Is There a "Scientific Method" to the Madness?

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Introduction

This is a curriculum unit that focuses on the Scientific Method for early elementary students. In 1st grade, students experiment all the time; they experiment with words, feelings, and actions. They experiment in Math, at recess, during any unstructured time, and even in Science. They experiment but they don't think critically about their experimentation. When something doesn't work they usually move on. In Reading, we try to get students to sound things out. I often ask students, "Does that sound correct? If not, change how you're pronouncing it." I want to take the deliberateness of how we read to how we do Science. What will you do? What do you think will happen? Did it happen? Why did it happen or why did it not happen? What do you think you can do differently to get your desired outcome? What can you take away from this experience?

Background

The elementary school where I teach is comprised of many different kinds of students with a variety of beliefs and experiences. Our school has approximately 1200 students from Kindergarten through 5th grade. There are nine 1st grade classrooms grouped together in three clusters of three rooms. This year I will have up to 25 students from Hispanic, African, Caribbean, Asian and Middle Eastern cultures, as well as students whose families are from the United States. My classes, historically, have students of which around 50% are African American, 30% are White and 20% are of other ethnicities, and are usually a close split between boys and girls. Socio-economically, my class will also be diverse with all economic classes represented. My school is a Title 1 school and qualifies for free lunch for all students. We live about one hour from the ocean, yet many of my students have never seen it, let alone gone swimming in it. The sum total travel experience of many students is the shopping trip to Walmart, and the weekly attendance at their family's house of worship. Most of my students' experiences are virtual through TV, movies, and video games.

Our grade level teaches Math and Language Arts four days a week. Fridays are our S^2 Day. On this day Science, in rotation with Social Studies, is taught for the whole day rather than daily, in 50 minute blocks. Depending on content and pacing, Science and Social Studies may also share that day. Language Arts and Math concepts are integrated into Science and Social Studies instruction where appropriate. This allows for deeper conversation and experimentation with the concepts we discuss.

Rationale

As I stated earlier, my 1st graders rarely think critically about their successes or their failures. Things happen because things happen. In our school, we are trying to build a culture of perseverance. If you don't understand something, keep working at it. If you get something wrong, try again. Many times, the student have a "throwing mud at the wall" approach, if you try enough times maybe something will stick. I want to have our perseverance be intentional. We try to instill a "Growth Mindset" in our students. We don't know things because we are smart, we know things because we ask questions and figure out answers. We tried something, we thought this would happen but it didn't. What can we change to get our desired result? Why can't we just change the answer to show what we want our experiment to prove? The Scientific Method seems a great place to start.

Many times, when working on a problem, my students do not achieve the expected outcome. 5+4 =10, what we have just read does not make any sense, and so on. If we go back and change something, a mistake, an oversight, or an assumption such as I forgot the number eight when creating my number line, or maybe I need to find out what a word means in the context of the story, or I should use what I know about a situation and apply that in my thinking, we can refine our hypothesis and start again. Why do we do experiments? To understand what happens, to solve a problem, and to increase our knowledge.

Daniel T. Willingham, a professor of psychology at the University of Virginia, wrote in a New York Times Opinion piece on November 27, 2017, about the importance of knowledge for students when they are trying to understand their reading. He states that students, especially in early grades, such as 1st, spend too much time on literacy instruction and not enough time acquiring content knowledge. According to his article, students spend 56% of their time on literacy instruction and only 6% on Science and Social Studies. This lack of engagement with content impedes their reading comprehension in older grades because they do not have the background knowledge to apply to their reading. When author's write, they do not write every detail one needs to understand their point, readers must infer to understand. Without content knowledge, this inferring becomes much more difficult.[1] While we may not be able to decrease our time spent on literacy instruction, what we can do is make our time spent on Science more productive, and it is my hope that this unit will help do just that.

Our other Science units in 1st grade involve solids and liquids, organisms, and a new unit on the sun and moon. I will create or modify lessons and experiments to incorporate the Scientific Method.

