Arguing With Evidence:
Using Models In the 6th grade Science Classroom
To Investigate Newton's Three Laws of Motion

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Challenges

H.B. DuPont Middle School serves approximately 800 students from 2 distinct backgrounds. Roughly 60% of the students come from middle to upper middle class, largely 2 parent families with at least one parent being college educated. The other 40% come from a lower socio economic background, often single parent, often with limited education. There is also a great disparity between the two groups in life experiences and access to technology. Two additional challenges are that a subset of these students have limited English proficiency and I will also be teaching an inclusion class that may contain students that have severe cognitive, verbal, physical and emotional limitations. This year, we are also piloting an honors science class for students that are academically gifted in ELA and/or Math.

For this curriculum unit, I will focus on my 6th grade Science classes. It will be incorporated in the present Forces and Motion unit in connection with looking at graphical and algebraic displays of linear and non-linear motion. My focus will be to create opportunities for students to argue with evidence.

Introduction

When Delaware decided to adopt the Next Generation Science Standards (NGSS), I was really excited. Although I had been involved with the Delaware Science Coalition from its infancy, I believed that it was time for a change. I realized that it would be a daunting task to overhaul a curriculum that had been crafted to spiral from Kindergarten through Eighth grade, moving from the macro (trees) to the micro (cells) and from the concrete (wood) to the abstract (transformation of energy).

In my role as a classroom teacher (first, second, fourth and fifth,) I spent many hours in learning how to use the Smithsonian, Foss, and state of Delaware-generated curricular materials covering first through fifth grade. In my role as the building's lead science teacher, I helped develop end of the unit assessments and took part in the arduous task of refining them until they passed the inter and intra reliability tests and then taught my fellow teachers at the district level how to score and use the two digit rubric to inform instruction.

A move to middle school meant another 200 + hours in training for grades sixth through eighth. I was heavily invested in the old standards and the kit based materials that were used to teach them. Not only had I trained on more than 20 in depth units but even acted as a trainer myself for a few of those same units at both the district and state level. Yet it had to be done because technology has changed the speed of science discovery.

We cannot teach students the content they will need in the future, but we can teach them to be more critical users of information, from how it is gathered, to its analysis and finally how it is communicated and used. The Next Generation Science Standards is a three-strand movement consisting of eight essential science and engineering practices, key concepts that run through all of science, and disciplinary core ideas. The change in expectation of student achievement in Science comes on the heels of educational reform in both English Language Arts and Mathematics. Three distinctly different fields, yet when examined closely, all have this in common: *Argue with Evidence*.

Rationale

Middle school students love to argue; my challenge is how to teach them to do it with evidence. With that in mind, I applied to and was accepted in the Delaware Teachers Institute seminar on mathematical proofs. It has been an interesting and humbling experience. Interesting, because I have been asked to work with mathematics beyond my comfort zone but in a very supportive environment with the net result of leaving each class with a little more knowledge.

In high school I hated Euclidian Geometry with its axioms and postulates. I viewed math as a series of algorithms to be memorized and then filled with numbers as needed. Although my view of mathematics has changed over the years from rote to understanding, I still struggle with geometric proofs. As the teacher, I'm used to knowing many of the answers or at least have some idea of where to find them. It was humbling at a recent seminar meeting to have the correct answer to a geometry problem regarding area of a triangle but lack the ability to argue why it was the correct answer. I didn't even know where to start and in that moment really identified with the majority of my students. I sat there, feeling completely lost, until the professor started connecting points and created a model that proved why my answer was correct. He then used that same model to help us derive an algebraic expression that could be used to predict future areas. Both the Common Core Standards for Mathematics and the Next Generation Science Standards emphasize the use of modeling as one of the essential practices.

While it was clear to me that teaching students to create, use, analyze, and modify models was an essential practice in arguing with evidence in both math and science, I struggled with the ambiguity of the word model and wondered with so many representations available i.e. diagrams, physical replicas, mathematical representations, analogies, and computer simulations, if one form was preferable than another. Should it be left to the student or should purpose determine the best model for a particular problem? Does teacher bias play a role? I was much more comfortable with the triangle area problem when it was modeled as an algebraic expression than when represented as a series of connected shapes. Had I inadvertently been limiting my students' creation of models by telling them to make a graph in this instance and draw a picture in another? In doing my research, I found that teaching students to use modeling was more involved than I realized.

Background

When Gardner proposed his multiple styles of learning, it created a revolution in instructional pedagogy. To address different learning styles, teachers were encouraged to present information in different modalities. In addition to the traditional written word, content was to be presented orally, visually, and where possible, kinesthetically. This approach applies to making and using models as well. Research on learning with representations has shown that interacting with an appropriate representation increases learner performance. Just as presenting information in multiple modalities was considered beneficial, it was thought that multiple external representations (MERs) would also increase understanding. Further research has raised the issue of not whether MERs are effective but what conditions affect their usefulness (Goldman 2003.) Before investigating what factors influenced the use of models, I needed to review what affected learning on the whole.

