Is Edgar Allan Poe Really a Mathematician?

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Abstract

In the following article, the authors discuss work associated with The Pit and the Pendulum, a three-week project-based learning unit. Inspired by Edgar Allan Poe's story of the same name, the project encourages students to connect their knowledge of trigonometry, physics, and language arts as they analyze Poe's classic work. In particular, students use clues from Poe's written descriptions to determine whether the prisoner in "The Pit and the Pendulum" has time to escape.

Keywords: dynamic geometry software, project-based learning, inquiry, secondary-level mathematics

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The adoption of the Common Core State Standards for Mathematics (Common Core State Standards Initiative and others, 2010) has precipitated a shift in the teaching and learning of mathematics in classrooms throughout the country (National Council of Teachers of Mathematics, 2010). In particular, the Common Core's emphasis on deep learning and application has brought into question the "one day, one topic" lesson plan model that has long been a fixture in school classrooms. Recognizing this new reality, the authors of this paper have shifted their instructional methods from a standard "lecture-homework-lecture" model to one that more fully engages small teams of students in project-based learning activities. Using the project-based learning (PBL) framework (Hallerman & Larmer, 2013), our instructional team has constructed a number of projects that require students to connect their knowledge of mathematics to other content areas as they solve meaningful questions in context.

In the paragraphs that follow, we highlight our work on one such project, a three-week project-based unit we refer to as The Pit and the Pendulum. Based on Edgar Allan Poe's story of the same name (Poe, 1843), the project encourages students to apply their knowledge of trigonometry, physics, and language arts as they analyze Poe's classic work. In particular, students use clues from Poe's written descriptions to determine whether the prisoner in "The Pit and the Pendulum" has time to escape. We describe the project in three sections. First, we share instructional details of the unit itself including sequencing, pacing, the use of technological tools, and samples of student work. Next, we describe steps that we took to address the needs of all learners, including those with individual education plans (IEP), as we highlight specific differentiation strategies employed at various stages within the project. Lastly, we assess the effectiveness of the project, providing revision ideas and further areas of possible investigation. For this project, our mathematics instructional team consisted of four educators: Judy, a mathematics teacher who taught an Algebra III/Trigonometry class; Jennifer, an Intervention Specialist who worked with several students in Judy's class; and Tamra and Todd, both mathematics education professors at local universities at the time of writing.

1. Instructional details

1.1. Phase 1: Project launch

We introduce students to the project with a YouTube video of Poe's *The Pit and the Pendulum* (Corman, 1961). Our students sit on the edge of their seats as narrator Vincent

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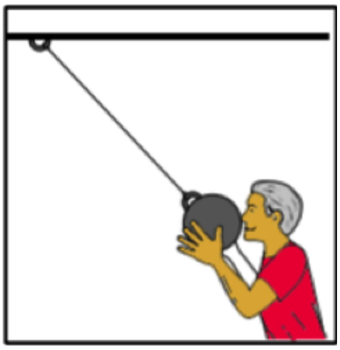

Figure 1: Bocce ball pendulum suspended from classroom ceiling

Price describes the lowering of a sharp pendulum, swinging and slowly descending toward a prisoner tied down to a platform. As the torture device begins to slice the flesh of the victim, we stop the movie abruptly. Not surprisingly, this frustrates students. *Aw! Mrs. Brown, why did you stop the movie? Does the prisoner die? Does he escape?* Reviewing the clip is a natural transition into the driving questions, which are "Does the prisoner really have time to escape?" and "Is Edgar Allan Poe really a mathematician?" based on the information given in the short story. Poe's writing provides us with clues regarding both questions. Using mathematics, physics, and careful analysis of Poe's text, students have all the tools they need to answer the questions posed above.

1.2. Phase 2: Exploring a model

Following a careful viewing of the film excerpt, students explore the plausibility of Poe's text using a pendulum we construct with fishing wire and a bocce ball suspended from the classroom ceiling. Students begin their analysis by observing a pendulum released from the tip of a volunteer's nose, as shown in figure 1.

Measuring the period

As the pendulum swings back and forth, some students are surprised (and relieved) to observe that the bocce ball never swings beyond the ball's original position. In other words, no noses are harmed in the demonstration. This initial exploration provides students with opportunities to discuss period, the time it takes for the ball to complete one full cycle away from the participant's nose and back again. Classmates record one period of the pendulum with a stopwatch as the pendulum completes one cycle.