Background

“Males have more teeth than females in the case of men, sheep, goats, and swine...”[2] If Aristotle said it, as he did in 350 B.C.E.’s The History of Animals, then it must be true. Why would we even check? Aristotle invented deductive logic: premise: all frogs can swim, premise: this is a frog, conclusion: therefore, it can swim. If your argument follows simple rules like not allowing more in the conclusion than the premises then it will always be valid. If the premises are true and your argument is valid then the conclusion will be guaranteed. If what you have is a frog, you don’t need to throw it in the water to see if it swims, deductive logic says it does.[3] Aristotle also recognized the importance of induction. If we observe a group of frogs swimming, we can make an informed guess that all frogs can swim. By generalizing from specific frogs to the species Aristotle started to “do” science. If we use inductive generalizations about the species to deduce a conclusion about an individual, this gives us the power of prediction, which is an important aspect of science.[4]

Somewhere along the ages, some natural philosopher must have looked in his wife’s mouth and counted her teeth. He had Aristotle’s deductive logic, premise: women have less teeth than men, premise: this is a woman, conclusion: she will have less teeth than a man. But this turned out to be false because the first premise was not true. So, he actually observed the phenomenon and found it to be untrue. Was this a step towards the scientific method? Did he have a hypothesis, do his experiment, collect the data, and reach his conclusion. Maybe he checked in her sister’s mouth, too. It seems obvious that Aristotle must have relied on accepted knowledge and not on his own observations and that everyone after relied on the expert’s assessment until the accepted knowledge was challenged and overturned. This started with a simple question, “Do men have more teeth than women?” and ended with observation, data collection and a conclusion being drawn. Of course, when you do this at school or at home, make sure you take into account any dental work that may have been done!

Before the Scientific Method was developed, men used observation and deductive logic to solve, explore, and categorize the wonders of our earth. These men were called natural philosophers. They studied “a wide range of subjects which Aristotle included in the physical sciences. According to this classification, natural philosophy is the science of those beings which undergo change and are independent of human beings.”[5] Natural philosophers used observation and deductive logic to solve, explore, and categorize the wonders of our earth.

St. Thomas Aquinas (1225–74) came up with “Natural Theology”, which stated that studying the natural world was a way to understand the mind of God. This meant that studying nature, in the Christian world, was not a heretical activity but was a way to understand and get closer to God. With his soul no longer in the balance, a natural philosopher could start asking bigger questions.[6]

At the time of the natural philosophers, another offshoot of the "scientific" world was being explored, that of alchemy. Unlike natural philosophers who published their works, alchemists worked secretly, using special symbols and stories to pass on their secrets.[7] Alchemists also traced some of their ideas to Aristotle, especially the idea that the nature of a substance was controlled by its proportions of elements. If you changed the proportions of the elements in a substance, such as lead, you would change the nature of that substance. If done right, it would change from lead into gold.[8] Alchemy was not only a Western phenomenon but was a popular pursuit in the Islamic world and in China where it may have led to the discovery of gunpowder.[9]

So, in the 1600's, we had natural philosophers and we had alchemists and human knowledge was increasing. Copernicus theorized that the solar system was heliocentric and the heavens didn't revolve round the earth. The earth was proven to be round and not flat. But, alas, lead was not turned into gold nor was an elixir found to stave off death. Alchemy was problematic because it was based on "statements and theories held to be true even though they hadn't been tested or proved",[10] such as Aristotle's idea that there are four elements: Air, Earth, Fire and Water. The "sciences" medicine, astronomy, biology, and physics had their problems, as well, especially the idea of "scholasticism which was based upon assumptions and the importance of authority."[11] As we can see with the human teeth example, just because an authority, in this case Aristotle, says it is so does not make it correct. It was time for a new approach.