Gardner's Theory of Multiple Intelligences

At the time I was pursuing my master's degree in education (1994-1996), there was a heavy focus on brain research. In designing lessons, our plans were supposed to be threefold. To deliver content, we should strive to address as many of Howard Gardner's multiple intelligence archetypes as possible. Gardner, Ph.D., Professor of Education at Harvard University, through his work on human cognition and human potential initially postulated that rather than being represented by a single IQ score, people's intelligence should be viewed through a variety of lenses. "These intelligences (or competencies) relate to a person's unique aptitude set of capabilities and ways they might prefer to demonstrate intellectual abilities." (Northern Illinois University, Faculty Development and Instructional Design Center n.d.) Educational theorists expanded his ideas beyond the demonstration of intellect to the preferred methods of content delivery. Initially, Gardner described six main types which he later expanded to nine. For the purpose of this paper regarding modeling, I've decided to limit the focus to the original six

1. Verbal-linguistic intelligence (well-developed verbal skills and sensitivity to the sounds, meanings and rhythms of words.)

2. Logical-mathematical intelligence (ability to think conceptually and abstractly, and capacity to discern logical and numerical patterns.)

3. Spatial-visual intelligence (capacity to think in images and pictures, to visualize accurately and abstractly.)

4. Bodily-kinesthetic intelligence (ability to control one's body movements and to handle objects skillfully.)

5. Musical intelligences (ability to produce and appreciate rhythm, pitch and timber.)

6. Interpersonal intelligence (capacity to detect and respond appropriately to the moods, motivations and desires of others.)

To make content more accessible, the plan was to deliver the same information through several different channels. Ideally, teachers would use a combination of survey and teacher observation to determine students' learning styles and then deliver information using students' preferred modalities. In reality, individuals are a combination and preferred learning style is mutable based on experience. There are also the questions of time and resources.

Bloom's Taxonomy of Learning

To assess student understanding, we were to scaffold tasks and questions along Bloom's taxonomy of learning. In 1956, Benjamin Bloom, PhD, edited the first volume of *Taxonomy of educational objectives: the classification of educational goals.* In this work, he described students' different levels of mastery of material based on their abilities to use it in tasks of varying intellectual requirements. The six levels are:

- Level I – Knowledge - Exhibits memory of previously learned material by recalling fundamental facts, terms, basic concepts and answers about the selection.

- Level II - Comprehension Level - Demonstrate understanding of facts and ideas by organizing, comparing, translating, interpreting, giving descriptors and stating main ideas.

- Level III – Application - Solve problems in new situations by applying acquired knowledge, facts, techniques and rules in a different, or new way.

- Level IV – Analysis - Examine and break information into parts by identifying motives or causes. Make inferences and find evidence to support generalizations.

- Level V – Synthesis - Compile information together in a different way by combining elements in a new pattern or proposing alternative solutions.

- Level VI – Evaluation - Present and defend opinions by making judgments about information, validity of ideas or quality of work based on a set of criteria. (15Oc)

Integrated Thematic Instruction (ITI)

The work of Bloom and Gardner came together under Susan Kovalik, with her focus on Integrated Thematic Instruction. The three areas of the ITI Model focus were originally called Brain Research, Teaching Strategies, and Curriculum Development, and are now known as: Biology of Learning, Instructional Strategies and Conceptual Curriculum. Originally designed to meet the needs of gifted students, it was expanded to meet the needs of all students with its emphasis on broader themes and multiple entry points for content acquisition (Gardner) and multiple ways to demonstrate understanding (Bloom). When I first began teaching elementary school in 1996, it was the focus of my curriculum planning. In the school and district where I worked, there were performance expectations but teachers had a great deal of choice in how to get students to meet those expectations. One of my first grade themes was weather. Reading books, singing songs, making rain sticks, acting out storms, doing condensation and evaporation experiments, and calculating temperature changes were a few of the sensory rich activities we did to build content knowledge and understanding.

Educational pedagogy is not static and the ITI model fell out of favor with the educational changes associated with an increase in mandated curriculum. Pacing schedules and grade specific materials across the four major content areas, math, language arts, science and social studies, severely limited the ability to do thematic instruction. Available time for exploration was negatively affected by additional time spent on small group remediation and testing associated with the response to intervention plans for literacy and math skills. At the elementary school level, investigative based science was especially hard hit as there wasn't time in the schedule. The lack of time for science is what led me to transition to middle school.

Educational best practices continue to evolve

Delaware has adopted the Common Core Standards for math and English language arts and the Next Generation Science Standards (NGSS). While there is minimal shared content, there are several areas of overlap where it comes to information processing. In all three, students are expected to argue with evidence. They are expected to use multiple sources and communicate understanding through different mediums. The Common Core standards for Math and the Next Generation Science standards both reference the analysis and creation of models. In making the move to the NGSS, there is again an emphasis on meeting performance expectations rather than on a set curriculum. How best to teach students to develop models has sent me back to the learning theorists. While there are aspects of Gardner, Bloom, and Kovalik that I think still have value, I needed to know more. To better align with the NGSS, I have to make a shift from what I am doing as a teacher to what my students are doing as learners.

Based on Gardner's work, I once thought more was better and my task was to present the same content in as many different forms as possible and that would increase my students' understanding and retention. A deeper review of learning research has me questioning this approach. According to George Miller (1958), our short term memory can only hold 5-9 chunks of information (seven plus or minus two) at any one time. A chunk could be numbers, letters, visual or auditory pieces of information. Subsequent researchers have even set the amount even lower depending on the nature of the chunk. Instead of enhancing their retention, had I been overwhelming students short term memory processing? The short answer seems to be that it depends on the nature of the chunks.

In Mayer's Cognitive Theory of Learning (1997), he states that people have two separate channels (auditory and visual) for processing information. Furthermore, there is a limit on how much a person can process through any one channel at a given time. Lastly, for learning to occur, it must be "an active process of filtering, selecting, organizing, and integrating information." In summary, "humans can only process a finite amount of information in a channel at a time, and they make sense of incoming information by actively creating mental representations." Before information can become part of long term memory, it needs to be actively processed. While Mayer doesn't expressly say not to use multiple modalities, his work suggests that people can be mentally overwhelmed and that time is required for processing before presenting additional material.