Discussion points

The pendulum demonstration motivates student discussion on a variety of topics suitable for students with a wide range of ability levels, such as:

- *Potential and kinetic energy.* At what point (or points) does the pendulum possess potential energy? At what point (or points) does the pendulum exhibit kinetic energy? (Suitable for Algebra I students)
- *Period.* How is the period of the pendulum affected by the height at which it is released? (Suitable for Algebra II students)
- *Speed.* Is the speed of the pendulum constant? If not, when are minimum and maximum speeds achieved? Will the pendulum eventually stop? If so, why? If not, why not? (Suitable for Algebra III/Trigonometry students)
- *Acceleration.* Is the acceleration of the pendulum constant? If not, when are minimum and maximum acceleration achieved? (Suitable for Calculus students)

1.3. Phase 3: Student-constructed models

Position and velocity graphs

On the following day, students anchor weights to a string to make their own pendulums. In small groups, they release the pendulums from ring stands and use motion detectors and graphing calculators to graph the following with respect to time: (a) the position of the pendulums; and (b) the velocity of the pendulums. These graphs are used to explore conjectures from the previous day's activities. Figure 2 illustrates two such graphs generated by students.

Analysis of position and velocity graphs generates lively discussion among our students. Some indicate that the graphs look quite similar (e.g.,

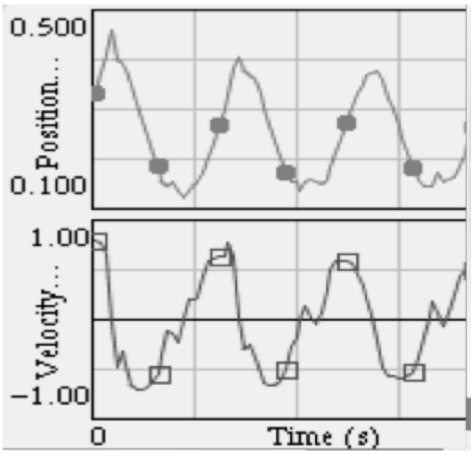

Figure 2: Top: position with respect to time, Bottom: velocity with respect to time (generated by a TI-Nspire CAS graphing calculator connected to a Vernier Motion Detector)

both "go up and down like a roller coaster"). Others notice some damping in the graphs (e.g., "the highest and lowest positions get closer to zero with each cycle"). Yet others focus on differences between the graphs (e.g., the times at which maxima and minima occur are not the same in the two graphs).

Geometric models

Using Geometer's Sketchpad (Jackiw, 2014) to model the motion of the pendulum allows the students to make further mathematical connections. In the construction illustrated in figure 3, from the activity A Sine Wave Tracer (Bennett, 2002) the student can drag point D right or left using Geometer's Sketchpad and see that point F moves horizontally across the sketch as well. As point E moves around the circle, point F moves up and down like a sewing machine needle. Starting with point D to the right of the circle and combining these two motions creates a sine curve, a periodic function that models the motion of the pendulum. The right semicircle represents the pendulum on its side, and as F moves up and down, it represents the period of the pendulum, which traces the diameter of the circle.

Adding the coordinate grid behind the sketch with the origin at the center of the circle allows students to estimate the circumference of the circle in grid units. Counting the horizontal distance of the curve and dividing by the radius, students estimate that the circumference of the unit circle is about 6.28, a close approximation for 2π.

Figure 3: Model of pendulum movement with Geometer's Sketchpad

1.4. Phase 4: Building arguments

Story Synopsis

The next few days in mathematics class were spent using the story to organize the information pertinent to answer the driving question, "Does the prisoner really have time to escape?" The prisoner tells us, "Looking upward, I surveyed the ceiling of my prison. It was some 30 or 40 feet overhead" (Poe, 1843, p. 12). He said the blade of the pendulum swung above him for what seemed like hours until it was 3 inches above his chest. "I saw that some ten or twelve vibrations would bring the steel in actual contact with my robe" (Poe, 1843, p. 15). He rubbed food from a nearby bowl onto the ropes that tied his hands down. He thought that the swarming rats could chew through the ropes to free him. "Yet one minute and I felt the struggle would be over" (Poe, 1843, p. 17). Perhaps it was one and a half minutes because he had been swooning in and out of consciousness.

