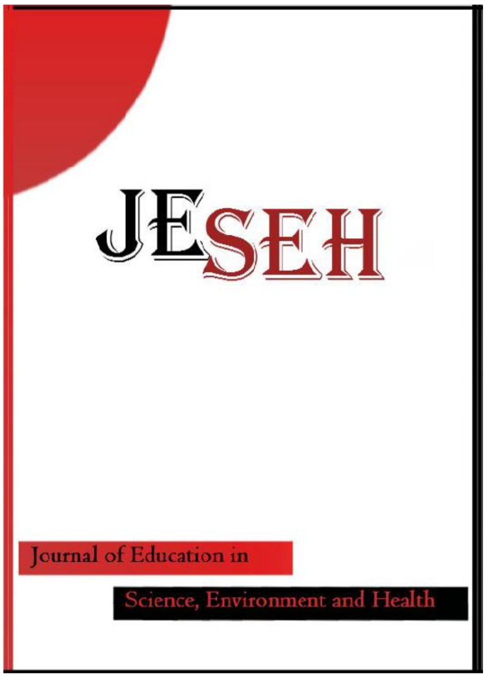


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# Using the Scientific Method to Engage Mathematical Modeling: An Investigation of pi

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## Abstract

The purpose of this paper is to explain how to use the scientific method as the framework to introduce mathematical model. Two interdisciplinary activities, targeted for students in grade 6 or grade 7, are explained to show the application of the scientific method while building a mathematical model to investigate the relationship between the circumferences and the diameter of circular objects. In the first activity, a research question is pursued as it relates to the stated hypothesis. In the second activity, the same research question is retained; however, the use of exploration helps to build the hypothesis. The activities serve as examples to show how middle school math teachers may use scientific inquiry to motive students' understanding of mathematical models as well as engage in science beyond the science classroom. Students will be able to identify, describe, analyze, interpret, validate, and report relationships between variables.

**Key words:** Math modeling, math integration, STEM education, Scientific method, Science education

## Introduction

Mathematics and science integration, as it relates to efficacious outcomes, benefits students (Berlin & White, 1994). In fact, a recent study infusing mathematics into an eighth-grade science curriculum supported the hypothesis that mathematics-infused science significantly impacts mathematics content knowledge, found student-reasoning skills increased for students in the infusion group, and these students "had more practice and were better prepared on a variety of mathematical concepts and scored significantly higher on the NYS eighth-grade mathematics assessment" (Burghardt, Lauckhardt, Kennedy, Hecht, & McHugh, 2015, p. 214). In addition, these researchers found that students in the lowest quartiles on the pretest showed the greatest improvement. Another study found that STEM activities are likely to foster or maintain science dispositions (Christensen, Knezek, & Tyler-Wood, 2015). The need for math and science integration is well established (Berlin & White, 1994). As a result, the need for teachers to have an array of activities to use science disposition in the mathematics classrooms should be encouraged. As they engage in mathematics and science integration, middle school math teachers can use mathematical modeling to motivate students to develop science dispositions.

Conceptual understanding requires a demonstration of how well learners have connected concepts and are able to display dispositions (Bransford, Brown, & Cocking 2000). Therefore, it may be argued that students need a curriculum with less emphasis only on skills building. Theorists posit that skills building (habituation), learning as conceptual (construction), and learning as social (enculturation)—each promoting understanding—should be balanced in the math curriculum and engaged with carefully and separately (Kirshner 2004). The opportunity to engage students in math modeling allows for increased conceptual understanding. The use of the scientific method while implementing mathematical models among middle school students provides an opportunity to engage in science dispositions.

The Council of Chief State School Officers (CCCSO) and the National Governors Association Center for Best Practices (NGA Center) suggest that, in the United States, school age children should use mathematical modeling. As a result, the Common Core State Standards for Mathematics (CCSSM), published by the CCCSO articulates mathematical modeling. These standards provide guidelines for what students should understand and be able to do (CCCSO & NGA Center, 2010), and they situate students at the intersection of conceptual understanding and content mastery (Conley & Gaston, 2013). The intent of the Standard of Mathematical

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Practice 4 (MP4): Model with Mathematics is to encourage teachers to engage students with modeling, which in turn, should increase their understanding of mathematical concepts while engaged with enriching experiences.

## Mathematical modeling

The Standard of Mathematical Practice 4 (MP4): Model with Mathematics suggests that teachers encourage their students to build models that link classroom mathematics and statistics to everyday life, work, and decision-making. According to the standard, modeling includes (a) identifying variables in the situation and selecting those that represent essential features, (b) formulating models that describe relationships between the variables, (c) analyzing and performing operations on these relationships, (d) interpreting the results, (e) validating the conclusions, and (f) reporting on the conclusions and the reasoning (CCCSO & NGA Center, 2010).