John Sweller's theory of Cognitive Load (1998) is even more specific in connecting short term memory to long term retention. He proposed that the contents of long term memory are "sophisticated structures that permit us to perceive, think, and solve problems," rather than a group of rote learned facts. These structures, known as schemas, are what permit us to treat multiple elements as a single element. They are the cognitive structures that make up the knowledge base. Schemas are acquired over a lifetime of learning, and may have other schemas contained within themselves." According to Sweller, although the number of chunks that short term memory can hold remains the same, the size of those chunks increase as the bits of information are linked. The change in performance occurs because as the learner becomes increasingly familiar with the material, the cognitive characteristics associated with the material are altered so that it can be handled more efficiently by working memory.

From an instructional perspective, information contained in instructional material must first be processed by working memory. For schema acquisition to occur, instruction should be designed to reduce working memory load. Cognitive load theory is concerned with techniques for reducing working memory load in order to facilitate the changes in long term memory associated with schema acquisition. Sweller proposes four specific strategies to minimize the demands on working memory:

Specific recommendations relative to the design of instructional material include:

- Change problem solving methods to avoid means-ends approaches that impose a heavy working memory load, by using goal-free problems or worked examples.

- Eliminate the working memory load associated with having to mentally integrate several sources of information by physically integrating those sources of information.

- Eliminate the working memory load associated with unnecessarily processing repetitive information by reducing redundancy.

- Increase working memory capacity by using auditory as well as visual information under conditions where both sources of information are essential (i.e. non-redundant) to understanding.

Unfortunately, there are times when educational theories are in opposition. A key aspect of the Next Generation Science Standards is the focus on the eight critical science and engineering practices. As part of these, is the move to means-ends problem solving and away from worked examples. The goal is not for students to repeat learned pieces of information but to explain phenomena and engineer solutions by linking evidence to crosscutting concepts and core disciplinary ideas. This does not mean that other parts of Sweller's recommendations cannot be used in working with models. As the human body is part of the sixth grade curriculum, I was particularly interested in the example provided on the human heart. In our current text, the illustration of the heart is separated from the text describing the various parts and functions. At various points in the reading, students were instructed to move from the text to the illustration, adding labels and descriptors. Classroom experience quickly showed me that students struggled with this task and I modified the lesson to label the heart parts and discuss the flow of blood before doing the reading. Without being specifically aware of Sweller's work, I had implemented recommendation four using two channels of information-auditory and visual to increase working memory capacity. My next modification will be to include the key parts of the text as descriptions under the diagram labels (recommendations two and three to avoid redundancy and taxing working memory by physically integrating the information).

Whereas both Mayer and Sweller focused on information processing as being either visual or auditory with finite processing capabilities as regards short term memory, Schnotz saw it more a dichotomy of depictive versus descriptive information, rather than text or pictures. He saw mental mapping as complementary representations on which people draw to solve problems, rather than an integrated representation. The difference is significant, especially when it comes to using and making models.

Shaaron Ainsworth takes a completely different approach, focusing not on the idea of multiple external representations (MERs) or even on the individual forms but on the circumstances that influence their effectiveness. According to Ainsworth, the DeFT (Design, Functions, Tasks) framework can be used to help predict whether someone will benefit from learning with a particular combination of representations. Breaking the acronym apart, De stands for the design parameters that are unique to learning with more than one representation. The f represents the different pedagogical functions that multiple representations can play. The t represents the specific cognitive tasks that a learner must use within a representation.

Design parameters in DeFT

Representations differ in their content, their target users and the teaching strategies used. According to Palmer (1977) an external representation consists of the real world situation, the model, what aspects of the real world situation that are being represented, what parts of the model are doing the representation and the correspondence between the two worlds. Ainsworth builds on Palmer's work by looking at the cumulative effect of multiple representations being different than just the sum of criticisms of the individual models. In this case, the design dimensions include the number of representations, the way the information is distributed, the forms of the representational systems, the sequence of the representations and the support for translation between representations.

Breaking it down further: Multi-representational systems have at least two models but often more which may or may not be available concurrently. Information can be distributed across several models which affects both the complexity of the model and redundancy of information. Does overlap provide reinforcement or unnecessary information processing? The less information conveyed the simpler the model but the more models needed. Regarding form, a typical multimedia system can display pictures, text, animations, sounds, equations, and graphs but should it? Gardner would say yes as the different representations address different learning styles but both Mayer and Sweller may argue against it as it requires too much processing. Schnotz would argue that it depends on whether the representations are descriptive or depictive with the associated mental processing loads. As for sequence, in what order should multiple representations be presented? Should it be unidirectional or should students move between models and if so, when? Regarding Translation, how does one model relate to another? Computers are particularly adept at being able to show interrelationships and how a change in one model translates into a change in another.