> Twice again it swung, and a sharp sense of pain shot through every nerve. But the moment of escape had arrived. At a wave of my hand my deliverers hurried tumultuously away. With a steady movement—cautious, sidelong, shrinking, and slow—I slid from the embrace of the bandage and beyond the reach

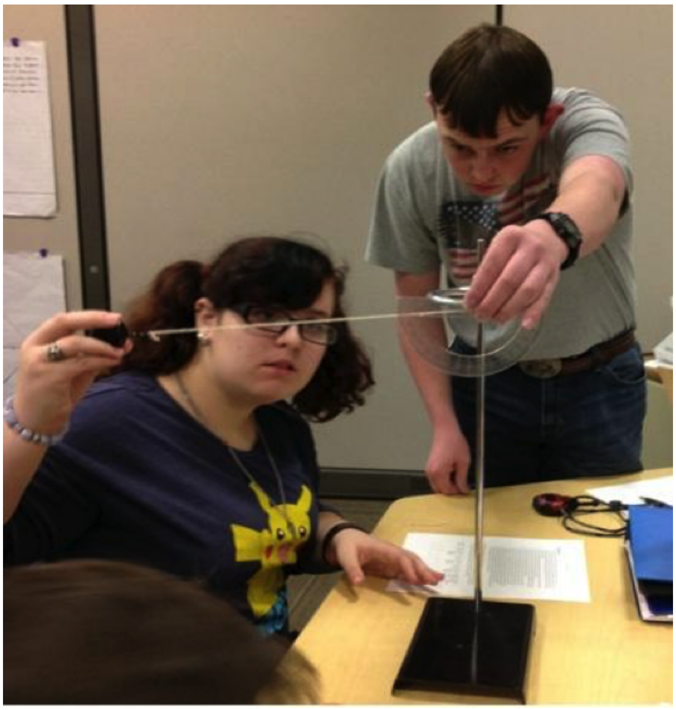

Figure 4: Students testing one of the three variables

> of the scimitar. For the moment at least, I was free. (Poe, 1843, p. 17)

The plan worked! This is how the story goes, but is it actually possible? The students realized that they needed to find a formula to be able to calculate the period of the pendulum and determine if 10-12 swings of 30-40 feet of rope would take between 1 and $1\frac{1}{2}$ minutes, which is the time the prisoner estimated for the rats to free him.

The students realized they needed to investigate the parts of the pendulum that may affect the period in order to model a relationship between that factor and the period. Students were divided into six groups, each of which constructed pendulums using ring stands, strings, and weights borrowed from the physics classroom (see figure 4). They tested three variables: amplitude (angle of release), the length of the string, and the weight of the bob. Each variable was explored by two of the six groups. Upon completion, the groups reported that, in their experiments, of the three factors that were tested, only the length of the string affected the period of the pendulum.

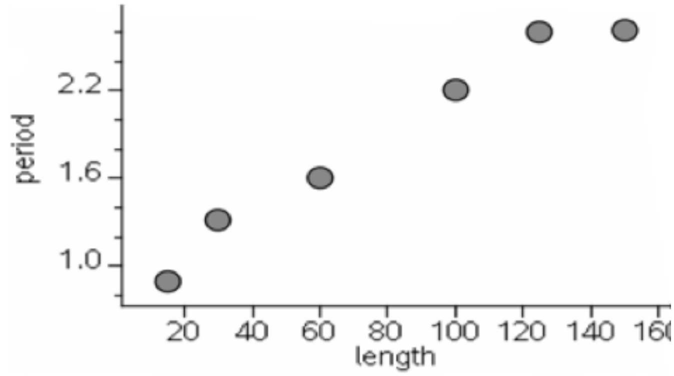

Figure 5: Scatterplot of period with respect to the pendulum length using the TI-Nspire CAS graphing calculator

The following day each group took a different string length: 15 cm, 30 cm, 60 cm, 100 cm, 125 cm, and 150 cm, and used the procedure from the previous days to find the period of the pendulum. The class created a scatterplot to illustrate their data, with the period on the x-axis, and the string length on the y-axis.

The graph suggested a quadratic relationship $L = g\left(\frac{T}{2\pi}\right)^2$, where L is the length of the string, T is the time of the period in seconds, and g is acceleration due to gravity (which in our problem we approximated as 32.2 ft/s^2). Figure 5 illustrates the graph of the inverse function, with length on the x-axis and period on the y-axis, yielding a square root function

$$T = 2\pi\sqrt{\frac{L}{g}}.$$

Techniques from calculus are required to derive the formula for the period of the pendulum, but from previous activities the students understood where the parts of the period of the pendulum equation came from.