The Scientific Method

After 2000 years, the Aristotelian way science was carried out was about to change. Francis Bacon (1561-1626) was a wealthy, highly educated Englishman who decided that maybe Aristotle's logic based arguments towards scientific reasoning actually led nowhere. People's understanding of the world had not changed much since the time of the Ancient Greeks. The scholastic view was actually hindering scientific exploration and not enhancing it. He posited that the laws of science should be discovered by gathering and analyzing data from experiments and observations. While he made no great scientific discoveries himself, his scientific method went on to revolutionize how science is done.[12]

Francis Bacon had a huge influence on Robert Boyle and Isaac Newton. These two scientists wanted to move away from the alchemical way of science, knowledge based upon speculation, and move to a system where experimentation allowed one to observe things as they actually are. Isaac Newton in his Principia Mathematica stated "We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising; nor are we to recede from the analogy of Nature, which [is] . . . simple, and always consonant to itself."[13] Basically, just because we want something to turn out one way, doesn't mean that it will, and we have to go where our evidence leads us. Alchemists wanted to turn lead into gold. They "knew" that matter was formulated based upon the ratios of the four elements. If they could change the ratio, they could change the matter. This was based upon speculation, there was no evidence that an alchemist could site that this was true. Using the scientific method, a scientist could disprove any claim that stated an alchemist turned lead into gold. As knowledge increased, atomic elements were discovered that could, in fact, have their properties changed, but that is a discussion for high school students, not first-graders.

Robert Boyle (1627–1691), in his younger years, had dabbled in the alchemical arts looking for the fabled Philosopher's Stone, a substance that could turn base metals into gold. As he grew older he formulated different ideas that did not go along with the alchemical tradition. He traded in secrecy and mysticism for openness and measurements. When he discovered what is now called Boyle's Law, "For a fixed amount of an ideal gas kept at a fixed temperature, pressure and volume are inversely proportional" (see https://www.grc.nasa.gov/www/k-12/airplane/boyle.html for a visual explanation), he published that finding instead of keeping it a secret. Boyle believed, like Galileo before him, that the world could be explained mathematically. Instead of an alchemical pursuit, Boyle wanted to turn chemistry into a scientific, quantitative one. Boyle rejected the Aristotelian elements of earth, water, air and fire and correctly defined elements as simple substances that could not be decomposed into other substances. Compounds were produced when elements combined to form new substances, unlike mixtures in which no new substances formed. He wrongly thought gold, silver and sulfur were compounds and not elements and it would take over 100 years for Antoine Lavoisier to devise experiments that would produce the first list of chemical elements.[14] Lavoisier built his table based on his own work along with works carried out by earlier natural philosophers such as Hennig Brand who, in 1669, discovered phosphorous by boiling down urine until a drop came out that burst into flames.[15]

Boyle took Bacon's idea about drawing conclusions only after you had obtained experimental data and expanded on it. He made clear the importance of good materials and equipment for conducting valid experiments. He showed that experiments could give conflicting data and that it was important to document all aspects of the experiment so it could be reproduced. He thought experiments should be conducted more than once to both refine experimental technique and explore any differences that may arise in the data. Don't forget, he also broke from alchemical practices by publishing his works.

In his work, Of Unsucceeding Experiments, Boyle recognized the importance of failure. If an experiment did not work as planned it could still provide great information. He likened it to merchants who didn't quit their professions if they ended up in different ports they just did business there, or explorers who found new and interesting lands when they were blown off course.[16] Failure opens the door for new discoveries.