Moving from the theoretical to application, let us consider the solar system. As part of aligning the Delaware State Science curriculum to the Core Disciplinary ideas of the NGSS, there is a proposal to move Earth and Space Science from eighth grade to sixth grade. The key science content is that planetary motion is determined by gravitational pull and that it is the varying gravitational pulls of the different moons and planets that keep the objects in our solar system moving in a set pattern. At the simplest representation is a model of the sun with the planets all arranged around in order with Mercury being the closest planet and Neptune being the farthest planet. While that captures the idea of a heliocentric system, it doesn't address gravitational pull being a function of an object's mass and distance. To get at that, we need a second model that shows those two aspects of a planet relative to the sun. A table can provide that information but the numbers are difficult for students to visualize and it doesn't show that actual orbital paths so students are led to believe that everything moves in a perfect circle. Now we can add a diagram with lines to show the different planet orbits but even that is difficult to show to scale based on the vast differences. Illustrators have to intentionally misrepresent planet positions in order to show the eight planets in a relatively compact form. Make and/or use a model of our solar system to explain planetary motions is a much more difficult task when multiple aspects are considered.

The Functions of an Appropriate Representation

Scaife and Rogers (1996) said that the choice of representations (models) should be determined by the way they support computational offloading, re-representation and graphical constraining. In other words, let the intended use determine both the design and sequencing of representation. Returning to the solar system example, if my goal is to have students compare different gravitational pulls (computational offloading), then my model would be a chart listing relative gravities that students could use to calculate their weights on different planets. In re-representation, similar information is shown in different models but one does it better as in the case of the 2D drawing of the planets and their orbits rather than displaying a static 3D model, even with the size of the planets shown in relative scale (marbles to basketballs). Graphical constraints brings us back to Schnotz and his distinctions between descriptive (symbolic) and depictive (iconic) representations. He sees depictive representations being more useful to provide concrete information i.e. a listing of gravitational pulls whereas descriptive representations are more open ended and can express abstract information as well and more general negations and exceptions. A table of relative planet gravities (depictive) informs students that the gravities of Venus and Saturn differs very little but a description of Saturn as a gas giant with a very small density due to its relatively small mass compared to its size can help students understand why that seeming anomaly can exist.

Cognitive tasks involved in learning with models

The last aspect of Ainsworth's DeFT framework is to look at the cognitive tasks associated with multi-representational systems. Learners need to know how a model encodes and presents information (the format). Each style of representation requires its own set of cognitive tasks. Written texts require that students be able to connect letters with sounds and then assign those groups of letters and sounds different meanings based on context. Science text is especially rich with new and often very specific vocabulary. Students need to have a frame of reference in which to develop comprehension. It is especially challenging for English language learners and students who struggle with written expression. Representations that focus on visual displays have their own challenges. In the case of graphs, the attributes are lines, labels, and axis. To make the most of the model, they have to understand how to work within and beyond the graph. In some cases, they need to actively work against their own perceptions to correctly interpret a graph. This is especially evident in analyzing time/distance graphs. A straight line sloping upward to the right is frequently misinterpreted as increasing speed as students associate going up with going faster rather than a straight line indicating constant speed. They are equally incorrect when viewing a line with a negative slope on the same type of graph, only this time they report slowing down. Before specific instruction, most will illustrate non-zero constant speed as a horizontal line.

Activity: Using Models to investigate Forces and Motions in order to meet the Next Generation Science Standards

One of the key science and engineering practices of the Next Generation Science Standards is the use of modeling to investigate and construct explanations for real world phenomenon. The use of mathematical modeling is also a key concept in Common Core Mathematics. The middle school physics content is the ideal content as it relies heavily on describing and explaining interactions of forces that are not visible. Students cannot see force, magnetic attraction or gravity but only their results.

The unit starts by having students connect position time graphs to story situations. In this pretest, which also lends itself to blended learning, students match up various graphs to the story of movement and then write short explanations of their thinking. What I anticipate will frustrate my students the most is not being given the correct answers at this point. The graphs have no numbers which forces students to look at them for patterns rather than being able to focus on specific values.

On the surface, speed seems like an easy concept. Speed is equal to distance divided by time; a formula relatively simple to memorize, plug values into, and spit out answers yet the concept is more difficult for students to grasp. When asked how to measure speed, my sixth graders referred to the radar guns used by the police. Further prompting elicited the ideas of using the same guns to measure the speed of pitches in baseball or hockey pucks across the ice but no connection was made to the relationship between time and distance. Even when they considered timing people in a race, it took several leading questions to get them to say that the distance had to be the same. Yet in a way, even that approach is incomplete as it only looks at keeping distant constant, yet in the majority of time when we talk about rates of speed, it is using a unit rate for time, not for distance.

Very few students experienced any degree of success in the pre-test of correctly interpreting the graphs even though several of the students could describe the speed algorithm. Some had worked with rubber band powered K'Nex cars the previous year but none had connected their speed data to a visual representation. Before getting them to use numerical data, I wanted them to focus on qualitative data. Under the old state standards, students moved step by step through a list of proscribed activities with a great deal of reading background information interspersed. Historically, this has caused my students to struggle as they had difficulty comprehending the text as well as seeing how the embedded activities matched the text. To give students more time to read and digest the material, I had even tried flipping these set of activities last year with the reading being completed at home and the investigations happening the next day in class. There was only a slight improvement in comprehension.