Students used the formula to generate a prediction for the period of the pendulum for the rope lengths, as shown in the leftmost column of the table in figure 6. They multiplied by 10 and 12 to get the second and third columns of the table. The students spent a day working in their groups to analyze the table and answer the driving ques-

Time -1 period	Time- 10 periods	Time- 12 periods	Length (ft)
7,00	70.0	84	40
6.55	65.5	78.6	35
6.06	60.6	72.72	30
5.54	55.4	66.48	25
4.95	49.5	59.4	20
4.29	42.9	51.48	15
3.50	35.0	42	10
2.48	24.8	29.76	5

Does the prisoner in "The Pit and the Pendulum" have time to escape? Given his assumptions, are there times when he will be able to escape and other times when he will not? Is Edgar Allen Poe really a mathematician? Based on the information extracted from the story (look for details) if he does escape, when do you think that happens? In other words, which assumptions are true? Brainstorm here. Use charts, tables, graphs, etc.

4 out of 8 times.
He could be a mathematician.
He escapes by the skin of his teeth (orchest really)
It was likely 10 periods, 30 ft and close.

Figure 6: Poe worksheet with student work

The prisoner does have time to escape.
If the pendulum hits him at exactly 60 sec
he's a goner. If the length is under 30
he can escape, if it is at a 1.5 minutes he can
escape with 30-40 ft but if it is a minute he will
not escape between those two lengths.

Figure 7: Student response to the driving question

tions. This analysis was not as straightforward and readily apparent as we expected, as shown in the student work.

An Aha! Moment

Table 1 uses the time for one period of the pendulum to calculate the time for 10 and 12 swings at 30 and 40 feet only. Initially, we saw the story like this:

40 ft	30 ft
Min: 10(7.0) = 70 sec Max: 12(7.0) = 84 sec	Min: 10(6.06) = 60.6 sec Max: 12(6.06) = 72.72 sec

Table 1: Initial period calculations

This answer seemed very clear cut. The prisoner has time to escape if the rats chew though in 60 seconds, but does not have time to escape if the rats chew through in 90 seconds.

Tamra brought a mathematics teacher candidate with her. The candidate was present during the pendulum investigation and in his solution table, he investigated the lengths of the rope in 5 feet increments between 30 and 40 feet rather than just the minimum and maximum ends of the spectrum. Each of the student groups used time frames of 60 seconds (1 min) and 90 seconds (1.5 min), excluding the times in between. The answer actually depended upon all of these factors: length of the rope, number of swing cycles remaining, and time for the rats to chew through the rope. Since all of these factors vary within the story, the students' solutions did as well. As the calculations in table 1 suggest, when the rope is 40 feet long and has 10 swings left, the prisoner will be cut at 70 seconds. So, if the rats chew through in 60 seconds the prisoner will escape with 10 seconds to spare; but if the rats do not chew through until 90 seconds, then he would have been sliced through 20 seconds earlier and would not have escaped. The work suggests that there was no unique correct answer to this question.

Even with this variation, the general consensus was that at some point in the given framework the prisoner would have had time to escape: Edgar Allan Poe was a mathematician after all!

Student Work Samples

Student work in figure 7 suggests that the students have it backwards. Can your students identify why this is not a correct solution and what the students were thinking?

In fact, there isn't a single correct solution, but the entire project is full of mathematics and lends itself to further instruction. In Advanced Pre-Calculus, we continued to study distance, velocity, and acceleration problems, finding the graphs and the equations, which led into a study of derivatives and integrals and how they relate to these problems. Some of these students also took Physics, which the lead teacher and student candidate visited, and they were studying the pendulum and simple harmonic motion as well and making connections between the topics being studied in the two classes. One student commented, "This is magical!" after another student elaborated on the connected concepts.

1.5. Phase 5: Foucault pendulum

The culminating piece of the project was a field trip to a local university that houses a Foucault pendulum. We timed the period and determined the length of the rope without direct measurement and discussed our findings with a physics professor who demonstrated simple harmonic motion to small groups of our students. Our students were surprised when the professor noted that he often forgets if gravity is divided by the length or length is divided by gravity in the period equation. He reminded us that much of what we study is logical and related to prior knowledge so that memorization isn't necessary. If students recall that the length of the period increases as the length of the rope increases, a result that was previously observed through experimentation, they can reason that the length must be in the numerator of the equation with gravity in the denominator. He also asked if we took into account the rate at which the pendulum was descending in the story. He thought it could be calculated from the information given. Based on this comment, the students realized that their project could be further explored. In science, initial findings lead to new questions in a never-ending cycle of inquiry.

