WORCESTER POLYTECHNIC INSTITUTE

Elementary Engineering

An Exploration into How Students Learn and the Development of Critical Thinking

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Abstract

The purpose of this Interactive Qualifying Project was to create, implement, and analyze engineering lesson plans for third grade students at Worcester's Canterbury Street School. The goal of the lesson plans was to introduce students to engineering, emphasizing critical thinking skills and development. The lesson plans were created for a dynamic classroom, and evolved as students developed a mastery of the material. This project reviews current educational theory (including student learning styles), offers engineering lesson plans that can be put into practice for future use, and analyzes evidence for how critical thinking is a skill that develops over time.

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Introduction

Fifteen years ago, Howard Gardner, Harvard University's leading educational theorist, wrote an influential essay which observed that the CEOs of many American companies struggle to find high-quality employees, mainly due to flaws in the American educational system (Gardner 1995). Today, this situation may still be true. According to the Worcester *Telegram and Gazette*, thirty-five underperforming schools in Massachusetts are in jeopardy; they must raise standardized test scores and improve graduation rates, or else the state will take them over. To help balance school budgets, Massachusetts will receive seventy-five million dollars in federal grants over the next three years. However, to apply for this funding, school districts must change their current strategies, including "replacing the principal and developing new instructional models like adding more teaching time" (Press 2010). It is clear that there is a need to change the typical teaching structure inside a classroom to promote a different kind of learning. I believe that at an early age, students should be taught problem solving techniques, which they may apply not only throughout their studies but also to become successful after graduation. I took this opportunity to explore dynamic lesson plans, the development of critical thinking inside a classroom, and analyzing student performance with regards to learning styles.

The goal of this IQP was to create comprehensive lesson plans to introduce third grade students to the fields of science and engineering. The lesson plans were tailored for the Canterbury Street School, located in Worcester, MA. The Canterbury Street School is an urban school with limited funding. This IQP uncovers whether science and engineering lessons require costly materials and training, and the benefits of allocating time for students to engage in subjects not heavily focused in their curriculum. The lesson plans were intended to demonstrate basic engineering practices, teach scientific principles, and engage students in hands on learning experiments. The ability to evaluate a problem and arrive at a solution is key to the fields of science and engineering, more so than the ability to memorize information. Therefore, the lessons focused not simply on the instruction of new material, but emphasized the development of each student's problem-solving skills.

The benefits of this project are twofold. An early introduction to engineering can expose students to future career opportunities that are not typically discussed until much later in their academic careers. In addition, young students perhaps for the first time in their educations, learned and practiced how to identify the objective of an open ended problem. Through critical thinking strategies such as brainstorming, they were encouraged to find a solution. Such lessons fill the gap left in students' education by the prevalence of standardized testing. In the current system, half of the school day is dedicated to standardized test preparation. Standardized tests do not necessarily judge a student's ability to think through a problem and justify their response. Also, many students are placed at a disadvantage if they do not naturally perform well on written tests (New York Times Editors 2010; Medina 2010; Ojalvo 2010; Dillon 2010). This project provided students with precious class time to hone their problem solving skills outside of a typical standardized test setting.

Teaching purposeful, or critical, thinking in the classroom is not a novel idea (Blatchford and Martin 1998; Laz 1998; Tishman, Perkins, and Jay 1995; Goetz and Grant 1988; Crooks 1988; LeCompte 1978). However, among the many books and research articles dedicated to this topic most focus on teaching students to think in a uniform way about any set of problems, rather than showing students how to take initiative in the thinking process. "Critical Thinking" books and articles describe strategies to influence student participation in class, demonstrate the importance of group work, and explain various teaching practices. These materials fail to explain the reasons for implementing the particular methods of teaching, and none of them support theories with evidence; consequently, they read like laundry lists of actions that should and should not be conducted in a class. It comes as no surprise that a static learning environment persists; one that could only be effective if all students had the same capabilities and learned in the same manner. For real classrooms with diverse student bodies, current literature does not help to create a dynamic lesson plan that can evolve according to the needs of the class and its individual students.

Formerly completed IQPs by WPI undergraduates designing science and technology lesson plans for students in Worcester Public Schools focused on presenting the notion of engineering rather than elucidating the skills an engineer uses. The stated goals of the projects were to raise interest in engineering and to help prepare students for standardized tests. (Wong, Rocci, Johnson, Costello, and Camesano 2005; Raimondi, Hines, Christopher, and Chu 2005; Ebersole, Shaffer, Strum, and Vitale 2005). The IQPs identified the need to introduce engineering in elementary school curriculums, but did so without understanding how students learn. As a result, the IQPs created static lesson plans which did not change as students became more familiar with the material and did not offer students the opportunity to think beyond the scope of the assignment.

This project sought to investigate how to teach a class not as a single unit but as a group of *individual* students, each with their own abilities and needs. According to the theory of multiple intelligence (MI) no two people share the same intelligence profile. Rather than describing intelligence as an on or off quality, which an individual either does or does not possess, the MI theory takes the view that each person has a unique constellation of intelligences (Gardner 1995; Gardner 2002). When applied to education, this theory does not limit students with the labels of "intelligent" and "unintelligent." It therefore requires that teachers utilize different approaches to a lesson in order to accommodate students with varying learning styles, in the hope that every student may have something to gain from every lesson.

Past IQP projects have introduced students to ideas of science and engineering, but neglected the question of whether the students actually acquired knowledge or skills applicable later in life. Science and engineering cannot be taught only through lecture and assigned reading and writing, methods based on memorizing facts. Not all students can learn from lecture, and they often need visual aids or hands-on projects in order to understand concepts fully. Although previous IQPs had various lesson plans, they all lacked an analysis of which students benefitted from which methods. Due to this, the IQPs did not determine whether students actually learned or simply performed assigned tasks well.

One of the main questions explored by this IQP is whether lesson plans should be designed for learning facts or for learning strategies. At first glance, the purpose of lesson plans appears to teach students a broad range of facts, in order to help them to pass tests. If so, students are not being taught to think about problems strategically but rather to regurgitate information. If lesson plans are designed to teach students various learning strategies, then written exams should not be as prevalent as they are in elementary school.

The IQP also questions whether critical thinking is a skill than can be taught or if it is a natural ability that develops over time. The approach I took assumes that every student has the capability to think critically. The lesson plans I have created were presented in such a way as to encourage students to think in different ways to solve a problem. If critical thinking can be taught, then students should be able to learn how to use previous experiences and what they are learning to problem solve for a variety of questions. Most importantly, students should be able to identify a future problem and be confident that they can solve it. If critical thinking is a skill that develops over time, regardless of learning habits, then students should show small gains in their problem solving abilities. By understanding how an elementary school student can learn critical thinking, then lesson plans can be adapted for students to better prepare them for their academic future.

Background

After four years as an undergraduate biomedical engineering student at Worcester Polytechnic Institute, I have extensive experience with the engineering design process. This process includes a Client Statement, which describes the need for a problem to be solved, the Problem Definition, Conceptual Design, Preliminary Design, Detailed Design, Design Communication, and Final Design (Dym and Little 2004). This formal articulation of the engineering design process allows an engineer to take an open ended problem and approach it systematically, a series of logical steps to reach a solution. In addition, the process can be adapted and applied to situations outside of engineering, such as science experiments or economics math problems. In essence, it allows students to tackle a wide variety of real-world problems efficiently and without hesitation.

A fresh view on learning systems outside of the engineering community is Howard Gardner, who believes that students must learn to think in a disciplined way (Gardner 2002). To teach the process of problem identification and the use of critical thinking, effective communication between students and the instructor is crucial. Effective teaching also requires an understanding of how students learn and the environment in which they learn best.

Critical thinking is not a simple phenomenon. To truly be considered critical thinkers, students must possess broad knowledge of a topic, from which they can derive unique conclusions. Authors of *The Thinking Classroom* related the term "critical thinking" to laughter. Laughter, they explain, is a simple action, but its meaning is often complex; a laugh can indicate happiness, nervousness, pain, and a variety of other emotions. According to the book, the action of thinking, like trying to interpret a laugh, is an attempt “to form an opinion based on inconclusive evidence” (Tishman, Perkins, and Jay 1995, p. 8).

The following sections analyze literature pertaining to metagonition, educational theory, learning environment, and learning styles. This information is pertinent to learning current knowledge relating to classroom interactions. I also analyze previous IQPs that taught engineering in primary schools. This review of the literature provided a basis for my methodology and helped to prepare me for my time as a novice teacher.

Metacognition

Reflection techniques are means used to develop critical thinking habits and help students to become aware of how they are thinking. By considering a problem before, during, and after solution attempts, students can become aware of how they think and develop effective thought processes. Before a problem is presented to students, students are instructed to clear their minds of distraction and focus on the topic at hand. While solving the problem, students concentrate on the objective and avoid straying off-topic. Afterward, students reflect on the thought process that led them to their conclusion. Even failed solution attempts have positive learning consequences, but only if this post-mortem reflection attempt is made. However, this last stage of reflection is often neglected, but when practiced so that it becomes habit, students can learn to relate their accomplishment to future problems (Tishman, Perkins, and Jay 1995).