This year, I decided to get rid of the reading all together and instead focused on having students create models of the different expressions of speed. I gave them the challenge to create five distinct dot patterns that showed three different constant speeds-slow, medium, and fast; and two accelerating speeds-one positive and one negative. In my initial presentation, I depicted acceleration as acceleration and deceleration, with students using the initial consonant of the latter as a mnemonic for decreasing. To make the patterns, the students used dot cars. A dot car is a specialized piece of science equipment, where a lever, powered by batteries, causes a marker to make dots at one second intervals. The cars have no forward motion of their own so it was up to the students to move the cars to create models of the assigned motions. Although some groups struggled with trying to move at a constant speed, every student soon linked the distances between the dots to relative speeds. They created posters and orally presented their findings. There were quantitative differences between group presentations of slow, medium and fast speeds but with each group's model there was a consistent increase of distance between dots as speed increased. Constant speed-dots equally distant from each other with changing speed represented by increasing or decreasing intervals between dots. Once they were comfortable with the visual representation and had the ability to manipulate the image by reading it right to left and left to right, they could accept the one term acceleration as change of speed for both speeding up and slowing down, with positive and negative being the modifiers. To measure individual understanding, I did a quick formative assessment where I described the type of motion and had students draw the corresponding dot pattern. To stretch their thinking, I asked for the dot pattern of a constant speed of zero. At this point, most students did not show a single dot.

The next step was to move from modeling rate of motion qualitatively to modeling it quantitatively. As written, students were to be taken step by step through the process with readings and focus questions. Based on their success with the dot cars, I again removed the reading and presented it as a problem: argue with evidence, which of two battery powered cars were faster. Students were provided with a meter stick, a timer accurate to hundredths and the cars as materials for their investigations. They could only use one of the cars at a time so racing them head to head was not an option. Although students could have chosen to keep either time or distance constant, almost every group chose to keep the latter. Furthermore, they decided to all use a distance of 100 centimeters. I circulated the room as they were setting up their data tables and informally checked their thinking. Was it a lack of understanding of the two possible methods or was it something else? It turned out to be both. Although the majority were familiar with motor vehicle speeds being miles per hour where time is the unit rate, their own personal experiences centered on keeping distance constant as in a fifty yard dash or doing the mile run in the gym as part of a fitness evaluation. A few students in my honor's section initially planned to keep time constant and measure the distance the car travelled. They shared that they thought it would make it easier to calculate speed if they ran the cars for 10 seconds and measured the distance, as dividing by 10 was simple. The difficulty was stopping the car at exactly 10 seconds and accurately measuring its position. When it appeared that their peers' data collection method, keeping distance constant, was quicker, they switched as well. While letting them choose the method gave them more ownership, I think next time I'll have the students do both and then compare them. I'll also substitute metric measuring tape for the meter sticks as the stick became the default distance.

Having discussed reproducibility and reliability of data several times earlier in the semester, it was good to see most students including at least three trials and finding the average of their data. We discussed mean, median, and mode as three "averages" but settled on using the mean as it best matched their small data sets. At this point, I had students write a claim about which car was faster and support it with evidence. In all cases, the red car should have run significantly faster as it was powered by 2 C cells while the blue car had only 1 battery and aluminum foil to complete the circuit. This is the first year, I've made this adjustment. Before, I used new and older batteries which only produced a slight difference which made for better argument but poorer graphs. Since my focus was on mathematical modeling and reading the story of the graphs, I wanted a bigger difference. Speed is a specific mathematical relationship of distance divided by time, units being equal. The greater the value, the greater the speed so the faster car will have the bigger number. All students correctly identified the red car as faster but then roughly a fourth struggled with the explanation as the only number they had was the average time it took to complete 100cm. How could the red car be faster if its number was smaller? Shouldn't the bigger number go with the faster car? At their tables, students began to argue with each other. Before the answer had been in their pre-reading and they'd look to see what the book said but now they turned to me. My answer was to remind them of how they had reported car speeds to me in miles per hour and do a quick sketch of a trip of 100 miles that took me 2 hours. I then asked them to make a comparable sketch of their experiment. Had they figured out speed or time? Adding calculators to the materials' table did not make all students instantly successful. Listening to their conversations helped explain why. "It took the red car 5.3 seconds to go the 100 cm so its speed is .0053 centimeters per second" When asked why, the student showed me his steps of 5.3 divided by 100 equals .0053 and then he added the units, centimeters per second. Although he "knew" that speed was said as distance per time, he hadn't internalized it as a proportional relationship with time being the unit rate. Instead of having them copy down the formula, I encouraged them to derive it from their common usage of miles per hour, with distance being the numerator and time the denominator in order to determine their own unit rates of centimeters per second. To further help them clarify their thinking, I modeled the multiplicative identity principle of one. When they were dividing the numerator by the denominator, what they were really doing was dividing both by the same number (denominator) to get the unit rate. What the student had done was calculate seconds per centimeter instead of centimeters per second. By having students see it as a proportional relationship and not just a division operation helped them better understand speed as a rate rather than just a number. Some of my students say that they think math is easier because it's just numbers and not words and yet being precise with language is what students need if they are to argue with quantitative data. The red car is faster because it took less time to go 100 centimeters than the blue car. Since it took less time to go the same distance, it means that it travelled a greater distance in the same time; it went a faster speed-distance per unit of time.

The next challenge was to have students find another way to collect qualitative and quantitative data to support which car was faster. They couldn't use a timer but any of the other science equipment was available. Again I was asking them to generate the investigation and data tables rather than follow the steps in the reading. To generate ideas, I used a think, pair, share technique where students first took three minutes to think about the problem as individuals, then they discussed it first with their shoulder partners and then with their tables. Lastly, a spokesperson from each table shared out with the group. They debated the merits of having a person move the dot cars alongside the red and blue cars to record the motion or having the dot car being pushed by the battery powered buggies. As a group they decided to have the buggies push the dot car because of their experiences in trying to create constant speed models. When asked how that would help them make comparisons, they said that they would compare the two dot patterns and the car that had the dots further apart would be the faster car which would give them qualitative data. When asked about quantitative data, their first idea was to count the number of dots but with further questioning, they decided to measure the spaces between the dots.