The Scientific Method can be boiled down to these five steps: A problem is stated. A hypothesis is formulated. An experiment is conducted. Data are collected. A conclusion is drawn.[17] After the conclusion is drawn, we can have a conversation about what happened and why. Then, if needed, rework our problem and/or hypothesis and start anew. As Dr. Joel Rosenthal, our seminar leader pointed out, “It’s more like an endless spiral staircase, where each conclusion leads to a new, more refined or elaborate hypothesis, which restarts the cycle. Each time we complete the cycle, our overall understanding of our world is improved and we move up the staircase…”

Our students will have to develop scientific vocabulary for this unit, including the terms problem, hypothesis, experiment, data, and conclusion. Students are familiar with problems; we all have them, we solve them in math but what, exactly, is a scientific problem? According to North Carolina State University’s LabWrite, “A scientific problem is something you don’t understand but you can do an experiment to help you understand. Scientific problems are usually based on observation of scientific phenomena.”[18]

We have a problem, so now we need a hypothesis. We could just do something and see what happens but, if we are intentional, we can use our background knowledge and some rudimentary research to formulate a hypothesis. Science Buddies defines a hypothesis as “a tentative, testable answer to a scientific question. Once a scientist has a scientific question she is interested in, the scientist reads up to find out what is already known on the topic. Then she uses that information to form a tentative answer to her scientific question. Sometimes people refer to the tentative answer as "an educated guess." Keep in mind, though, that the hypothesis also has to be testable since the next step is to do an experiment to determine whether or not the hypothesis is right! A hypothesis leads to one or more predictions that can be tested by experimenting.” [19]

Merriam Webster gives a student friendly definition of an experiment as “a procedure or operation carried out under controlled conditions in order to discover something, to test a hypothesis, or to serve as an example.”[20] Controlled conditions are where we set the environment. How much of something do we use, and at what temperature? This can be formulated in our predictions. “Predictions *often* take the shape of "If ____then ____" statements, but do not have to. Predictions should include both an independent variable (the factor you change in an experiment) and a dependent variable (the factor you observe or measure in an experiment).”[21]

As stated above we have an independent variable and a dependent variable. As we gather our data or information, we can adjust our independent variable to alter the outcome of our experiment. When we do this we need a new hypothesis, such as, what happens when we add more or less? Or this instead of that? If we have more than one independent variable what happens then? If I add more of a substance and shake it instead of stirring it, is the experiment still valid? If we change two variables we do not know which one may have caused the observed outcome. Variables need to be changed one at a time and data collected for each permutation.

After our experiment, we need to formulate a conclusion. Was the experiment successful? Did what we think would happen actually happen? What did we do that caused this? If our experiment was not initially successful, should we change anything? What happened then? Our conclusion could be something as simple as, when A was done to B, then C occurred. When vinegar was added to baking soda, bubbling occurred. When water was added to baking soda, the baking soda got wet. In first-grade, we can use what we observe to formulate our conclusion. We can also go deeper, what is it about the vinegar that caused the reaction that the water did not?

If our hypothesis is correct, others should be able to recreate our experiment and get the same data. We need to keep notes so that our experiment can be recreated exactly. In the baking soda example, if we have a pound of baking soda and a drop of vinegar, the same reaction won't be seen as with a teaspoon of baking soda and 4 ounces of vinegar. When our hypothesis is wrong, what can we learn from that? I tell my students that many experiments don't provide the desired results. If they did, there would be no more new discoveries and no need for scientists!

Application

Why exactly do people need to explain things that they don't understand or that don't fit in to their preconceived notions? What happens when that explanation is just made up? What happens when what you "know" about the world is not actually correct? How can the Scientific Method help us to think critically about the world around us? These are big questions to ask in first-grade. Many students attribute things they don't understand to the divine. God makes it rain is the most universal example. But whether God does or doesn't isn't our concern, the science of it is. When we think critically about our world it will help make a better place for all of us. By understanding what and why things happen, we can actually effect change, both positive and negative. The Scientific Method can help us with our thinking and therefore enable us to effect change. By being deliberate in what we do, thinking of a problem, using what we know, doing an experiment, collecting data, and reflecting on what the data shows, we can understand our world. Students want to explain their world. In my class, I have a "Wonder Wall". Students wonder about all sorts of things but never how to spell a word, or how much two numbers add up to. They wonder about the world around us. First-grade students really are natural philosophers at heart, and now we will give them the tools, the Scientific Method, to become Scientists. When we teach them to think critically, to ask new questions and then answer them, themselves, we empower them to envision and then to create a brighter future.