According to educator Chet Meyers, critical thinking begins when students encounter “disequilibrium” in their environments, indicating a need for change. This disequilibrium is cognitive, where students are presented a problem they have yet to encounter. A mathematical example is teaching students how to find the volume of an object. In a basic sense, if students first understand the theory behind calculating area, then asked to find the volume of an object, they are met with a task that is not obvious and students must determine a way to overcome the disequilibrium. Meyers explains, “The abilities to make sense of new experiences and to envision possibilities outside one’s own immediate experiences are important ingredients of critical thinking” (Meyers 1987, p. 26). Meyers hints at, but does not explicitly state, the importance of creativity. To “envision possibilities outside one’s own immediate experience,” one must engage in a creative act of thinking.

Asking questions, thinking of answers, and generating ideas all are signs of creativity (Craft 2003). When a question is asked, a creative thought is any that holds value in developing an answer (LaChapelle 1983). Creativity draws upon the sum of past experiences, motivation, and a person’s personality. The key to being creative is motivation. Knowledge and technical skills are also important, but excessive focus on these areas can narrow a person’s thought process. When encountered with group work, creativity is affected by leadership, structure, and the group’s composition (Woodman, Sawyer, and Griffin 1993). When students are met with disequilibrium, for example, in the form of a challenging activity, the learning cycle begins. First, students interact with the unfamiliar subject matter they will be taught. Teachers at this stage of the cycle raise questions, offer encouragement, provide direction for student thought, and nudge the discussion toward the intended topic. After the students have been introduced to the situation, the teacher asks questions to place the new concepts into a problem context. Then the students apply these concepts to a new but related set of materials, such as practice exercises.

At this point the teacher becomes the mentor and offers support for independent inquiry rather than guiding discussion directly to the correct solution (Meyers 1987).

Clearly, creativity is a crucial aspect of critical thinking, but defining "creative" is not so simple. Gardner argues that creativity is not limited to one subject such as Math or History, but encompasses all areas of thought (Gardner 1986). This descriptive criterion of creativity can be applied to disciplines outside of the technical field. Students who understand that having a creative mind allows them to generate ideas or ask good questions may see that they are able to take different approaches to other tasks. If so, students will be able to approach problems unconventionally and to explore beyond their boundaries.

It was important to develop insight into metacognition and how to influence creativity in the classroom. I wanted to create an environment that encouraged the students to think and not simply repeat given information by raising non-obvious questions and encouraging disequilibrium. Incorporating reflection techniques and looking for signs of creativity helped me to do evaluate the students. However, metacognition literature did not provide significant insight into categorizing creativity. I was left questioning whether students were thinking creatively or if they were simply guessing and putting no thought into their work.

Educational Theory

Education can be divided into the areas of practice and theory. A pure theorist believes that a person outside of the classroom can effectively predict how students will respond to material and make decisions on how concepts should be presented to students. On the other hand, a pure practitioner believes a person can learn from his or her own experiences teaching inside a classroom without any outside influences. Teachers typically do not rely on either extreme, but on a balance of the two (Barrow 1990).

Understand the audience is applicable both to a theorist and practitioner. The audience of the lesson is as important as the information being presented to them. A good teacher is one with experience, skill, ideal personal characteristics such as humor and honesty, and an understanding of the subject (Barrow 1990). The teacher must know the theory of how students learn and what to teach, but also constantly evolve as an educator, adjusting to meet the needs of each new class of students.

Oftentimes, educators fail to demonstrate to students the practical uses of their education. To remedy this, educational theorists propose the presentation of real-world applications of ideas to students. However, not all of the topics taught in classrooms directly relate to everyday life. Vocational schools try to overcome this obstacle by teaching technical skills which can be applied to a career after graduation. Curricula such as these involve hands-on experience with tasks students can perform outside of a classroom. Some believe that motivational problems students often encounter in the school system would be eliminated through the vocational form of teaching (Tishman, Perkins, and Jay 1995). Meyers presents an alternative view regarding motivational issues, particularly in terms of how they affect creative thinking. In his view, experience can develop critical thinking skills, but its effectiveness is hindered when students lack optimism and motivation. To overcome these challenges, he advocates the creation of a hospitable environment which encourages interactions among students and between students and teachers; quiet reflection also expands critical thinking abilities by giving students time to digest the information. If given ample time for group work and individual reflection, Meyers suggests that students will be able to focus on their experiences and develop critical thinking skills (Meyers 1987).

Motivation has been shown to help encourage participation in a classroom. This motivation can be tangible, in the form of awarding prizes, or intangible, with the use of verbal praise, but the goal of the lesson plans themselves must be clear to the students. It is the task of the instructor to keep students focused by clearly explaining the class expectations. Less uncertainty in an assignment reduces the likelihood of confusion, which could negatively influence the students' motivation. The instructor can also manage the classroom by telling the students how much time they should take to complete an assignment, thus preparing them to spend that amount of time working and preventing distraction (Allen 1986). At any grade level, confusion in the classroom is a common problem. Just because the instructor understands the material does not mean that the students will. To improve the students' understanding and motivate learning, the instructor can encourage them to ask questions and clarify concepts. Creating an atmosphere in which students can actively participate makes the classroom a more comfortable environment. Based on the questions and answers of students, the instructor can identify gaps in the understanding of the students and modify lessons accordingly (Statzner 1994).

Ultimately, the literature shows that balance between theory and practice is important. It is unhelpful when an instructor teaches students by pure theory, which can limit students' breadth of knowledge. It also unwise for an instructor to teach their classrooms based purely from their experiences with little regard to research conducted studying classroom interactions.

Additionally, it is not the responsibility of the instructor to have students choose a career at an early age, as is the case in vocational schools; this practice can lead students to hastily choose professions that do not best suit them. Instructors play an important role in how students learn and must make sure students are challenged to learn and apply their knowledge to their lives in order to achieve success.

An important question left unanswered is how to incorporate theory and practice into a lesson plan. I believe that lesson plans should be dynamic and can change depending on the classroom and student involvement. I think that theory provides the subject matter, setting, and processes that are all conducive to effective teaching while the "practice" aspect is seen through the experiences of a teacher and the teacher's ability to modify a lesson as it is being taught.

Learning Environment

A school is a place where information is presented to students so they can learn. The curriculum is typically structured to give students a knowledge base in math, science, and the humanities. In addition, schools teach more subtle lessons which are not explicitly stated. This "hidden curriculum," as one article called it, provides students with skills that will help them behave properly in society after they have finished their formal education. It accustoms students to achieve by setting goals and then working towards them, and also trains them in time management, proper attendance, and business hierarchy (in which the teacher is the authority figure or "boss"). The hidden curriculum emphasizes work ethic and the students' ability to accomplish tasks through their own skills; to instill mindset in students, it assigns individual activities with little communication among students (LeCompte 1978).

One use of this hidden curriculum is to prepare students to enter the work force. In industry, workers must perform their own functions and cannot always rely on others for assistance. Companies want employees who are able to think independently and to work without constant guidance. Where the hidden curriculum falls short, however, is in its complete emphasis on individual rather than group effort. Although workers should not depend on regular oversight, they should still be able to interact with others. Cooperating with coworkers can be difficult for many reasons, varying from differences in personality to conflicting systems of beliefs. Particularly, communication is an essential skill for aspiring workers during job interviews. If they are unable to present themselves well and demonstrate their ability to interact with others at a business level, then those seeking jobs will remain unemployed. The hidden curriculum teaches students to manage their time and attain their goals, but it must not be forgotten that students must learn how to interact with others in the real world.

Gender

Currently, the typical public-school classroom is coeducational. Teachers must be able to accommodate the needs of both male and female students; as well, they must be able to identify what circumstances require a specific teaching strategy due to gender differences. Classrooms decorated with masculine and feminine artifacts or ones in which the teacher expresses stereotyped attitudes do not have a clearly understood impact on students. This is mainly because environmental influences obscure which traits are learned versus which traits are inherited. A study by the University of Georgia examined gender differences in education by observing classroom behavior in elementary school, and found that “boys [were] being encouraged to lead and act, whereas girls were encouraged to follow and watch” (Goetz and Grant 1988).

These observations would not hold true today, especially in science and technology curricula, where programs are adopted specifically to raise female interest in these typically male dominated subjects. From personal experience as a student in grammar school through college, I have noticed that female students are equally encouraged to lead and act compared their male counterparts. These twenty year old observations are dated in today’s society where female and male students are equally asked by teachers to lead group work and participate in class.

