thinking time on the design if they knew how to make a paper airplane. During the free inquiry lesson, students created paper airplanes that didn't have any possibility of flying. Although no specific data was recorded concerning time on task, it was obvious to me that the guided inquiry lesson group had their paper airplanes flying sooner, and students worked on different designs to create a better paper airplane.

The same was very evident in the fulcrum/lever lesson. The students in the guided inquiry lesson group did not waste time trying to determine what to do. They quickly began working with their fulcrum placement and lever to complete the project. They also came away with a better understanding of the lesson as evidenced by their responses on the post-test.

Another important consideration is that even in random groups, it is essential to observe the make-up of the group. Lessons on teamwork and how to get along in a group create a better environment for students in the field study. A student had to be moved from one group to help that group to be able to function as a team and not have a dictator. The student dictated to the new group, but the teacher was more involved in the activity and the students were not as willing to be controlled.

In summary, guided inquiry STEM lessons generally seem to result in better student outcomes since students are provided with background information that allows them to get on task more quickly. Teacher support and guidance throughout the project also helps ensure students remain on task and focus on the lesson objective. Free inquiry STEM lessons might be more suitable for students that already possess the required background information, are more experienced with the task at hand, and have a very high interest in the topic being studied.

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Appendix A: Paper Airplane Engineering Pretest Group A

Note: Group A used "free inquiry" method of instruction.

Students	Who is the "customer" for your paper airplane design?	What are the criteria for your design?	How can you use, measure, or prove that your plane meets the criteria?	What constraints are there on your design?
A1a	Our teacher Miss Ring	A design for an airplane that goes far	Use a ruler. It goes about the same distance	pieces of paper
A1b	Miss Ring	It has to go far now. It has to be done quickly	Use a ruler. It goes about the same distance every time.	4 pieces of paper
A1c	Miss Ring	A far distance paper airplane	Use a ruler-it goes about the same distance every time	4 pieces of paper
A1d	Our teacher Miss Ring	A plane that goes far and four identical planes done quickly	Use a ruler-it goes about the same distance every time	4 pieces of paper - 5 minutes
A2a	Miss Ring	A far flying and reliable airplane	Calculator and testing	15 minutes
A2b	Miss Ring	Far and steady	It has to go far - calculator	15 minutes/16 papers
A2c	Miss Ring	Far, fast, reliable	Calculator	15 minutes
A2d	Miss Ring	Far, fast, reliable	A calculator	15 minutes /16 paper

Appendix B: Average Flight Distances

Free Inquiry Method of Instruction		Guided Inquiry Method of Instruction	
Group A1	**Group A2**	**Group B1**	**Group B2**
244	364	58	190
267	359	39	29
247	332	60	188
155	140	33	188
28	328	74	29
153	15	58	28
248	241	201	238
234	226	131	207
302	197	379	312
326	35	171	24
324	349	132	181
24	149	226	288
212.7 Inches	227.9 inches	130.2 inches	158.5 inches

Appendix C: Paper Airplane Engineering Pretest Group B

Note: Group B used “guided inquiry” method of instruction.

Students	Who is the "customer" for your paper airplane design?	What are the criteria for your design?	How can you use measure, or prove that your plane meets the criteria?	What constraints are there on your design?
B1a	Miss Ring	Fast and straight, far	We can show her our design -15 minutes	16 pieces of paper
B1b	Miss Ring	Fast and straight, far	We can show her design	16 pieces of paper and time limit
B1c	Miss Ring	Fast and straight	We can show her design	16 pieces of paper and 15 minutes
B1d	Miss Ring	Fast and to go straight	We can show her our design -15 minutes	16 pieces of paper and a time limit
B2a	Miss Ring	Distance, reliable, fast	You can fly it and it goes a good distance	15 minutes 16 sheets of paper only 1 scissors and tape
B2b	Miss Ring	Distance, reliable, fast	You can fly it and it goes a good distance	15 minutes, 16 sheets of paper scissors and tape
B2c	Miss Ring	It has to fly fast. It has to be reliable. It has to fly far.	You can fly it and it goes a good distance	You had 15 minutes tape, scissors, and 16 sheets of paper
B2d	Miss Ring	Distance, reliable, fast	You can fly it and it goes a good distance	15 minutes 16 papers scissors and tape
B2e	Miss Ring	Distance, reliable, fast	You can fly it and it goes a good distance	15 minutes 16 sheets of paper only 1 scissors and tape

Appendix D: Paper Airplane Engineering Posttest Groups A

Note: Group A used "free inquiry" method of instruction.