Questions, however, are raised about the successful implementation of the standard. For instance, how do teachers lead students in their ability to describe how one quantity depends on another and to apply what they know to simplify a complicated situation? How do teachers get students to identify important quantities and map their relationships using tools, and mathematically analyze these relationships to draw conclusions? How do students interpret their mathematical results in the context of a situation and reflect on whether the results make sense? How best do teachers assess knowledge? How do teachers afford students the opportunity to meet and exceed MP4?

Teachers need to know that the CCSSM does not provide a prescriptive approach to the question: How best should math teachers engage students in modeling? However, teachers need the confidence to know that implementing these standards provide learning opportunities and classroom benefits. Therefore, we propose that the scientific method affords not only an option as an overarching approach to assist teachers with the implementation of mathematical model but also provides learning opportunities.

## Scientific Method

According to The National Research Council (NRC), students should develop an understanding of science in order to engage the world in which they live. Furthermore, they reiterate that “students need to understand what is meant….by observation, a hypothesis, an inference, a model, a theory, or a claim and be able to distinguish among them” (NRC, 2012, p. 79). As a result, students experience the foundation of scientific inquiry. With this in mind, science standards for states around the country have all included scientific inquiry as a mandatory part of science courses in schools. Although the newest version of the recommended science standards do not include the scientific method as a standard, the focus on its incorporation as the underpinning in science investigations of every concept suggests the importance of the use of scientific method as early as elementary school (Achieve, 2013). Scientific inquiry is a process in which students, guided by their teacher, attempt to discover the answer to a question or problem (Gormally, Brickman, Hallar, & Armstrong, 2009). Scientific inquiry is important because it teaches students how to explore their environment in a logical manner. Science inquiry involves all students actively learning by answering questions through data collection and analysis (Bell, Smetana, & Mills, 2005).

Science teachers have the responsibility for teaching the process of science as well as the science content but invariably spend most of their time in the classroom teaching content (Stiles, 1942; D’Costa & Schlueter, 2013). Science teachers know that science inquiry is important but do not have the confidence or knowledge to go beyond the cookie cutter labs and therefore identify these labs as inquiry when they are not (Bell, Smetana, & Mills, 2005). An excellent way to motivate students is to present them with a problem or question to solve (Prince & Felder, 2007). D’Costa and Schlueter (2013) and Gormally, et al. (2009) report that while students find scientific inquiry more challenging than the traditional method of learning science by taking notes, students admit that they learn more and had a more rewarding experience. D’Costa and Schlueter (2013) and Gormally, et al. (2009) argue that science teachers need to teach students these science-processing skills, which allow students to ask questions, formulate hypotheses, test these hypotheses and arrive at answers to their questions. Students can then apply these skills to other aspects of their lives outside of the science classrooms.

The scientific method provides an accessible approach to inquiry that presents an effective and convenient way that allows students to experience the process of science (Blystone & Blodgett, 2006). The scientific method involves a series of steps, namely, observation, question, hypothesis, materials, procedure, data collection, data analysis and conclusion (Blystone & Blodgett, 2006; Palmer & Mahan, 2013). However, the danger in teaching the scientific method is that students may believe it just involves these simple steps (Lederman, et al., 2014; McPherson, 2001). While no specific set of steps could possibly consider all of the strategies a researcher may use to answer a question and to understand the world, the steps of the scientific method is a good approximation to use (Blystone & Blodgett, 2006; Guy, 2001). Many students reach the college level knowing how to recite the different steps of the scientific method but fail to understand the process, e.g., the use of variables (D'Costa & Schlueter, 2013). Therefore, it is important that science teachers scaffold the various steps of the scientific method to allow students to learn the stages without becoming frustrated and giving up due to perceived failure and just being content to learn the steps by rote without understanding (D'Costa & Schlueter, 2013).

## Connecting Math and Science

Measurement is a concept common to math and science as seen in both sets of standards (Achieve, 2013; CCCS, 2010; NRC, 2012). Therefore, measurement is a good topic to use to integrate math and science in the classroom (Hurley & Normandia, 2005). Exposing students to the role of math and science as an integrated unit is important (Arnett & Van Horn, 2009). Such integration is necessary for an increase in knowledge acquisition and application (Cawley & Foley, 2002; Weinburgh & Silva, 2011). Furthermore, Arnett and Van Horn (2009) report that students appreciate learning math in the context of science. Activities that integrate math and science help students to practice skills such as hypothesize, measure, collect and analyze data, form discussions and conclusions (Schlenker & Schlenker, 2002).