Teaching Strategies

My classroom is set up in table groups of three to four students. Students are grouped heterogeneously by reading scores. We do a lot of partner activities with each place at the table assigned a number 1–4 and a letter, either A or B. This configuration helps with classroom management with "1's work with 3's, 2's with 4's and partner A goes first" helping to cut down on the time spent pairing up students. Students also do a lot of talking amongst themselves about the material we are covering. Students participate in "Timed Pair Share" activities where each child, after think time, gets a chance to explain their thinking to their partner and then a few will report out on their conversations to the class. With any experiments that we do, it is important that every child thinks about what is going on. I do not want a situation in which one person who gets the materials while the other person does it, another collects the data and so on. Students need to be equally involved in all aspects of the lesson, but especially the data collection and the drawing of conclusions. Letting one partner do all the thinking will not benefit either partner.

Some challenges I foresee are related to my students' attention span. What experiments can they do that will hold their interest not only on the first try but on subsequent tries, as well? Experiments need to be inexpensive and easy to set up and to do. Finally, the experiments need to be both safe and engaging.

Activities

In the Colonial School District, we are adopting the Next Generation Science Standards and, as such, we are redoing our Science Curriculum. We have four units that we will investigate, one of which will last all year. The units are Bright Days / Dark Nights, once a month throughout the year, Catching the Wind, Solids and Liquids, and Organisms. I want to embed my Scientific Method Unit into each of our investigations.

Introduction

Using Google Earth, I will take my students to the Leaning Tower of Pisa and tell them the story of Galileo and how, according to legend, he dropped two balls, one heavy and one light, from the top of the tower to answer the question which would hit first. Which do they think hit first? What if he had dropped a bowling ball and some feathers? That is our question. Students will take what they know of the items and formulate a hypothesis. On YouTube, http://bit.ly/2Bnkpub, there is a video of what happens when you drop those items at the same time. Of course, the bowling bowl hurtles to the ground as the feathers float gently down. I'll stop the video after the bowling ball hits and we will have a discussion. We can drop some feathers and a tennis ball in the classroom to see first-hand what happens. Will the tennis ball hit first all the time? We can change different variables. What happens inside? Outside? In the light? In the dark? Why do the students think the tennis ball hits first? I'll ask the students if they think the air all around us has anything to do with it. What if there was no air? Which would hit first? Students will now make their predictions based upon what they have already observed. I'll take their answers and then we will continue watching the video. In the video, the bowling ball and feathers are dropped in a large vacuum chamber with the air sucked out. This time the feathers and ball hit at the same time. Why did that happen? Was their prediction correct?

What was different between the first experiment with the ball and feathers and the second? If the weight of the items does not make a difference in how fast they drop, but the way the interact with the air around them does, what will happen if we drop a tennis ball and a heavier but similarly sized baseball? Will the heavier baseball hit first or will they hit at the same time? This discussion is a great way to segue into our 1st unit, Catching the Wind and also into the idea that gas is a state of matter just like solids and liquids because it has mass and takes up space.

Catching the Wind

In our Catching the Wind unit, students build and "race" sail boats. Students learn and use the Engineering Design Process Define the Problem, Do Background Research, Specify Requirements, Brainstorm Solutions, Choose the Best Solution, Do Development Work, Build a Prototype, Test and Redesign[22] which correlates very well to the Scientific Method and gives a starting point for using the Scientific Method in later units. My goal for this lesson is to have students be intentional when they choose the materials they will use to construct their sails. Materials the students have available for sails are felt, tissue paper, wax paper, and index cards any of which must be attached to a popsicle stick and then secured to a raft. Students also have plastic coffee stirrers and tape available. In the unit, students usually pick their materials either randomly or because they see another student choose it. I want students to think about what they know about the materials before they choose them. As most students have rarely come into contact with felt, tissue paper, or wax paper, this will require time for the students to explore the materials. What do they know about the materials after examining them. Why do they think felt might make a good sail? Why not? I want them to systematically go through each item and figure out the pros and cons. I want them to think about what wind is. We use a fan to generate the wind. How can they "catch the wind" to propel their boat forward? Again, instead of throwing mud at the wall, I want them to be intentional; using their newly acquired background knowledge, have a reason they chose one material over another. Why will their material work better than the others? When the experiment is finished I want the students to draw conclusions about why their material either worked or did not. In the engineering process, students do not necessarily draw conclusions about their trial. The felt did not work because it was too heavy. The tissue paper did not work because it was too flimsy. The index card worked because it was light and rigid. If their material did not work because it was not rigid, could they create something, specifically a frame, that will allow their material to catch more wind?