2. Differentiation/Intervention

The main strategy for differentiating instruction is to address it in the planning process. We planned the project together over a series of about four meetings, each approximately two hours in length. We started with the overall learning targets, broke down the strategies needed to attain the targets, and planned activities to lead the students to answer the essential question. As the math teachers discussed ideas gained from previous pendulum explorations, the intervention specialist asked clarifying questions, identified areas of possible struggle, and suggested ideas for scaffolding instruction. For example, the cumbersome computations and mathematical processes on the worksheets were broken into simpler steps using the row headings, such as "divide row C by 10," to find the average of the period. An example of cross-curricular modification happened in the English classes. The students on individualized education plans were given copies of the story with important information underlined, and had to explain why it was important. The other students had to extract the important information from the unmarked story.

Additionally, we practiced the activities as a group, placing ourselves in the roles of the students, following the directions to perform the experiments, use the technology, and complete the investigations. This helped alleviate confusion for the students, and made their work time more seamless and productive. Involving teachers with different perspectives enhanced the quality of the unit.

Finally, it was beneficial for the teachers to support one another by team-teaching the lesson. Judy, the classroom teacher, lead the instruction and Jennifer, the intervention specialist, was present in the classroom throughout the project. On the days of experimentation, Tamra and Todd attended as well and worked with small groups of students, asked necessary questions, and alerted the lead teacher when students were confused so necessary alterations could be made.

3. Assessment of Lesson

Continuous informal assessment occurred throughout the lesson. The teacher asked questions, making note of student responses. As the students showed understanding, the lesson continued. When the students were not able to respond correctly, adjustments were made in the lesson to clarify concepts. The presence of multiple teachers made it easier for the needed changes to occur. For instance, when the scientific concepts of the pendulum were introduced, we decided the students needed to time the period several times in order to understand the concept of an unchanging period. This allowed the students to experience the idea of measuring a period, therefore clearly defining it. We also noticed during the lesson that the students would need to understand the concept of the unchanging period to have a better understanding in future activities.

More formal assessment occurred using the graphs the students created and the worksheets they completed. Again, the teacher graded their work immediately in order to give feedback to the students before moving forward to ensure the concepts were understood and prior knowledge was properly utilized.

4. Acknowledgments

The authors would like to acknowledge the teachers, Jackie Harris (English), Jenn Reid (English) and Hope Strickland (Physics) of the Dayton Regional STEM School, Dr. Todd Smith, Associate Professor of Physics at the University of Dayton, and the secondary mathematics teacher candidate Cody Brannum of Central State University for their contributions to this project.

Author Note: All worksheets for this project-lesson are found at the end of the article.

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Appendix A
Pendulum Unit: Amplitude

1. The variable to test is the amplitude or angle of release. You want to determine if changing the angle of release of the pendulum changes the time for the period of the pendulum. That means the length of the string and the weight of the bob or bob type must be controlled but the amplitude or angle of release will vary.

2. Choose the length of string and keep it the same for all three trials. This does not need to be measured, just keep it the same each time.

3. Choose the bob. This does not need to be weighed, just keep using the same one for each trial.

4. Tie the string to a T-stand. Tie the bob to the end of the string. This will be the same for each trial. Release the bob from an angle of chosen degrees and record it in the first column of the table below. This will change for each trial. Release the bob and time the periods of the pendulum for 10 full swings. Record that in the table below. Then divide that number by 10 to get the average time for 1 period of the pendulum at that angle. Do three trials and divide the total time by 3 to get the average in the final row of the table.

5. Change the angle of release and record the angle used in the second column of the table and repeat step 4 above. Complete the second column of the table.

6. Choose a third and final angle of release that is different from the two already tried and complete the third column of the table below.

Note: You don't necessarily need to measure the angle of release. You could just mark three separate angles on a protractor as a, b, and c, and release the bob from those points each time to keep this variable controlled. Whether or not it affects the period is what is important. If the times change as the angle of release changes then you will know amplitude has an effect on the period of the pendulum.

		Angle of release		
A	Trial 1: 10 periods in seconds			
B	Trial 1: 1 period in seconds (divide row A by 10)			
C	Trial 2: 10 periods in seconds			
D	Trial 2: 1 period in seconds (divide row C by 10)			
E	Trial 3: 10 periods in seconds			
F	Trial 3: 1 period in seconds (divide row E by 10)			
G	Total time for all three trials of the pendulum (add rows B, D, and F)			
	Average time for three trials of the period of the pendulum (divide row G by 3)			

Pendulum Unit: Length of the string

1. The variable to test is the length of the string. You want to determine if changing the length of the string changes the time for the period of the pendulum. That means the weight of the bob or bob type and the angle of release must be controlled but the length of the string will vary.