Classroom Size

One counterintuitive study performed in London, England researched the effect of class size on student achievement. Most assume that students will receive more individualized attention in a smaller classroom and progress further than those in larger classes. The rationale behind this view is that teachers will be able to identify which students have problems with the material and work with them closely. The results of the study showed that the classroom size did not affect the most capable students, who excelled regardless of how many others were in the classroom and skewed testing data as to how classroom size affects academic performance. The gifted students rarely needed additional attention from the teachers and could achieve in a large classroom. The smaller classes often consisted of less gifted students who needed specialized attention from the teachers. Although there was no direct correlation between the number of students in the classroom and how well they performed, there was a noticeably increase in class participation in smaller classrooms (Blatchford and Martin 1998).

How classroom size affects student progress can also be evaluated by studying the use of group work to advance students' abilities. Two main issues that complicate group work are the nature of the assigned task and the confidence students have in group participation. If that task is meant to be done individually, then the many conflicting opinions of a group can hinder the students. Likewise, even if the task is appropriate for a group, if no students have the confidence to voice their ideas, then the group will not be able to complete their work. Yet another factor is the number of students in the group. A group too large for a task will have too many voices but a group too small will not have enough (Blatchford and Martin 1998).

The study by Blatchford and Martin found that students who perform well in school do so regardless of their class size. An area to further investigate this topic is whether there is a limit to a student's development in a classroom with varying class size. According to the study, academically apt students can understand the material and do not need focused attention from a teacher to succeed. I think that further research should be conducted to determine the baseline aptitude for a class size to be insignificant.

Testing

When planning a lesson, it is important to include a way to measure the students' progress. Generally, evaluations or tests can reveal how well students know the material. The difficulty and style of the questions must be considered carefully. When questions are too hard or too open-ended, students often skip them, providing which gives the instructor with no feedback on their level of comprehension. Also, these questions often reflect the ability of the students to repeat the memorized material, rather than thorough understanding or developed thinking skills (Crooks 1988).

Tests can also have a psychological influence on the students, and even redefine their interest in class or topic. When students believe they will be given a test that exceeds their capabilities, then the material itself becomes less important to them than a passing grade on the test. The effectiveness of testing is questionable. Tests can be used to reinforce good study habits and to ensure students pay attention to their lessons, but only when the tests require thought and preparation to complete. If a test places too much emphasis on simple memorization, students will judge that they only have to study by cramming the night before. This may produce satisfactory grades for the students but it is less effective for a student's long term memory. To overcome this problem, the use of practice tests is common. Practice tests are especially useful for multiple choice tests because students are able to see the types of questions that will be asked and the depth of understanding they need to have (Crooks 1988).

Testing frequency and types of questions are issues that must be taken into account when creating a lesson. If tested too frequently, students will spend too much of their time studying for exams, rather than broadening their knowledge of the topic through their own curiosity and thought. On the other hand, if not tested enough, students may not be motivated to review the material at all. Inadequate reviewing can lead to poor classroom performance and unwanted stress. A common trend in testing is that higher standards of grading lead to higher performance. Pushing students beyond their comfort zone on tests forces students to prepare more (Crooks 1988).

Developmental Factors and their Correlation with Age

A difficult part of teaching is assessing the abilities of students at different ages. It is essential to understand the pupils receiving the lesson and how well they will be able to understand the information. Determining what to expect of different age groups can be a challenge. Consider, for instance, the phrase “act your age.” Using this phrase leads one to believe that age is something performed rather than a number indicating the length of a person’s life. Is age simply a physical statistic, or is it an index of accomplishment? When children told that they are mature for their age, it is understood that they behave in ways others at their age could not. Individuals at the same physical age can still have differing levels of maturity, so what is appropriate for one ten-year-old may not be for another ten-year-old (Laz 1998).

These considerations make it clear that the physical age of the students must not solely determine the content of a lesson. Lessons must be appropriate to skill and maturity levels, not physical age, and the students should be exposed to domains in which they excel (Gardner 1986). It is important to challenge students to grow even after they have reached the recommended skill level for their age group. It is also important to realize that not all students of the same age will grasp the material the same way.

Research on learning environment encompassed a broad range of topics ranging from ways to prepare students for the world ahead of them to the effects of testing in a classroom. Although important to understand, gender, class size, and age were variables I could not change during the course of this IQP. These factors were brought to my attention as things to be aware of in a classroom, and I could compare conclusions from my experiences to what other researchers have found.

Learning Styles

Classrooms are filled with students from diverse backgrounds who have different learning abilities. As Howard Gardner's Multiple Intelligence theory puts it, individuals cultivate unique intelligence profiles. The current intelligence profile of a person determines the best method by which he or she can learn. Three general categories of learning styles exhibited by students are auditory, visual, and kinesthetic (Griggs, Barney, Sederberg, Collins, Keith, and Iannacci 2009; Begel, Garcia, and Wolfman 2004; McKeown 2003; Felder and Silverman 1988; Budoff and Quinlan 1964).

Auditory learners tend to use verbal communication to express their ideas and learn best from lectures. Visual learners are able to develop pictures in their memory, including graphs, written words, or art to comprehend new concepts. Kinesthetic learners prefer to manipulate active movement, such as hands on projects or acting out examples as ways of learning

(McKeown 2003; Felder and Silverman 1988). An influential and widely cited paper regarding Engineering Education and learning styles, “Learning and Teaching Styles In Engineering Education,” describes the importance of acknowledging that each student has a different learning style and identifying what their learning style is. The paper concludes that the ability for a student to learn in a classroom is related to the compatiblity bewteen the teacher’s teaching style and the student’s learning style (Felder and Silverman 1988). In a classic study of primary school students, Milton Budoff and Donald Quinlan of the University of Massachusetts found that students learn more effectively through an auditory medium as compared to visual representations, a theory that had been proposed previously with no hard evidence to support it. The two men tested second graders using word-pairs that they learned from reading books in their classroom to prove the theory (Budoff and Quinlan 1964).

Budoff and Quinlan’s nearly fifty year old study has been cited by numerous times over the years as means to continue word-pair recognition studies. However, the literature is guided more to student’s progress towards reading rather than comprehension of words. Therefore, Budoff and Quinlan’s study should be seen as a presentation of auditory and visual testing rather than concrete evidence as to the beneifits of either learning style.

Once an instructor recognizes the best way a student learns, then lessons can be modified to enhance that student’s chances of success. Over the years, instructors have been moving away from the traditional methods of standing in front of a classroom and lecturing (Griggs, Barney, Sederberg, Collins, Keith, and Iannacci 2009). For example, kinesthetic lesson plans have been developed to help students learn computer science. Computer science is taught traditionally by showing students programming code, a beneficial teaching means for visual learners, and then students are instructed to practice programming. Students who are not visual learners, however, will have a difficult time trying to apply what they see for their own applications. Kinesthetic lesson plans show students how to use arm and body gestures to represent programming code, which has been shown to help students to learn fundamental concepts of programming before they are asked to solve a problem (Begel, Garcia, and Wolfman 2004).

The importance of understanding which category a student falls into for a learning style is clear. Other ways of differentiating learning styles that run parallel to auditory, visual, and kinesthetic are deduction/induction learning and active/ reflective learning. Deduction learning is where a student starts with basic theory and then moves onto applications. Induction learning is not as immediate as deduction, as it requires many examples to be demonstrated before theory is learned. Active learners like to test theories through experimentation and learn through doing rather than through passively observing lectures. Any student can be described as a combination of these learning styles such as a deduction-auditory learner. Instructors who understand the learning style of students in a classroom are better prepared to teach the students in a way that will benefit them the most (Felder and Silverman 1988).

Learning style literature categorizes students into groups based on which sense they utilize for learning; sight, hearing, or touch. The literature does not define how to test or place a student into a specific category, or which categories are optimal for school settings. Much of the differences are qualitative and based on how the teacher views the student's actions in the classroom. Ideally, lesson plans could be created to quantitatively test a student's learning style and tailored to promote their success.

Previous IQPs on Elementary Engineering Education Topics

The goals of formerly completed IQPs by WPI undergraduates were to raise interest in engineering and to help prepare students for standardized tests (Wong, Rocci, Johnson, Costello, and Camesano 2005; Raimondi, Hines, Christopher, and Chu 2005; Ebersole, Shaffer, Strum, & Vitale 2005). These lesson plans exposed students to projects such as pulley demonstrations and paper airplanes to demonstrate engineering principles (Raimondi, Hines, Christopher, and Chu 2005). Other lesson plans presented real world engineering applications such as space shuttles, and characterized the specific type of engineer who works with these applications, in this case aerospace (Wong, Rocci, Johnson, Costello, and Camesano 2005).

In previous years, educational IQPs focused more on teaching and researching engineering and science material rather than educational literature. The IQPs identified the need to introduce engineering in elementary school curriculums and imposed lesson plans without researching how students learn, the school environments in which try to learn, and how students at various stages of social and emotional development interact with one another. As a result, previous IQPs created static lesson plans which could not change or be adapted as students became more familiar with the material taught to them and did not offer students opportunities to think beyond the scope of the assignment.