Sciencebuddies.com has an interesting chart, http://bit.ly/2w8Amhk, that describes the differences between the Scientific Method and the Engineering Process. They state that many projects, such as I would say catching the wind, fall in a gray area between science and engineering.[23] I think that this activity is a good starting point for us to discuss both the Scientific Method and the Engineering Process.

Solids and Liquids

Our second full unit is on States of Matter where we specifically look at Solids and Liquids. An experiment the students will do, involves what happens to a solid when it is put in a liquid. We'll start with a hard candy such as a peppermint and a glass of water. We will state a question such as what happens to the peppermint when you place it in water? We will then formulate a hypothesis using our background knowledge of what happens when we put a peppermint in our mouth. Next, we place our peppermints in the water. It is important that we cover the cup with plastic wrap to counteract evaporation. We will collect the data. We will weigh the cup, the peppermint, the cup after water is added and subtract the weight of the cup to get the weight of the water, the wrapped cup of water before we add the peppermint, after we add the peppermint, and after a few days when it "disappears". Now we will ask, where did the peppermint go? Students will come up with an answer based upon their observations. To show that peppermint is still there, just in a different form, we will unwrap the cup and let evaporation take place. We will then weigh the dry cup with the resulting solids of the peppermint and subtract the weight of the cup. What will our answer be? Why? So where did the peppermint go? The dissolved peppermint and water formed a mixture, "…mixtures are about physical properties, not chemical ones. That statement means the individual molecules enjoy being near each other, but their fundamental chemical structure does not change when they enter the mixture."[24] In other words, mixtures can be separated into their component parts and evaporating the water does just that.

Organisms

Our final unit in 1st grade Science is Organisms. In our classroom, we have terrariums with pine seedlings, moss, pill bugs and millipedes. We also have aquariums with guppies, snails, and aquatic plants. We learn the difference between living things and non-living things and we learn about what all organisms need to survive. One of the things our organisms need is food. The experiment we use is adapted from Sally Kneidel's Creepy Crawlies and the Scientific Method. I am going to get tadpoles and put an even amount into two aquariums. I am going to make sure that the water temperature is the same in the two tanks. Our question will be what happens to a tadpole's rate of development when food is scarce. Students will use what they know about food to come up with a hypothesis. The first group of tadpoles will be fed a measured amount of boiled lettuce by students, every day. The second group will be fed that same amount but every other day. Students will measure tadpoles, excluding their tails, and chart the development of both sets of tadpoles and come up with a conclusion. Another experiment using tadpoles could be based upon water temperature where we keep the food availability the same but keep one aquarium cold and the other at room temperature.

Resources

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Article that talks about the need for background knowledge to facilitate reading comprehension.

Appendix A

This unit will implement Next Generation Science Standards for 1st Grade and Kindergarten. Emphasis will be placed on using observations to describe patterns of what plants and animals (including humans) need to survive and meet their needs and asking questions, making observations, and gathering information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.

Common Core State Standards for 1st Grade will also be addressed including students will follow accepted rules for discussion of ideas and be able to ask and answer questions about the experiments and be able to describe people, places, things, and events with relevant details and in complete sentences.

Notes

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