Stu-dents	Why is it important to have criteria for this engineering problem?	Why was it important to know the constraints when working on this problem?	Did you have any trouble doing this project because of the criteria or constraints?	If we did this activity again, and you had a more time or materials, what would you do differently?	What would you change?
A1a	Than all we would is make an airplane	Then you would not know how far it needs to go.	No	Nothing	We have more time
A1b	So that we know what we are making and the requirements the costumer wants	So we get what the customer wants	No	I would build a better airplane. I would think about it.	I would get a better book about paper airplanes
A1c	So we can know our goal	So we know that it can't go short and it has to go far which is the criteria	Iit was a little hard to make a plane that goes far	I would follow the instruction in the book	I would have different materials.
A1d	So you don't build something that goes long but goes slow when someone wants it to go short but far.	Well you could end up doing something too much or something too less. so you know what to make	Yes, she wanted it to go fast and that's hard. Especially when you can't control it.	I would construct it with the folds more perfect.	Well I would only work on one airplane then I could perfect it.
A2a	Fast and easy	Time	Yes	More time	I'd make it longer
A2b	If we didn't it may have turned out rough	I don't know	No	Nothing I loved it	Nothing
A2c	Because something could go wrong	not available	No	Make up way more things	Less rules more fun
A2d	So we had a goal to reach	so you know what to make	yes	test more planes types -make a couple of each	I would change the time we had more different materials -concentration

Appendix E: Paper Airplane Engineering Posttest Group B

Note: Group B used "guided inquiry" method of instruction.

Students	Why is it important to have criteria for the engineering problem?	Why was it important to know the constraints when working on this problem?	Did you have any trouble doing this project because of the criteria or constraints?	If we did this activity again, and you had a more time or materials, what would you do differently?	What would you change?
B1a	Because it is good to have eveters	To see how it will fly	Getting it to fly to this side to this side	Do it better	I liked flying our planes. I do not like how we cooperated
B1b	To make sure that it is what the customer gets, what he or she gets, time	To make it fast, straight, and simple if people want to make it	Not lots of paper and not enough time	Try more ideas	The amount of paper we got that my team use to much paper for bad planes, improve the throws and how much paper we use
B1c	Not answered	Not answered	Not answered	Not answered	Not answered
B1d	For the build for the paper airplane	To know what to do	No, it was fun especially with a group	I would of made it bigger	I would improve the time and when we had to count how far the plane went it took a while.
B1e	To learn from your mistakes	We had 15 minutes to build paper airplanes	Yes, because none of them flew a long distance	Not make square planes have a point more time	Not answered
B2a	So that you don't make something the customer doesn't want.	It is important so that people don't complain that they didn't get the right thing.	Yes, because a lot of airplanes twisted or didn't go far.	I would make the airplane neater and tape it.	Not answered

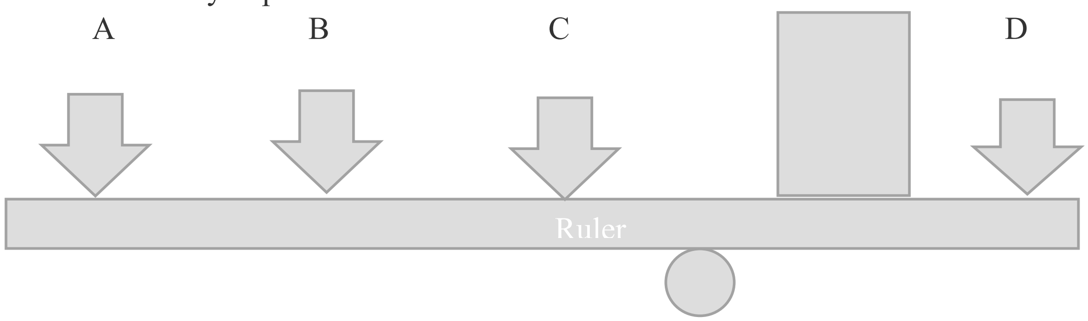
B2b	You would not know how to build it	You would have no rules or how to build it.	Yes, It would not fly far enough.	I would take my time and do it slower.	I liked how we got to work in groups. I didn’t like how a kid said one plane won when it did not.
B2c	It would be folded paper if their wasn't	Because constraints are important	No, I didn't	Make better airplanes	One of my favorite things about this is that we got to make paper airplanes. I didn't like that there are so many kinds of airplanes to pick.
B2d	To know what the things you have to do	To see what you need to do and build	Yes we had to construct something that has what it needs	Nothing. I really liked everything we had to do	Nothing I really liked it I wish we could do this all the time.