Past IQP projects introduced students to ideas of science and engineering, but neglected the question of whether the students actually acquired skills applicable to other courses. The habits of scientific thinking and engineering problem solving cannot be taught only through lecture and assigned reading and writing tasks. Not all students can learn from lecture, and they often need visual aids or hands-on projects in order to understand concepts fully and exercise their own undeveloped talents. Although previous IQPs had contained an impressive array of lesson plans and projects, they generally lacked critical analysis of how students benefitted from different methods of teaching. As a result, it is unclear whether and how students' actually learned skills as opposed to performing assigned tasks of memorization and recall well.

Methodology

The goal of the lesson plans was to present third grade students at the Canterbury Street School with an opportunity to practice critical thinking skills using engineering principles. I chose this school because it is located in a low-income neighborhood in Worcester, where students do not have the same resources as more fortunate schools. Canterbury Street School students do not have access to standard science or social studies text books, and rely on the teachers to provide the material. The school itself has limited supplies including paper and pencils. I visited a classroom for one hour a day, two days a week, the most time I could be allotted due to the students' busy schedule. During the first week, the teacher taught the lesson while I observed and learned how to interact with students. In the following weeks, I was comfortable with the students and taught the lessons while the teacher observed. Each week, over the course of my eight-week practical teaching experience, I introduced, applied, and reviewed a new topic over the course of the two days.

I created six lesson plans using the Worcester Public School 3rd Grade Frameworks as guidelines, Appendix A. The frameworks are presented in Table 1.

From the beginning of the project I knew that I wanted to spend the last few weeks of my time in the classroom having the students build a structure that they could take home with them, an enjoyable as well as educational activity. Each weeks lesson plan was structured to foster the development of new skills for the students which would help them to complete the construction project.

Table 1: Massachusetts 3rd Grade Science Frameworks

Students will…

03.SC.IS.01	Ask questions and make predictions that can be tested.
03.SC.IS. 02	Select and use appropriate tools and technology in order to extend observations.
03.SC.IS. 03	Keep accurate records while conducting simple investigations or experiments.
03.SC.IS. 04	Conduct multiple trials to test a prediction. Compare the results of an investigation or experiment with prediction.
03.SC.IS. 05	Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiments.
03.SC.IS. 06	Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.
03.SC.TS.01	Identify materials used to accomplish a design task based on a specific property, e.g., weight, strength, hardness, and flexibility.
03.SC.TS.02	Identify and explain some of the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.
03.SC.TS.03	Identify a problem that reflects the need for shelter, storage, or convenience.
03.SC.TS.04	Describe different ways in which a problem can be represented e.g., sketches, diagrams, graphic organizers, and lists.
03.SC.TS.05	Grasp an understanding of the metric measurement system.

The lesson plans were also written with instructor guidelines designed to inform a teacher what key skills and comments should be taught, which parts of the framework are involved, and the specific lesson objectives. Additionally, the lesson plans allow any future teacher to modify how each lesson is taught based on how well the class understands the material. The lesson plans were not designed to be followed in a rigid, step-by-step manner. Instead, they include an overview of ideas and expected outcomes. In this way the lesson plans are dynamic tools which could evolve as the students became more familiar with the material being taught over two days and help to move the lessons along if students fully grasped the material earlier than expected.

In the first week, students were supposed to learn a set of vocabulary words that are commonly used in engineering problems and scientific experiments. These words were *guess*, *evidence*, *investigate*, *hypothesis*, *problem*, *comprehend*, and *demonstrate*. This vocabulary list was intended to be used by the students each week to describe what they were doing, helping them to practice the words in different contexts. In the second week, I introduced the students to two types of problems, those that can be solved and those that cannot. To do this, I incorporated into the lesson the framework 03.SC.IS.02 and 03.SC.TS. 04. With this foundation built during the first two weeks, the students were expected to be able to use the same tools and procedure for the following weeks. The third week was dedicated to helping students communicate their ideas aloud to the class. From the educational research, I found that brainstorming activities help students to learn from each other and provide means to generate ideas for the construction projects. During the fourth week, students were introduced to their building projects and attempted to start using all of the skills they learned in the previous weeks. In the final four weeks, students tried to construct a bridge and a tall freestanding structure.

The layout and sequence of the lesson plans was organized to provide students with an experience much like one occurring in an engineering classroom. The first weeks were dedicated to teaching students what is known about the subject matter, including definitions of key concepts and exposure to the notion that some problems can be solved while others cannot. The following weeks were intended to build upon these axioms and prepare students to complete hands on projects with little direction from the teacher.

Some limitations were imposed on this project that could not be altered. These were the class size, class gender, prior knowledge students had, and the amount of time I was given to run activities in the classroom. The original class size was seventeen students, but this number varied based on absences and if students left during my teaching time to meet with tutors. Out of the seventeen students, eight were male and nine were female. I tried to gauge the student's prior knowledge by talking with the teacher before creating the lesson plans and then reviewing the lesson plans prior to implementing them which helped to identify areas where students might have trouble. The most significant limitation of this IQP was the time constraint. I was able to enter a classroom for one hour twice a week, which was the maximum time allowed by the teacher.

Week 1

To begin the first lesson, the teacher asked the students if scientists and engineers talk like ordinary people. The students were unsure of the answer so I briefly explained what an engineer is and the importance of having a specific set of words to describe a problem, using examples from my personal experience to help them understand. When the class understood, the teacher proceeded with the lesson. The words presented to the students on the first day were "guess," "evidence," and "investigate."

The teacher asked the students to define the words and she created a list in front of the classroom so students could refer to it later. After the definitions were discussed and understood by the students, the teacher set up an experiment with a glass of water. She asked the students to use their new vocabulary words to describe how the temperature of the water would change throughout the day. Students were allowed to rise from their seats and to touch the water in the cup, which helped them to engage the material hands-on. This part of the activity caught their attention, and afterwards they were more eager to volunteer in class and appeared more excited to learn.

During the second lesson, the teacher requested that the students tell her what words they remembered from earlier in the week and explain how they related to the experiment. Then, with the same methods used on the first day, she taught the words “hypothesis,” “problem,” “comprehend,” and “demonstrate” to the class.

The purpose of the first week was to create a common and specific language for the students. With this vocabulary knowledge, the students would have the ability to use their newly learned words and definitions to help them explain their thinking process when assigned tasks later in the project.

Week 2

On the first day of week two, the students’ assignment was to draw five different shapes. The shapes needed to have four connected sides and the sum of the angles used in the shape needed to equal three hundred and sixty degrees. To start class discussion, I wrote on the board “What is an angle?” and “How many four sided shapes can you name?” After the discussion I had the students write on their own papers different ways they could add up to three hundred and sixty using four numbers. These two tasks were intended to help students prepare for their assignment. Once the students understood angles and that combinations of four numbers could add up to three-hundred and sixty degrees, they could draw the shapes. However, it took much longer than anticipated to teach the students how to measure angles, and the students spent the rest of the day practicing the use of protractors. The assignment had to be completed on the second day of week two.

The initial plan for the second day was to ask the students to draw five triangles whose angles summed to 100 degrees, an impossible task to complete. In this lesson, the one hour time constraint was a limitation, making it necessary to skip the triangle task. The goal of week two was to determine how students react to two different problems, one with a solution and the other without one. It would have been useful to see if students became curious or discouraged and how their thinking differed in such a situation.

Week 3

In the third week of class I introduced students to brainstorming. The first day was used to discuss what brainstorming is and why it is important, and ended with a class discussion on ideas about how to solve two problems. The first problem I proposed to the students was "How do you move snow off the roof of a skyscraper?" I then asked students how snow is moved in a nonspecific situation, which methods would be applicable to the roof of a skyscraper, and to describe their reasoning. After students generated a list of ideas and narrowed the list based on the objective, I asked the students how they would solve the problem. The same procedure was used to ask students how to move sand off the roof of skyscraper and how sand differs from snow. Both discussions ended with asking the students to form a hypothesis about how to solve the problem and how they could conduct an experiment to test their hypothesis.

To start the brainstorming process for day two, I presented the students with the question "How can you travel across the United States?" As on day one, the students had to generate a general list, in this case of general ways of travelling, and then narrow their list to choose a preferred method. "How would you protect a hand?" and "How would you protect a foot?" were the next to questions the students were asked to brainstorm.

The week of brainstorming helped students to generate lists of ideas, a key step to solving an engineering problem. Most importantly, students were able to see how ideas can build off one another and understand the value of working in groups.

Week 4

Week four was used as an introduction to the students' engineering project. The task was to create a bridge out of twenty Popsicle sticks. The bridge had to be one Popsicle stick tall and two Popsicle sticks long, and also had to support a five-pound weight. To start a class discussion, I asked the students to explain the purpose and importance of bridges, and to name the materials from which bridges can be constructed. Next, using an overhead projector, I showed students pictures of bridges (Appendix B), and in this context, reiterated the same questions.