From a classroom management stance, I had each group run three lengths of "track"-register tape-and use the best to represent their average data. In retrospect, I should have remodified some of the cars so that either the red or blue car could have been faster which would have given their investigation more authenticity but at the time was only focused on what I wanted in connection with their graphical models. Students measured the interval spaces and then rounded to the nearest whole number. We discussed how even the slightest change in direction could result in a slightly different interval value even when we knew the car was moving at a constant speed and that all the intervals should be the same. Students then made a double bar graph comparing distance traveled over each one second interval for the red car and the blue car. It provided an excellent opportunity to review independent and dependent variables, scale and the importance of labelling. To help my visual learners, students graphed in red and blue. I didn't accept a student's explanation that the red car was faster because its bar was taller than the blue car's bar unless she tied the height of the bar to the distance travelled in that one second interval. As a quick formative assessment, I asked if that would still be true if instead of distance, the bars represented time to go one interval. The majority of the students responded in that case, the shorter bar would be the faster car because it took less time. On reflection, to increase the rigor, two other questions could have been: would the story be the same if the axis labels were switched and on the same lines, what could the axis be labeled so that the shorter bar represents the faster car?

Students next graphed total distance travelled against time, creating a double line graph. Many struggled to create the data table. In previous years, I've given them the data tables for individual intervals and for total distance and had them complete both before doing any graphing. It caused some problems as students weren't sure which data table to use for which graph and the exact measurements didn't match adding up the rounded intervals. In addition, students struggled with finding best fit lines due to the limitations of scale in plotting their points. This year, I had the students focus on one data set at a time in both collecting the data and in the graphing. To get around the true measurements not matching the rounded intervals, I had students add up the whole numbers to create the total distance travelled data table. It was a disaster as the majority of students either became frustrated at their not being sure of what to do or worse, successfully did it but by rote with no understanding. Having experienced it both ways now, I'm definitely going back to measuring the total distances and plan to add having them draw colored lines on their "tracks" of the intervals. Even with scale plotting issues, students can still see that constant speed makes a straight line graph. In sixth grade, only students in pre-algebra are familiar with slope as a mathematical relationship between the change in the y axis compared to the change in the x-axis but all my students have a conceptual understanding of the steepness of a hill. In using their double line graphs to support which car is faster, they said that when you look at the time, the red line is higher than the blue; it makes a steeper hill.

While being able to create, analyze, and describe numeric, visual, and graphic displays of constant motion and other linear functions is important, much of science phenomena is not linear. Gravity, which affects all things, is one of those. In sixth grade, it isn't important that they be able to graph the acceleration but just identify that it does. This activity is done as a demonstration with the dot car being allowed to roll down a platform. As the angle of the platform increases, the faster the dots get further apart from each other. Students make their predictions and then we look at the evidence as a class. On large chart paper, students can see after plotting just a few points, that there isn't a best fit straight line but a curved one.

Reflection

At this point, I will be reintroducing the position time graph and story matching activity. My expectation is that students should be able to correctly match and write reasonable evidence statements for motion of constant non-zero speed and changing speed as it relates to movement away from a start with distance increasing. Informal questioning shows me that some will still identify a loss in distance as a change in speed even when the graph shows a straight line. What they still struggle with is a constant speed of zero being represented by a horizontal line in a position time graph. Both of these concepts are addressed again in the 7th grade common core math standards.

With this common background on modeling motion that is clearly visible, students will begin to address the physics standards from the Next Generation Science Standards by viewing motion as the sum of different forces on an object. They are moving from the concrete of showing motion that they created by moving the dot car or that they saw with the battery powered buggies to representing forces.

In previous years, I've modeled representing the different forces by doing a series of demonstrations and having students copy my force diagrams. This year, the students will create their own demonstrations of motion due to gravity, air resistance, object at rest-supportive force, object being pushed with and without constant speed, and elastic forces -bouncing ball and rubber band. The focus will be on showing relative sizes and directions using force arrows but no actual computation.

In addition to their own force experiments, all students will examine how a marble travels around a whole paper plate compared to its path when a quarter of the plate has been removed. Supportive forces from the plate's rim keep the marble moving in a circle but without the edge in the cut plate, the marble rolls off the plate in a straight line. This is part of the lead in to explaining the motion of the planets in our solar system. In the absence of any other force acting on them, the planets should also move in straight lines. Since they don't, there must be another force at work, which is gravity.

The unit concludes with students taking a closer look at Newton's three laws of motion. The first law- that an object at rest stays at rest and an object in motion stays in motion unless acted on by unbalanced forces is only partially accepted by students. They can more readily accept the staying at rest part but struggle with the staying in motion part because it doesn't match their daily observations. One way to model it is to show the video from the institute of highway safety showing the forward motion of the crash test dummies. Even though the car's forward motion is stopped in a collision, the occupants' forward motion continues until something else stops it.

The second law states that a change in an object's motion depends on the sum of the forces on the object and the mass of the object. Qualitatively, students can observe that it takes less time for a heavy ball to roll down a ramp than a lighter one. Students then create their own model by adding weights to the dot cars to collect quantitative data to support their argument.