## Activity – Investigating pi using the Scientific Method

These activities outlined here offer two possible uses of scientific inquiry as it relates to one research question. The research question remains the same; however, the variation occurs with a hypothesis that is stated or not stated. First, we introduce the activity with the stated hypothesis and then we show the activity without a stated hypothesis. In the first activity, students experience the step by step approach of the scientific method, whereas in the second activity students are exposed to scientific inquiry without the guidance of a hypothesis. This removal of the hypothesis introduces students to the idea that scientific inquiry does not need to follow a prescribed set of steps (Lederman, et al., 2014).

In these activities, students receive guidance through the steps of the scientific method in order to investigate the relationship of the circumference to the diameter of circular objects. The steps used in these activities are questioning, researching, hypothesizing (in first activity), data collecting and analyzing, discussing and concluding. These activities offer two possible uses of scientific inquiry as it relates to one research question. The research question remains the same; however, the variation occurs with a hypothesis that is stated or not stated.

### Hypothesis Stated

Question: What is the relationship between the circumference and the diameter of a circular object?
Research: Students research the meaning of the words circumference, diameter and how these terms are related. Students discover that the relationship of the circumference of a circular object to its diameter is the constant pi.

Hypothesis: If the circumference of circular objects is measured then the diameter of those objects will have a relationship to their circumferences that is constant. Here, the teacher may take the opportunity to scaffold or guide students to arrive at a particular hypothesis. The teacher uses deductive language in guiding students to formulate the hypothesis. Materials are then selected for activities to test the hypothesis.

Materials: For illustrative purposes we used the following materials:
- a penny, hula hoop, plate, cd, cookie
- tape measure or string and ruler
- pencil
- paper
- Table for data collection and calculation (see Table 1)
  (A spreadsheet coded incorporates an opportunity for integrating technology)

Procedure: First, measure the circumference and diameters of the circular objects. Next, enter the measurements on the data table. Then complete calculations which includes finding the ratio of the average circumference to its respective average diameter.

Data: We conducted three trials in the measurement of the circumference and diameter for each object, then found the average so as to arrive at a measurement that is as accurate as possible (see Table 1). This may stimulate some discussion about measurement, accuracy and the purpose for central tendency.

Table 1. Data collected and compiled

| Object | Circumference | | | | Diameter | | | | Ratio |
|---|---|---|---|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Mean | Trial 1 | Trial 2 | Trial 3 | Mean | |
| Penny | 5.8 | 6.1 | 6.3 | 6.07 | 1.8 | 2.1 | 1.9 | 1.93 | 3.1379 |
| Hoop | 222.2 | 221.8 | 222.6 | 222.20 | 71.5 | 71.8 | 71.4 | 71.57 | 3.1048 |
| Plate | 79.0 | 78.8 | 78.7 | 78.83 | 25 | 24.6 | 24.9 | 24.83 | 3.1745 |
| Cd | 38.0 | 37.6 | 38.3 | 37.97 | 11.9 | 11.6 | 12.2 | 11.90 | 3.1905 |
| Cookie | 14.5 | 14.3 | 14.3 | 14.37 | 4.6 | 4.6 | 4.7 | 4.63 | 3.1007 |
| | | | | | | | | Mean | 3.1417 |

Analysis of data: For each of the circular objects, three measurements were taken and computation of the ratio of the circumference to its diameter revealed a range of approximate measures from 3.1007 to 3.1905 with an average of 3.1417, an approximation of the value of the constant pi. In science experiments, error is calculated to ascertain the precision of calculations so as to the lessen limitations of the experiment. We calculated an error of 0.0001. [Error = experimental value – theoretical value]. The percentage error is 0.0032%. [Percentage error = (error / theoretical value) x 100].

Conclusion of experiment: The hypothesis states if the circumference of circular objects is measured then the diameter of those objects will have a relationship to their circumferences that is constant. Since the relationship of circumference to diameter of all of the circular objects had an average constant of 3.1417, the hypothesis is not rejected. Therefore, the relationship of the circumference to the diameter of a circular object is constant. We discussed the limitations of the experiment. The limitations of this investigation include inaccuracy of measurements of the circumferences and diameters of the circular objects as indicated by the percentage error.