The second day of week four began with a quick review of the previous class, focusing on the materials used to build bridges. The class listed the materials and determined the advantages and disadvantages of each. With some assistance, the students reasoned that wood is an inexpensive, easily shaped material and the closest substitute to wood would be Popsicle sticks. I finished the second day fully describing the bridges they would be building.

Weeks 5/6

Week five was dedicated to planning the bridge project. On the first day, the project objectives and specifications were reiterated to the students. Then, I led a class discussion, prompted by the question of whether it is important to plan a building project or to build as soon the materials are received. After a little convincing, the students agreed that planning was necessary, and that the best way to plan for this project was to draw sketches of how their bridges would be built. The students spent the rest of the session drawing different bridge designs while I reminded them that they would only be able to use twenty Popsicle sticks.

The second day of week five and the entirety of week six were spent building the bridges. By the end of week, six students had not completed their bridges and it was clear that none could hold the five-pound weight.

Weeks 7/8

Weeks seven and eight followed the pattern of weeks five and six. On the first day of week seven, I introduced the students to a new building project; this time, they had to build the tallest structure in the class using forty Popsicle sticks. Before the students started sketching designs, we discussed some of the problems they had with their bridges and why the bridges could not hold the weight. After our discussion, the students spent the remaining time sketching their structures.

The last three classes were spent constructing the buildings. I constantly reminded students that the buildings needed to stand up and asked the students how they planned to accomplish this. Most of the students created sides for their structures with no thought as to how the sides would connect and stand on their own. Only one student finished the project.

Results and Discussion

Over the span of eight weeks, I observed and taught engineering based lesson plans in a 3rd grade classroom. The lesson plans were designed in advance but with room to evolve as students became more familiar with the material and to account for student to student learning variability. I constantly encouraged the class to participate so I would know who understood the material and who had questions.

During the course of the experimental phase of the IQP, both the teacher and I recorded written notes during class. The notes included observations of the students' answers and actions during the lesson plans. These notes provided data to analyze how effective the lesson plans were at teaching students. The following section describes the results of the lesson plans, grouped in to five categories. These categories are *vocabulary, think-pair-share, classroom interactions, hands-on learning activities,* and *significant observations,* which encompass different aspects of all the lesson plans.

Vocabulary

The words presented to the students for the vocabulary lessons were *guess*, *evidence*, *investigate*, *hypothesis*, *problem*, *comprehend*, and *demonstrate.*

I chose to dedicate two lessons primarily to teaching students a set of vocabulary words which I believed would help them to express their thought process. These lessons comprised the first week I attended the school. I was introduced by the sponsoring teacher as an engineering college student. To help the class understand why I wanted to teach vocabulary, the teacher asked the class if engineers and scientists talk like ordinary people. Most of the students were unsure how to respond to this question, but one student said, “They make things dazzling.” After being asked what he meant by this, the student explained that it was a different way to say “They make something pretty.” After talking with the student for a short period of time, I learned that he was trying to express his impression that scientists and engineers use more precise words than ordinary people.

The classroom was familiar with and could describe the definitions of all the words the teacher presented except “hypothesis.” By the end of the second lesson all of the students still had an impression that a hypothesis could be defined by using many of the words they previously learned. The students’ understanding of hypothesis was limited and appeared to be more of a restatement of what was being taught rather than connecting *guess, evidence, investigate, problem, comprehend*, and *demonstrate* together. The two hour time period used to teach the vocabulary was enough time to teach the words but another hour of class should have been taken to further develop the student’s ability to use the words comfortably, rather than have them try to recite definitions from memory.

I wanted to incorporate vocabulary words into each lesson plan so students could practice using them on a weekly basis. It was evident at the start of week two, however, that this would not be the optimal way to use my limited classroom time. Although the words were written on paper in front of the classroom, students still struggled to use them to describe their thoughts in the second week’s math lesson. During the math lesson, students were asked to use a protractor to draw a shape with four sides whose internal angles measured 360 degrees. The students were also asked to write down different four number combinations that sum to 360 degrees. Ideally, students would have generated a *hypothesis* as to how many four sided shapes they could draw, *investigate* their hypothesis by drawing the shapes, and *demonstrate* verbally to the class their results. The students' inability to use the words could have been in part from the lesson itself, if it did not effectively demonstrate the importance of knowing the words and how to use them other than repeat their definitions. Another reason for the student's unwillingness to use the words to describe their thoughts is that the words were superfluous to the students' understanding of the consequent lesson plans. I found that asking the students to choose an appropriate word actually interrupted and slowed down their thought process, dangerously distracting their involvement with their work.

My midcourse correction, choosing not to pursue a structured list of words for the students to use, did not seem to limit their subsequent ability to express how they were thinking. Throughout my visits to the classroom, most students were able and willing to voice their problems and could describe what they were doing and why, whenever I asked them.

Think-Pair-Share

A common practice used at Canterbury St. School in the classroom is called "Think-Pair-Share" (TPS). After asking a question to the students, who typically sit in groups of two, the teacher instructs the students to "TPS." During this time the pair of students discusses the question with each other and has to present the opinions of each other. TPS forces to the students to not only communicate their thoughts with a peer but also listen to what their group member is saying and present it to the class. When asked what the definition of *comprehend*, a pair of students were able to build upon each other's ideas. The first student said, "to know what we read" which was a not a specific answer but her partner followed the comment with, "to understand."

Although I had researched think-pair-share as part of my literature review prior to creating lesson plans for this project, I did not foresee how effective TPS was in a classroom. TPS provided an unanticipated structure to the lesson plans. Since the students were familiar with discussing their thoughts on a regular basis, having students participate did not require much prompting or convincing. In terms of participation, the students who were best able to voice their partner's opinions during a TPS exercise were also the ones who participated the most in class.

One of the most intrigue features of TPS was the enthusiasm students had helping each other, especially in later lesson plans which required students to construct structures out of Popsicle sticks, Figure 1. I believe that the TPS contributes to this enthusiasm because students are able to build relationships with their classmates during the TPS time. During most lecture based learning, students are encouraged to listen only and not to talk in class. TPS provides time where students can interact with one another and see what each student is capable of doing. One student regularly explained the lessons to another student who had problems with understanding directions.

Classroom Interactions

TPS was a good means to have students communicate their ideas, and the ideas of students around them, but was largely ineffective for the brainstorming lesson plans. A greater amount of students volunteered information when working as a large classroom rather than working in small groups. Also, students were better able to build upon ideas from each other in the larger groups. Most students who participated in class discussions were academically at grade level. One out of the two students who were designated as “above grade level” participated rarely, whereas the other student participated frequently in class. Table 2 shows the academic distribution of students and their learning styles.

Table 2: Analysis of Learning Styles and Developmental Stages

	Learning Type		
	Visual	Kinetic	Auditory
Above Grade Level			Jackie
			Joyce
At Grade Level	Juanita		*
	Jazmyne		*
	Alana		*
	Bryce		*
	Meshia		*
	Tanisha		*
	Jean		*
Below Grade Level	*	Jeremiah	
	*	Bryant	
	*	Lilyana	
	*	Adam	
	*	Alex	
	*	Hailey	
	*	JeanCarlos	
	*	Darnell	

* Second form of learning

As seen in the Table 2, most of the students in the class perform at or below grade level. The most striking observation is how the different learning styles correlate to student academic performance. In this 3rd grade classroom, “above grade level” students are auditory learners, “at grade level” students are visual learners, and “below grade level” students are kinetic learners.

The second student who was performing above grade level was also the best student at communicating their ideas when I would walk around and talk to the students during the lessons. Almost half of the students were academically below grade level and had trouble voicing the problems they were having. One student in particular was consistently unable to follow directions and did not understand what was being asked of her, even when other students explained the lesson.

Students who showed less initiative and understanding of the projects were, surprisingly often, the most willing to help other students. These students did not appear to avoid work but they tended to simplify their projects too greatly, so that they “finished” their tasks ahead of other students. When students thought they were finished ahead of schedule, I would go over the project specifications with them to see if they still believed they were finished. Not wanting to intervene too much with their work I would tell them “good job,” and encourage them to think about what they would be doing the next class. Shortly after leaving the students, they would find others in need of assistance and spontaneously help them with their projects.

During the weeks where students built structures, I observed that a handful of students naturally understood how to approach the project and worked more efficiently than their classmates. I noticed that other students tried to imitate these students’ structures and the precocious ones were not upset that their work was being copied.

Hands on Learning Activities

The first “hands on” activity I asked the students to engage in was learning how to use a protractor. By trial and error, I learned right away that explaining in front of the class how to draw two lines and use the devices to measure the angle in between them was not an effective teaching method. I found it more effective to teach a few students, who then taught other students. Surprisingly, a student who is academically below grade level was the first to understand how to use the protractor.