Appendix F: Lifting with a Lever Posttest

Lifting with a Lever

1. Which piece of playground equipment is an example of a lever?
    a. Slide
    b. Basketball hoop
    c. Seesaw or teeter-totter
    d. Ladder

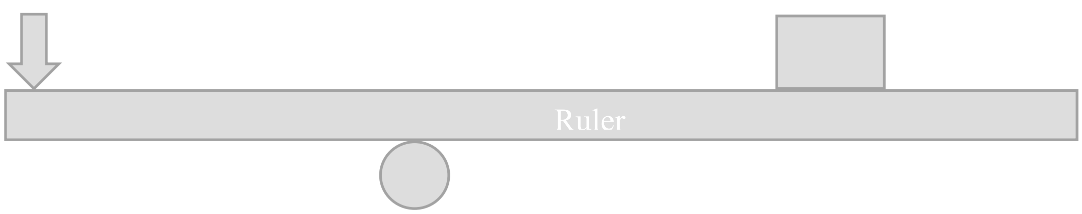
2. Where should you push on this lever to make it easier to lift the box?



3. You push on this lever at the arrow. Where should you place the pencil to make it easier to lift the box?

A.

B.



C.

D.

4. What are some examples of materials you could use to make a simple lever?
    a. A long piece of wood and a piece of pipe
    b. A strong tree branch and a rock
    c. A ruler and a piece of chalk
    d. All of the above

5. A door is also a type of lever. If a door is already open a little bit, and you want to open all the way. It will open most easily if you:
    a. Push near the doorknob
    b. Push near the hinges
    c. It will open just as easily no matter where on the door you push.

6. If we did this lesson again, what would you do differently?

7. What did you learn from this lesson?

8. What did you like about this lesson?

9. What didn't you like about this lesson?

Appendix G: Fulcrum Project Multiple Choice Posttest Groups A and B

Note: Group A used "guided inquiry" method of instruction and Group B used "free inquiry" method of instruction.

Students	1. Which piece of playground equipment is an example of a lever?	2. Where should you push on this lever to make it easier to lift the box?	3. Where should you place the pencil to make it easier to lift the box?	4. What are some examples of materials you could use to make a simple lever?	5. A door is a type of lever. If a door is already open a little bit, and you want to open it all the way. It will open most easily if you:
Type of Question	Identify	Application	Application	Identify	Application
Correct Answers	c	a is best answer	c is the best answer	d	a
Other answers		b could also be proven to work	b could work	all answers are levers	
A1a	c	a	b	d	b
A1b	c	c	b	d	c
A1c	c	c	c	d	a
A1d	c	a	c	d	a
A2a	c	a	c	d	c
A2b	c	a	c	d	a
A2c	c	d	c	d	a
A2d	c	a	b	d	a
	100%	62.50%	100%	100%	62.5%
B1a	c	d	c	a	a
B1b	c	c	c	d	a
B1c	c	a	c	b	b
B1d	c	b	b	c	b
B1e	c	d	d	d	a
B2a	c	a	b	d	a
B2b	c	b	b	d	a
B2c	c	a	b	a	a
B2d	c	a	didn't understand the questions-drew pictures that were correct	d	b
	100%	55%	77%	55%	66%

Appendix H: Fulcrum Project Short Answers Posttest Groups A and B

Note: Group A used "guided inquiry" method of instruction and Group B used "free inquiry" method of instruction.

Students	6. What would you do differently?	7. What did you learn from this lesson	8. What did you like about this lesson?	9. What didn't you like about this lesson?
A1a	Nothing	That pennies can lift a bara of soap	How we got to learn about levers	Nothing
A1b	Would not use a ruler		The building	I liked everything
A1c	Group pennies in smaller groups	That it lifts easier when the pencil is closer to the object	That we got to learn how the weight changes when you change the location of the pencil	We could've used a different object.
A1d	I would use more material	That you can do alaot with a little	How I learned new things about pulleys	You only get to do it 3 times
A2a	I'd change nothing it was great.	about levers and gravity	everything	nothing at all
A2b	working by ourselves	It's harder than you think to lift stuff like that	not to much rules	We had to work together.
A2c	More things to use	What a lever is	all of it because I had fun and it was easy	Nothing because it was fun and easy
A2d	I would have the instructions	How to make a lever	what we made	the Team members were fooling around
B1a	I would have more materials	You can. if you move the soap forward you can use less pennies	We all worked in a group and had fun	That we didn't listen to other peoples' ideas
B1b	To get a book about this quicker	That a lever can help a lot	everything	About a team member being a boss
B1c	I don't know	I don't know	I don't know	I don't know

B1d	I would use more objects.	Balance	liked do the project	I didn't really like my team.
B1e	Everything, Nobody listened to my ideas.	Nothing	Nothing	Everything
B2a	I would use more materials	That it is harder to make things with tape and rubber bands than you think	I liked that everyone in the group worked together	That we didn't have enough time to finish
B2b	I would use less pennies	It helps to use teamwork	That we had no distractions	Some kids didn't have their own project
B2c	work faster	nothing	nothing	that the teacher didn't help us
B2d	more axes	about levers	team work and talk to each other	how we didn't have more materials