**Hypothesis Non-stated**

The variation of our experiment using the non-stated hypothesis affords students a shift from thinking that a hypothesis should always be constructed (McPherson, 2001; Lederman, et al., 2014). Non-stated hypotheses disabuse students of this notion and encourages exploration. Students are able to use the scientific inquiry, but come to the realization that engaging in exploration and pattern seeking motivates the formulation of hypotheses. The scientific inquiry may or may not utilize a hypothesis (McPherson, 2001). Here, students state their research questions, but explore explanations that lead to the construction of a hypothesis. We use the activity above as a framework to demonstrate the use of the non-stated hypothesis in scientific inquiry.

Question: What is the relationship between the circumference and the diameter of a circular object?

Research: Students research the meaning of the words circumference then discuss possible ways that mathematics may be used to find the relationship between the circumference and the diameter. The teacher could use discussion to encourage the use of addition, subtraction, multiplication, and division.

Materials: We used the same objects for illustrative purposes.

Procedure: We followed the procedure from Activity 1.

Data: Since they afford the most accurate measurements, we used the average measurements from the first activity.

Analysis of data: We made the following observation. For each object, an exploration to detect patterns in the results for each computation of addition, subtraction, multiplication, and division reveal differences (see Table 2). From the results, the additive and subtractive magnitudes reveal no immediate discernible patterns. However, the ratios suggest a consistency. The use of central tendency (the mean) for these ratios shows an approximation to three decimal places of 3.144 and 0.317 respectively. We used the first approximation and calculated an error of 0.003. [Error = experimental value – theoretical value]. The percentage error is 0.076%. [Percentage error = (error / theoretical value) x 100].

Table 2. Data used to compute the mathematical operations

| Object | Circumference + Diameter | Circumference - Diameter | Diameter - Circumference | Circumference / Diameter | Diameter / Circumference |
|---|---|---|---|---|---|
| Penny | 8.00 | 4.14 | -4.14 | 3.145 | 0.318 |
| Hoola hoop | 293.77 | 150.63 | -150.63 | 3.105 | 0.322 |
| Plate | 103.66 | 54.00 | -54.00 | 3.174 | 0.315 |
| Cd | 49.87 | 26.07 | -26.07 | 3.191 | 0.313 |
| Cookie | 19.00 | 9.74 | -9.74 | 3.104 | 0.320 |
| | | | Mean | 3.144 | 0.318 |

Conclusion of experiment: The research question pursued was to investigate the relationship between the circumference and diameter of circular objects. While there was no stated hypothesis, four basic mathematical operations of addition, subtraction, multiplication, and division were invoked as points of departure for exploration. We found that the ratio of the circumference to the diameter and its inverse afforded a detection of the simplest pattern. Armed with these results, it was concluded that circular objects share a common relationship grounded in their ratio, and this ratio is found between each object's circumference and diameter. The discussion about the implications were similar to the first activity.

## Discussion and Conclusion

Our activities serve as examples for teachers to interweave notions of scientific inquiry while engaging students in math modeling. Such integration reinforces concepts, clears up misconceptions, and increases the ability to apply concepts in real life situations. In these two activities, teachers scaffold the scientific method to motivate middle school math students to grasp notions of mathematical modeling. Ernest (2002) posited that learners need confidence—mathematical empowerment in their knowledge and skills; confidence in their ability to engage in routine and non-routine tasks; confidence in their ability to understand new and taken as shared mathematical ideas and concepts; a sense of mathematical self-efficacy; and to have a sense of personal ownership and creative approaches to mathematics. Mathematical empowerment fits into the expectations of mathematical modeling.

As an extension, students can look for patterns. Students can be challenged to transfer this knowledge into real life situations. For example, they can be asked to design a wheel for a given diameter and confidently predict that the circumference will be a little over three times that of the diameter. Students can be asked to examine various bicycle tires.

The goals of mathematics and science inquiry driven by the scientific method, as outlined above, coincide with problem solving and pattern recognition. Since students experience math rife with computation, students conclude that mathematics does not involve exploration and investigation. For many students, integrating math and science is a novel way to think in the mathematics classroom. In the experiments above, students see how mathematical and scientific knowledge integrate to investigate and answer questions. The students get to see mathematics in action, rather than in the usual abstract manner. Computations come with exploration and thinking.

Mathematicians use a method of inquiry when problem solving; therefore, mathematics activities align with the scientific method. Mathematicians and scientists solve problems, with and without hypothesis in their search for answers. With some guidance from the teacher, students experience constructing hypothesis, gathering and analyzing data, then formulating conclusions and engaging in discussions to explore a mathematical phenomenon, namely pi. Scientific investigation coupled with mathematical modeling provide opportunities for students to build intellectual dispositions. Scientists use mathematics and mathematicians engage science. Mathematical modeling affords space for science and mathematics to integrate conceptual knowledge building.

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