Students were most enthusiastic about the lesson plans where they constructed structures from Popsicle sticks. This is most likely because the students were able to talk to each other and did not need to remain sitting in their chairs. The activity leading up to the construction, sketching their ideas, was not a success. The students did not appear to understand the importance of planning ahead before building a project. Some drawings used separate lines to designate the specific amount of Popsicle sticks while other students scribbled on their paper so they could begin building right away. During the tallest structure project, one student drew a brick house with windows in it, even after I asked him if his structure was going to be constructed from brick or have windows, both questions to which he replied no.

The most significant problem I noticed when the students were building their bridges was that they did not allow proper time for the glue to dry. A hot glue gun would have been far better for this project but there was a risk that the students would have been burnt by it. If I could redesign this project I would have students bring their sketches and Popsicle sticks to me, one at a time, so that I could supervise their use of a hot glue gun. I think that the choice of glue was a major factor contributing to student failure to finishing their bridges. After the bridge project was over we had a classroom discussion about the problems each student experienced during the project. The students agreed that they would need more time to complete the next project because only one student was close to finishing (see Figure 2). I led a discussion about what was slowing down the building process, the main issue being the glue, and I sought their input into how to alleviate this problem with the next project.

During the time I stood in front of the class to teach, I would try to consult with students regarding their questions, or share my observations for improvement rather than directly give them the answers. I wanted students to be fully engaged in the material and develop thinking patterns so they would be able to look for the problems and generate solutions to their questions in the future. This type of teaching also helped me to move away from being a lecturer and move towards an advisor of their project teams. I found that if I encouraged students to participate and answer their own questions, they were more willing to talk to me during the course of the project.

As a result of the Socratic method of instruction which I tried to practice, the class agreed that building their new structure in sections would help to minimize down time when waiting for the glue to dry. Another problem the students had was having their bridge stand upright. During the lesson where they were instructed to create the tallest structure in the class, Figure 3, I would walk around the classroom and ask each student how their Popsicle sticks were going to stand upright and if they anticipated any problems with stability.

The hands on learning activities where meant as a way for students to apply all the skills they learned in previous lessons to a fun project. I think that students saw this as an opportunity to play rather than demonstrate their newly learned skills. I felt that if the hands on activities were more structured then the students would have been able to see the connection between how they could brainstorm ideas and communicate their problems and try to solve them but adding more structure could also lead to students being less creative.

Significant Observations

I found that it was difficult for 3rd grade students to think about a problem during and after its proposal as suggested by the authors of "The Thinking Classroom, Learning and Teaching in a Culture of Thinking." Once the students in the classroom had their mind set on a solution, they were not easily dissuaded from it. Even after voicing suggestions, the students were unlikely to drop their own ideas and follow how I would approach the problem. I think it would be difficult for 3rd grade students to sit and think about the problem they are having with a project, especially a hands-on project, because they tend to want to move around and interact with their surroundings.

Think-Pair-Share helped to encourage participation in class, but despite Allen's research findings, external motivation was not needed (Allen 1986). TPS provided a means to start a class discussion and the whole class could be incorporated by calling on one student to discuss what their partner said. From there another student could volunteer information until the students were comfortable talking in front of the class. TPS helped students to voice their ideas at a comfortable scale, to one person, then to present the ideas to a larger scale.

By Craft's definition, students showed signs of creativity because they were able to ask questions, think of answers, and generate ideas (Craft 2003). My findings corroborate this interpretation; my students were able to excel at different aspects of the lesson plans. One student who had a difficult time focusing on sketching and building a bridge nevertheless understood how to use a protractor quickly.

A month after leaving the classroom I spoke with the sponsoring teacher to discuss the students' classroom performance and her long term observations about the impact of my instruction. I questioned whether my teaching helped or influenced any students after I left. The teacher told me that one student consistently uses the vocabulary words that were taught the first two weeks of the lesson plan including *hypothesis.* The teacher also stated that, although direct connections between my lesson plans and students further classroom involvement could not be made, the lesson plans helped students to practice brainstorming techniques. The students in the third grade classroom brainstorm on a daily basis. From writing assignments to math problems, the students generate ideas and make lists.

Results and Discussion Figures

Figure 1: Students working together to build a structure.

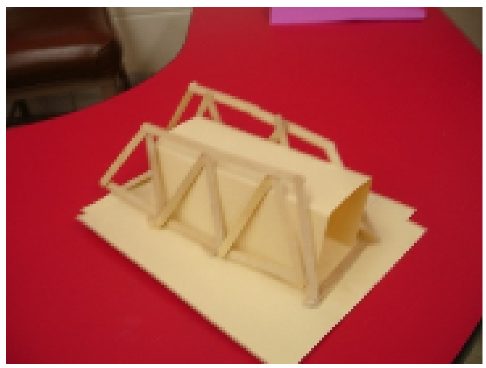

Figure 2: One student's Popsicle stick bridge.

Figure 3: The student with the tallest freestanding structure in the class.

Conclusion

Prior to completing this project, I wanted to understand whether critical thinking can be taught by classroom lessons or if it is a skill that develops over time from personal experience. Answering this question would determine if lesson plans should be created to teach facts or teach learning strategies.

From what I observed during my time in a third grade classroom, I conclude that critical thinking is a skill that develops over time. With each lesson I taught, I tried to create a situation in which the students were not directly given all of the information they needed, to encourage them to think creatively and independently about the task. For example, during the protractor exercise I did not tell students how many different combinations of 4 numbers there were that equal 360 degrees. I wanted the students to try as many number combinations as possible to realize that a limitless amount of solutions can be found. This was intended to help students to understand that there are many solutions to a question and they should not limit their thinking. Although most of the time I needed to pose questions to start the thinking process, I made sure that the lesson plans were not created to be followed in a step by step manner. I saw improvements with students being able to ask questions to help solve the non-specific details of the lesson plans towards the end of the eight weeks.

I see the ability to ask questions as the fundamental step to begin the critical thinking process. If a student understands that there is information they do not have, then I consider that the student comprehends the problem they are assigned. As students continued to work with the lesson plans I created, they started to develop a sense of what information they did not have to solve their problem. Most of the students could not follow the lesson plans without additional direction from myself, but were becoming more comfortable asking questions. These observations lead me to believe that practicing new types of lessons that do not present all of the required information to students upfront helps to develop critical thinking skills.

As I learned about different students' learning styles in the classroom, the question of whether lesson plans should be created to teach facts or learning strategies became more clear; it is more important to teach strategies than facts. Lesson plans should be created so they can adapt to each student because each student learns differently. If the lesson plans are designed to teach facts, then only a certain portion of the class will benefit from them. Lesson plans that teach learning strategies are more beneficial to the class as a whole. Students who learn how to think and understand a problem will be able solve future problems.

If the lesson plans I created had been more fact based, and followed a procedure that was not meant to change, then only the two students who happened to be auditory learners would have been able to learn. Two students in a classroom of eighteen were able to follow directions the first time given and could understand what I was asking them to do. The rest of the classroom needed constant reiteration and support to continue the lessons. Only a small portion of students in the classroom would benefit from a lesson plan that taught in a fact based manner. The rest of the students would not understand the material and fall behind in the curriculum. For this reason, I think that if a lesson plan teaches learning strategies, then more students can comprehend and retain the material.

During our final meeting, I wanted to see if students were able to make connections between what they learn in engineering lessons and other courses. I asked if they thought what they learned over the past eight weeks could be applied to other subjects when I leave. One of the students answered, "We learned math and science, so we can use it for that." I then asked if this was the only application, or are there others. Another student answered that they could use brainstorming for different subjects. I then discussed with the class about how we had to think about each lesson and whether we can use those kinds of general thinking skills in every subject.

I wanted students to see that developing critical thinking skills can be universally applied over their spectrum of courses. I think that the students were able to make this connection but could not articulate their understanding in the language I wanted to hear. From the first day of class where the students guessed what would happen to a class of water left in the classroom to the last day of class where students were struggling to erect a structure, every time I entered the classroom they needed to think about what they were doing and engage the material.

Two areas of attention brought forth by current literature are whether classroom size or gender plays a role in students' performance in a classroom. I did not set out to measure the effects of these variables, nor did I have any opportunity to assess the significance of classroom size, but I did notice a trend in gender with regard to classroom performance. However, my analysis of gender performance was very limited. I observed one classroom with seventeen students. During my visits the classroom size deviated at most by three students, who were either absent or left the classroom for reading or math tutors. The gender difference was roughly fifty percent; 8 male and 9 female students. One male and one female student comprised the two students who perform above grade level. Most of the females in the class perform at grade level while most of the males in the class perform below grade level. A possible reason for this difference is that, from my observations, the female students in this particular third grade classroom were more mature than the male students and were able to focus and follow directions more attentively.