To introduce students to Newton's third law of motion, that every action has an equal and opposite reaction, I would start with what seems like a discrepant event. Have two students of obviously different physical builds duct tape bathroom scales to their hands. Have the smaller of the two stand with her back to a wall, arms outstretched while the larger of the two pushes against her. When asked which student has more force, 6th graders will usually state the larger student. Showing the readings on the bathroom scales reveal that the forces are equal. They then create their own model of colliding forces and draw the resulting motions.

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Bautista, Alfredo, Michelle H. Wilkerson-Jerde, Roger Tobin, and Bárbara M. Brizuela. "Diversity in Middle School Mathematics Teachers' Ideas about Mathematical Models: the Role of Educational Background." Tufts University. http://www.cerme8.metu.edu.tr/wgpapers/WG6/WG6_Bautista.pdf (Accessed December 13, 2015).

Interesting article that looks at a study that compares a teacher’s background with their views on modeling. It is a nice companion piece to the German article which introduces the idea of teacher bias in both providing assistance and in teaching modeling based on the teachers learning style.

Bloom, Benjamin, M.D. Engelhart, E.J. Furst, W.H. Hill, D.R. Krathwohl. “Taxonomy of Educational Objectives: The Classification of Educational Goals.” David McKay Company (1956).

Blum, Werner and Rita Borromeo Ferri. “Mathematical Modelling: Can It Be Taught And Learnt?” Journal of Mathematical Modelling and Application. http://gorila.furb.br/ojs/index.php/modeling/article/viewFile/1620/1087 (Accessed December 13, 2015).

Extremely in depth scholarly article on studies that looked at the effectiveness of the tool and the benefits and pre-requisites for using it based on studies done in a German classroom. References Montessori style and also brings in teacher bias of preferred modeling. Goes into more detail on 7 step modeling method and presents the simpler 4 step phase. The extensive citation list provides a lot of jumping off points to pursue additional research.

California State Board of Education. “Appendix D. Mathematical Modeling” State of California. http://www.cde.ca.gov/ci/ma/cf/documents/aug2013apxdmathmodel.pdf (Accessed December 13, 2015).

State of California’s definition and non-example of what mathematical modeling looks like. Good basic definition. Can serve as the overview of using mathematical modeling.

Carrejo, David J. and Judy Reinhartz. “Facilitating conceptual change through modeling in the middle school science classroom.” U. S. Department of Education. http://files.eric.ed.gov/fulltext/EJ1044004.pdf (Accessed December 13, 2015).

Provides a blueprint of a lesson where students develop their understanding of the interrelationship between speed, distance and position. They use multiple ways to model constant and changing speed. As a culminating activity, they “read” the story behind different time and distance graphs. Incorporates technology in the form of go motion pro sensor. Aligns with both NGSS and the current 6th grade unit on motion and design.

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English, Lyn D. "Complex Modelling in the Primary and Middle School Years: An Interdisciplinary Approach" Springer Science + Business Media. http://eprints.qut.edu.au/64825/ (Accessed December 13, 2015).

Faculty Development and Instructional Design Center. “Howard Gardner’s Theory of Multiple Intelligences.” Northern Illinois University. http://www.niu.edu/facdev/resources/guide/learning/howard_gardner_theory_multiple_intelligences.pdf (Accessed December 13, 2015).

Goldman, S. R. “Learning in Complex Domains: When and Why Do Multiple Representations Help?” Learning and Instruction. 13 (2003): 239-244.

Green, T. and K. McKie. "The Vitruvian Man." galileo.org. http://galileo.org/tips/davinci/vitruviantask.html (Accessed December 13, 2015).

Modeling task where students are asked to support Davinci’s portrayal of Vitruvian man, higher order thinking, multistep requiring self direction-could be tied into human body unit for gifted class or even done in connection with art teacher no theory but does address larger modeling issue of exact data versus reasonable data for predictions.

Kovalik, Susan, and Karen D. Olsen. “ITI: The Model, Integrated Thematic Instruction.” Susan Kovalik & Associates. (1993).

Mayer, R.E. “Multimedia Learning: Are We Asking the Right Questions?” Educational Psychologist. 32(1) (1997): 1-19.

Middle School Math and Science. "BIG Numbers." The Ohio State University. http://msms.ehe.osu.edu/category/problem-solving/ (Accessed December 13, 2015).

Interesting lead in article on 'rescuing' students rather than letting them struggle some with problem solving-relate back to use of modeling techniques-questions versus answers "What could you do to better understand the problem vs draw a picture" goes back to other article on students not cognitively referencing different problem solving techniques explicitly on their own.

Middle School Math and Science. "Ratios as Seen in Scale Factors." The Ohio State University. http://msms.ehe.osu.edu/category/scale/ (Accessed December 13, 2015).

Link to engaging activities that focus on using models that are of high interest to students-pursue at a later time when constructing lessons for specific content.

Miller, George. “The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information.” http://www.musanim.com/miller1956/ (Accessed December 13, 2015).

Modeling Middle School Mathematics Project. “Data Analysis.” MMM Project. http://www.mmmproject.org/data.htm (Accessed December 13, 2015).

Provides a link to several different math programs and their use of interactive activities to explore key math concepts. Although it doesn’t apply to my physics unit, the trashketball lesson would be good as an alternative to data toss (inside activity), an enrichment activity (it introduces stem and leaf plot as well as reinforcing using a bar graph for mean, median, mode and range) or a remedial one for RTI math. Students move around the room at three different stations shooting for 1, 2 and 3 point shots, total up their scores, and then analyze the data. Video link would allow me to assign it as a flipped classroom item with students doing the preview before the in-class data collection.