Having the opportunity to teach in a third grade classroom was a rewarding experience. After the first week of the IQP, the students were comfortable with my presence in the classroom and became excited when I would arrive. I looked forward to teaching the students and they looked forward to a new lesson each week. As the weeks progressed I was able to build relationships with the students and they were more eager to participate in class. One of the more memorable experiences was talking to a student with a behavior problem. I sat down and asked if he liked when I came and taught engineering, to which he replied yes. After talking to him about his day and how his project was going I told him that the teacher was not going to let him participate if he continued to misbehave while I was not there. When I talked to the student about the consequences if he were to get in trouble, I did so with real concern. He understood that I was trying to help and put the fun projects I was teaching into perspective. I came back the next week I asked the teacher if the student's attitude and behavior changed, and she told me it had. The student was able to continue the project. I felt that to reach this student, it took me getting to know him and providing him with the right motivation to stay on track.

Continuing this project further would provide more insight into what it takes to develop engineering lesson plans for elementary school students. Future work in classrooms should focus on creating lesson plans that help to identify the strengths and weaknesses of students. Consequent lesson plans can build on this information so all students are able to learn based on their natural set of skills. I think this will help to motivate their learning because problems will not appear to be daunting tasks. This however will not work for those students who do not desire to learn. Literature review, while useful, does not entirely prepare a teacher for the classroom experience because the classroom is always evolving. As the classroom evolves, so should the lesson plans that are taught to the students. Students who understand one lesson might not understand another. If lesson plans do not evolve, or have any built-in flexibility, then students who struggle with fundamental material will not fully develop their skills and reach their fullest potential.

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IQPs

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Appendix A

Lesson 1

Lesson Title: Introduction to Vocabulary

Lesson Time: 1 hour

Summary: The purpose of the lesson is to introduce students to a list of vocabulary words they will use in future lessons. The list will create a common and specific language among the students to help express their thoughts.

Learning Objectives:

03.SC.IS.01 Ask questions and make predictions that can be tested

Vocabulary Words and Definitions: from dictionary.com

Guess:

1. to arrive at or commit oneself to an opinion about (something) without having sufficient evidence to support the opinion fully.
2. to estimate or conjecture about correctly: to guess what a word means.
3. to think, believe, or suppose.

Hypothesis:

1. a proposition, or set of propositions, set forth as an explanation for the occurrence of some specified group of phenomena, either asserted merely as a provisional conjecture to guide investigation or accepted as highly probable in the light of established facts.
2. a proposition assumed as a premise in an argument.

Investigate:

1. to examine, study, or inquire into systematically; search or examine into the particulars of; examine in detail.
2. to search out and examine the particulars of in an attempt to learn the facts about something hidden, unique, or complex, esp. in an attempt to find a motive, cause, or culprit.

Research:

1. to explore or examine in order to discover
2. to look at, read, or examine (a record, writing, collection, repository, etc.) for information

Comprehend:

1. to understand the nature or meaning of; grasp with the mind; perceive

Demonstrate:

1. to make evident or establish by arguments or reasoning; prove
2. to describe, explain, or illustrate by examples, specimens, experiments

Justify:

1. to show (an act, claim, statement, etc.) to be just or right
2. to defend or uphold as warranted or well-grounded

Verify:

1. to prove the truth by evidence; confirm;
2. to ascertain the truth or correctness of, as by examination, research, or comparison

Evidence:

1. that which tends to prove or disprove something; ground for belief; proof

Question:

1. a problem for discussion or under discussion; a matter for investigation
2. a matter of some uncertainty or difficulty

Doubt:

1. to be uncertain about; consider questionable or unlikely; hesitate to believe
2. to distrust

Procedure:

Day 1: The teacher will begin the lesson by explaining the definitions of three vocabulary words followed by a thinking activity. The teacher will ask students to think about a particular situation and have students describe their thoughts. The goal of the lesson is to introduce students to words related to the scientific method and develop understanding of their meanings in context.

Day 2: The teacher will begin the lesson by reviewing the three words presented on Day 1 and any new words the students thought of during Day 1. The students will then form small groups and the teacher will present new situations to the students; they will discuss the situations amongst themselves. Halfway through the lesson the teacher will ask the students to leave their groups and go back to their original seats. The teacher will lead a discussion to see if students thought of new words to describe the situations and then present the rest of the vocabulary if the students need more guidance.

Day 1:

The teacher will present the words “guess”, “investigate”, and “evidence” to the students and ask who already knows the meanings of the words. The teacher will then explain the definitions and tell the students that they will be using these words in the next assignment.

***Questions Asked To Students*:**

- I would like you to imagine something. Pretend that, before you left for school this morning, you filled a glass with warm water and left it outside. What do you think will happen to the water in the cup by the time you get home?
    - Teacher asks which vocab. word describes their answers (“guess”)
    - The teacher will lead the discussion based on response. Students could possibly answer that there will be less water in the cup or that it will no longer be warm. The teacher will ask them how they would know if their guesses were correct, leading students to use the words “investigate” and “evidence”.

- I guess that when I get home the water will be cold. I think the reason the water became cold is because the heat escaped.
    - Which word(s) will help me to prove this?
        - See if students use the words “research,” “investigate,” “demonstrate,” “justify,” “evidence”
- How would you know my idea was correct?
        - See if students use the word “verify”
- If you are unsure about the answer then there is…?
        - See if students use the words “doubt” or “question”
- What is a way to comprehend a problem
        - See if students use the word “research”

    - Note if students can arrive at the word “hypothesis” on their own

Goal of Day 1: The goal of Day 1 is to introduce three basic vocabulary words to the students. These three words will help students to understand the purpose of the thinking exercise. It will be observed, through the teacher’s questions, whether the students arrive at the other words on the vocabulary list.

Day 2:

The teacher will review the vocabulary words the students learned on the first day and ask which words pertained to which situation. If the students did not generate the word "hypothesis," the teacher will also explain this word. The teacher will then ask students to form small groups and start the discussion by asking students a series of questions:

- How would you:
    - Travel to the moon ?
    - Sail across the ocean?
    - Dig a hole the fastest?

The teacher will encourage students to use the vocabulary they learned and specific words to describe how they would complete each task.

After the three tasks are discussed in groups, the teacher will have an class discussion in which all of the groups share their conclusions with each other.

Goal of Day 2: The goal of Day 2 is to see if students are able to continue to use the vocabulary words learned from Day 1 and see if the students need to increase their vocabulary knowledge to specifically describe a problem. Also, it will be observed if the students need the entire list of vocabulary words or if they understand how to approach a problem through their own experiences and through the words introduced at the beginning of the lesson.

Lesson 2

Lesson Title: Possible/Impossible Tasks

Lesson Time: 1 hour

Summary: The purpose of the lesson is to determine how students reaction to problems with definite and indefinite solutions. The students will relate the words they learned in Lesson 1 to their new lesson.

Learning Objectives:

03.SC.IS.02 Select and use appropriate tools and technology in order to extend observations.

03.SC.TS.04 Describe different ways in which a problem can be represented

Procedure:

Day 1: The teacher will assign students to draw five different shapes. The shapes will need to have four sides and their internal angles must sum to three hundred and sixty degrees. The students will be given protractors to measure the angles.

Day 2: The teacher will assign the students to draw five triangles whose internal angles sum to one hundred degrees. The students will be given protractors to measure angles. The students will be assigned to draw five triangles, opposed to one, so they do not believe the task is any harder than that of Day 1.

Day 1:

The teacher will present the drawing assignment as a question. The teacher will ask, "How many four sided shapes can you draw whose internal angles sum to 360 degrees?", encouraging students to answer with the words they learned in the previous week. The teacher will then instruct students to test their hypothesis by drawing five shapes individually. Halfway through the lesson, the teacher will instruct the students to stop their work so they can have a discussion about who could accomplish the task. Students will also be asked to look at the shapes drawn by their classmates. The class will end with a discussion revolving around the vocabulary words and how they related to the problem. Discussion will also focus on how students interpreted the problem, how they solved it, and what the students can do next time if a *similar* problem was assigned.

Goal of Day 1: The goal of Day 1 is to learn individual student capabilities and learn how they work on a given assignment. Special note will be taken if students are able to conclude that any four sided shape has internal angles that measure three hundred and sixty degrees.

Day 2:

The teacher will present the drawing assignment as a question, following the pattern of Day 1. The teacher will ask students to draw five triangles whose internal angles sum to 100 degrees. Halfway through the lesson, the teacher will instruct students to discuss their findings and whether anyone completed the assignment. Discussion will focus on relating this problem to future problems, explaining to students that there is not always a solution. The teacher will also ask for students' reactions to being assigned a problem that could not be solved. Discussion will also encourage the students to discuss methods (such as research techniques or asking questions) for future problems that are difficult but not impossible.

Goal of Day 2: The goal of Day 2 is to determine how students react to a problem that is impossible to complete and if their reactions will influence how they perceive future problems. Notes will be taken on students who become discouraged because the problem cannot be completed, who become curious as to why none of their triangles are meeting the specifications, and who stop working because they do not believe the assignment can be completed (if a student stops working then the teacher will ask why they are doing so).

Lesson 3

Lesson Title: Brainstorming

Lesson Time: 1 hour

Summary: The purpose of the lesson is to introduce students to brainstorming and communicating their ideas with classmates. The students will practice writing down their ideas and explaining them to other students. Students will think about a given problem, current solutions for the problem, their own solutions, and describe which methods they would chose to solve the problem. Students will be encouraged to use the vocabulary from Lesson 1.

Learning Objectives:

03.SC.IS.01 Ask questions and make predictions that can be tested.

03.SC.IS.03 Keep accurate records while conducting simple investigations or experiments.

03.SC.TS.01 Identify materials used to accomplish a design task based on a specific property, e.g., weight, strength, hardness, and flexibility.

03.SC.TS.04 Describe different ways in which a problem can be represented e.g., sketches, diagrams, graphic organizers, and lists.

Procedure:

Day 1: The teacher will tell the students that this class time will be dedicated to brainstorming, and ask if students know what brainstorming is or have had experience brainstorming. The teacher will emphasize generating lists and expanding on ideas of other students.

Day 2: The students will have more practice with brainstorming, working in small groups and individually.

Day 1:

The teacher will tell students that today's class will focus on brainstorming. The teacher will ask which students have heard of the term and have had previous experience with brainstorming. Students who volunteer information will be asked to discuss their experiences with the class. The teacher will then present the students with the question, "How do you move snow off the roof of a skyscraper?" The teacher will ask students how snow is moved in a nonspecific situation. Then students will be asked which methods would be applicable to the roof of a skyscraper and why. After students have generated a list of ideas and narrowed the list based on the objective, the teacher will ask the students how they would solve the problem. The same procedure will be used to ask students how to move sand off the roof of skyscraper and how sand differs from snow. Both discussion will end with the teacher asking students to form a hypothesis and determine how they could conduct an experiment to test their hypothesis. Special note will be taken if students can determine the different consistencies of sand and snow or if the teacher needs to present them with this information. The teacher will also encourage students to ask questions to better understand the problem.

Goal of Day 1: The goal of Day 1 is to introduce students to the idea of brainstorming and have them practice as a large group. This will help students become accustomed to generating ideas and building upon ideas from other students. Participation will be noted as well as the diversity of ideas. For particularly interesting ideas the teacher will ask students how they thought of them.

Day 2:

Day 2 will involve a similar procedure to Day 1. Students will be given a task to brainstorm based on what is currently known about a problem, determine how they would solve the problem, and justify their reasoning. The students will be given the question, "How can you travel across the United States?" to start the brainstorming process. They will work individually for a short period of time, hand-writing their answers. Then students will be asked to stop what they are doing and brainstorm for the question, "How would you protect a hand?" and after a limited amount of time students will be asked "How would you protect a foot?" Students will be asked to form groups of two and compare answers, adding notes to each other's papers. Next, students will form groups of three and repeat the same process. After this the teacher will ask students to go back to their seats and have a discussion about what happened.

Goal of Day 2: The discussion of Day 2 will not rely on the teacher as a mediator, but rather focus on building students' confidence in generating ideas. Day 2 will also be used to see if students follow the same method of brainstorming from Day1. Also, Day 2 will see if students set limitations or assumptions on the problem such as choosing a method that will best allow mobility, or if they ask questions such as "protection from what?"

Lesson 4

Lesson Title: Introduction to Bridges and Materials

Lesson Time: 1 hour

Summary: The purpose of the lesson is to introduce students to the project they will be asked to complete over the following weeks. The lesson will revolve around showing students, with an overhead projector, different bridges and asking the students to identify the materials used to build them.

Learning Objectives:

03.SC.IS.03 Keep accurate records while conducting simple investigations or experiments.

03.SC.IS.06 Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

03.SC.TS.01 Identify materials used to accomplish a design task based on specific property, e.g., weight, strength, hardness, and flexibility.

03.SC.TS.03 Identify a problem that reflects the need for shelter, storage, or convenience.

Procedure:

Day 1: Before visual aids are presented, the teacher will lead students in discussing their perceptions of bridges, including their purpose and materials used. Then pictures of bridges will be displayed and a class discussion will follow about the materials they see.

Day 2: The teacher will review the material from Day 1. Discussion will follow about the bridge materials and the benefits and limitations of each.

Day 1:

The teacher will ask students what the purpose of a bridge is, starting the class discussion. The discussion should focus on why bridges are used, their importance, and what materials they are made out of. Discussion can also include alternatives to bridges to help keep students thinking. Then pictures of bridges will be displayed in front of the class and discussion will focus on what material the bridges are constructed from. The teacher will end the class by telling students that they will be building their own bridges in the upcoming weeks.

Goal of Day 1: The goal of Day 1 is to introduce students to bridges first through a general discussion and then with real world pictures. The purpose of Day 1 is primarily to engage students into the idea of real world applications of engineering and provide background information for their upcoming project.

Day 2:

The teacher will review the different bridges showed on Day 1 and the materials used. The teacher will then ask students to generate a list of possible bridge building materials and have the students describe which materials are best for different situations (including cost, weight, strength, flexibility, and availability). A discussion will follow, starting with "If we build a bridge in the classroom, which material do you think will be best?" The teacher will help lead students to choosing wood as the building material and have students determine that Popsicle sticks would be an adequate choice.

Goal of Day 2: The goal of Day 2 is to reiterate the materials used in bridge construction and have the students decide the best material to build a bridge in the classroom. Special note will be taken of the students who are leading discussion and how much the teacher needs to lead the conversation.

Lesson 5

Lesson Title: Introduction to Bridge Project

Lesson Time: 1 hour

Summary: The purpose of the lesson is to introduce students to the project they will be asked to complete over the following weeks. Students will learn how to draw conceptual designs and create prototypes from them.

Learning Objectives:

03.SC.IS.03 Keep accurate records while conducting simple investigations or experiments.

03.SC.IS.06 Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

03.SC.TS.01 Identify materials used to accomplish a design task based on specific property, e.g., weight, strength, hardness, and flexibility.

03.SC.TS.03 Identify a problem that reflects the need for shelter, storage, or convenience.

Procedure:

Day 1: The teacher will perform a brief demonstration about how to draw bridge prototypes on paper. Then students will spend the class drawing their own.

Day 2: The teacher will review the material from Day 1 and students will build prototypes from their drawings.

Day 1:

The teacher will tell students that they will be building a bridge using twenty Popsicle sticks; the bridges must hold five pounds of weight and must be one Popsicle stick tall and two Popsicle sticks long. After, the teacher will demonstrate on the board how to draw preliminary designs of bridges, using lines to represent the designated amount of Popsicle sticks. There will also be a discussion on why it is important to draw multiple designs before starting to build a project. Students will spend the remainder of the time drawing bridges.

Goal of Day 1: The goal of Day 1 is to introduce students to the project and have them develop engineering design skills, primarily drawing preliminary designs. Special note will be taken to students who draw different perspectives of the bridges and who draw multiple different designs.

Days 2/3/4:

The teacher will review the previous lesson and ask students the importance of drawing the bridges before building prototypes. Then the teacher will allow students to build their bridge prototypes for the remainder of the class. The class will end with a discussion regarding the reasons why each student designed the bridges the way they did.

Goal of Days 2/3/4: The goal of these days is to have students describe their reasoning for building their bridges and have them practice the idea of creating a small scale prototype.

Lesson 6

Lesson Title: Introduction to Tallest Structure Project

Lesson Time: 1 hour

Summary: The purpose of the lesson is to introduce students to the final project they will complete. Students will continue to practice drawing conceptual designs and create prototypes from them.

Learning Objectives:

03.SC.IS.03 Keep accurate records while conducting simple investigations or experiments.

03.SC.IS.06 Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

03.SC.TS.01 Identify materials used to accomplish a design task based on specific property, e.g., weight, strength, hardness, and flexibility.

03.SC.TS.03 Identify a problem that reflects the need for shelter, storage, or convenience.

Procedure:

Day 1: The teacher will discuss the students' experiences from the bridge project and then students will spend the class drawing their structures.

Days 2/3/4: The teacher will review the material from the previous day and students will build prototypes from their drawings.

Day 1:

The teacher will tell students that they will try to build the tallest structure in the class using forty Popsicle sticks. There are no dimensional limits on the structure, but students are only allowed to use this number of sticks. Then, the teacher will discuss what the students noticed, their accomplishments, and the problems they experienced during the bridge project. Students will spend the remainder of the time drawing their tall structures.

Goal of Day 1: The goal of Day 1 is to introduce students to the project and have them practice the skills they learned from the bridge project. Special note will be taken to students who draw different perspectives of the structures and who draw multiple different designs.

Days 2/3/4:

The teacher will review the previous lesson. Then the teacher will allow students to build their structures for the remainder of the class. The class will end with a discussion regarding the reasons why each student designed the structures the way they did.

Goal of Days 2/3/4: The goal of these days is to have students describe their reasoning for building their structures and have them practice the idea of creating a small scale prototypes.

Appendix B

Pictures of various bridges presented to the class