Next Generation Science Standards. “The Next Generation Science Standards.” http://www.nextgenscience.org/next-generation-science-standards (Accessed December 13, 2015).

Palmer, S.E. “Fundamental Aspects of Cognitive Representation.” Cognition and Categorization. (1978): 259-303.

Qiu, Jinjia. Theory and Practice in Teaching Mathematical Modelling at High School Level." Mathematical Modelling in Education and Culture. http://www.sciencedirect.com/science/article/pii/B9781904275053500304 (Accessed December 13, 2015).

Article looks at mathematical modeling in China, good addition to research based on German schools for international and multicultural focus.

Scaife, M. and Y. Rogers. “External Cognition: How Do Graphical Representations Work?” International Journal of Human–Computer Studies. 45(2) (1996): 185-213.

Schnotz, Wolfgang. “Commentary – Towards an Integrated View or Learning from Text and Visual Displays.” Educational Psychology Review. 14(1) (2002): 101-120.

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Appendix

Next Generation Science Standards Addressed

<u>MS-PS2-1</u>

Apply Newton’s Third Law to design a solution to a problem involving the motion of two colliding objects

<u>MS-PS2-2</u>

Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object.

Common Core Math Standards addressed

CCSS.MATH.CONTENT.6.EE.A.2.C

Evaluate expressions at specific values of their variables. Include expressions that arise from formulas used in real-world problems. Perform arithmetic operations, including those involving whole-number exponents, in the conventional order when there are no parentheses to specify a particular order (Order of Operations).

CCSS.MATH.CONTENT.6.RP.A.3

Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.

CCSS.MATH.CONTENT.6.RP.A.3.B

Solve unit rate problems including those involving unit pricing and constant speed.
Use functions to model relationships between quantities.
Understand the connections between proportional relationships, lines, and linear equations.
Represent and analyze quantitative relationships between dependent and independent variables.

CCSS.MATH.CONTENT.7.EE.B.4

Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities.

Use properties of operations to generate equivalent expressions.

CCSS.MATH.CONTENT.6.EE.B.6

Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set.

CCSS.MATH.CONTENT.6.EE.C.9

Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation. For example, in a problem involving motion at constant speed, list and graph ordered pairs of distances and times, and write the equation $d = 65t$ to represent the relationship between distance and time.

CCSS.MATH.CONTENT.8.EE.B.5

Graph proportional relationships, interpreting the unit rate as the slope of the graph. Compare two different proportional relationships represented in different ways. For example, compare a distance-time graph to a distance-time equation to determine which of two moving objects has greater speed.

CCSS.MATH.CONTENT.8.F.B.4

Construct a function to model a linear relationship between two quantities. Determine the rate of change and initial value of the function from a description of a relationship or from two (x, y) values, including reading these from a table or from a graph. Interpret the rate of change and initial value of a linear function in terms of the situation it models, and in terms of its graph or a table of values.

CCSS.MATH.CONTENT.8.F.B.5

Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear). Sketch a graph that exhibits the qualitative features of a function that has been described verbally.

CCSS.MATH.CONTENT.8.F.A.2

Compare properties of two functions each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions). *For example, given a linear function represented by a table of values and a linear function represented by an algebraic expression, determine which function has the greater rate of change.*

CCSS.MATH.CONTENT.8.F.A.3

Interpret the equation $y = mx + b$ as defining a linear function, whose graph is a straight line; give examples of functions that are not linear. *For example, the function* $A = s^2$ *giving the area of a square as a function of its side length is not linear because its graph contains the points (1,1), (2,4) and (3,9), which are not on a straight line.*

Curriculum Unit Title

Arguing with Evidence:
Using Models in the 6th Grade Science Classroom to Investigate Newton's Three Laws of Motion

Author

Terri Eros

KEY LEARNING, ENDURING UNDERSTANDING, ETC.

Motion can be represented in words, pictures, graphs and mathematical equations.
The change in an object's motion depends on the sum of the forces on the object and the mass of the object.
A change in mass creates a change in force.

ESSENTIAL QUESTION(S) for the UNIT

How can constant and changing speed be represented visually?
How can constant and changing speed be represented mathematically?
What is the relationship between the sum of forces and motion?
What is the relationship between mass and force?

CONCEPT A	CONCEPT B	CONCEPT C
Words, pictures, graphs, and equations can serve as models for constant and changing speed	The change in an object's motion depends on the sum of the forces and the mass of the object	A change in mass creates a change in force.
ESSENTIAL QUESTIONS A	**ESSENTIAL QUESTIONS B**	**ESSENTIAL QUESTIONS C**
How can constant and changing speed be represented visually? How can constant and changing speed be represented mathematically?	What is the relationship between the sum of forces and motion?	What effect does mass have on force?
VOCABULARY A	**VOCABULARY B**	**VOCABULARY C**
Speed, acceleration, positive, negative, interval, rate, ratio, constant speed, changing speed, linear, non-linear	Force diagram, vector, gravity, air resistance, friction, elastic force, supportive force	Mass, weight

ADDITIONAL INFORMATION/MATERIAL/TEXT/FILM/RESOURCES

Dot motion cars
Battery powered buggies
Go motion pro camera software
IIHS DVD Understanding Car Crashes-It's basic physics
IIHS DVD Understanding car crashes When physics meets biology
http://files.eric.ed.gov/fulltext/EJ1044004.pdf *Provides a blueprint of a lesson where students develop their understanding of the interrelationship between speed, distance and position. Aligns with NGSS and incorporates technology.*