2. Choose the bob and keep it the same for all trials. This does not need to be weighed, just keep it the same each time.

3. Choose the angle of release. It doesn't matter what the measure of the angle is. What matters is that the angle of release stays the same for each trial and does not change. So once you choose an angle, keep using the same one for each trial. You could just use halfway between 0° and 90°.

4. Tie one unit of string to a T stand. This can be one foot or 20 centimeters or whatever you choose. Record this length in the first column of the table below.

5. Release the bob from the chosen angle, and time the periods of the pendulum for 10 full swings. Record that in the table below. Then divide that number by 10 to get the average time for 1 period of the pendulum at that angle. Do three trials and divide the total time by 3 to get the average in the final row of the table.

6. Change the length of the string by making it longer or shorter and record that in the second column and repeat step 5 above. Complete the second column of the table.

7. Choose a third and final string length that is different from the two already tried and complete the third column of the table below.

Note: You don't necessarily need to measure the length of the string. You could just mark three separate lengths as a, b, and c or double and triple the length of a to get b and c. Whether or not it affects the period is what is important. If the times change as the length of the string changes then you will know that string length has an effect on the period of the pendulum.

		Length of string		
A	Trial 1: 10 periods in seconds			
B	Trial 1: 1 period in seconds (divide row A by 10)			
C	Trial 2: 10 periods in seconds			
D	Trial 2: 1 period in seconds (divide row C by 10)			
E	Trial 3: 10 periods in seconds			
F	Trial 3: 1 period in seconds (divide row E by 10)			
G	Total time for all three trials of the pendulum (add rows B, D, and F)			
	Average time for three trials of the period of the pendulum (divide row G by 3)			

Pendulum Unit: Weight of the bob (bob type)

1. The variable to test is the bob. You want to determine if changing the weight or type of bob changes the time for the period of the pendulum. That means the length of the string and the angle of release must be controlled but the bob weight and type will vary.

2. Choose the length of the string and keep it the same for all trials. This does not need to be measured, just keep it the same each time.

3. Choose the amplitude (or angle of release). It doesn't matter what the measure of the angle is. What matters is that the angle of release stays the same for each trial and does not change. So once you choose an angle, keep using the same one for each trial. You could just use halfway between 0° and 90°.

4. Tie string to a T stand. Tie one bob to other end of the string. You can choose from washers, ping-pong balls, quarters, tennis balls, etc. These will change for each trial since this is the test variable. Record the bob type in the first column of the table.

5. Release the bob from an angle of chosen degrees. Release the bob and time the periods of the pendulum for 10 full swings. Record that in the table below. Then divide that number by 10 to get the average time for 1 period of the pendulum at that angle. Do three trials and divide the total time by 3 to get the average in the final row of the table.

6. Change the bob at the end of the string and record the type used in the second column below and repeat step 6 above. Complete the second column of the table.

7. Choose a third and final bob that is different from the two already tried and complete the third column of the table.

Note: You don't necessarily need to measure the weight of the bob. You could just use three different materials that seem to be lighter or heavier than each other. Whether or not it affects the period is what is important. If the times change as the weight or type of bob changes then you will know that the bob has an effect on the period of the pendulum.

		Bob type or weight		
A	Trial 1: 10 periods in seconds			
B	Trial 1: 1 period in seconds (divide row A by 10)			
C	Trial 2: 10 periods in seconds			
D	Trial 2: 1 period in seconds (divide row C by 10)			
E	Trial 3: 10 periods in seconds			
F	Trial 3: 1 period in seconds (divide row E by 10)			
G	Total time for all three trials of the pendulum (add rows B, D, and F)			
	Average time for three trials of the period of the pendulum (divide row G by 3)			

Pendulum Unit: The period of the pendulum

Now that we know that the length of the string is the variable that affects the period of the pendulum, we can make a graph to see the pattern in these two relationships. Set up your pendulum using the string lengths assigned to your group. Measure to the bottom of the bob. Use the same procedure you used when testing the pendulum variables and complete your portion of the chart below to share with the class.

		Length of string (in cm)					
		15	30	60	100	125	150
A	Trial 1: 10 periods in seconds						
B	Trial 1: 1 period in seconds (divide row A by 10)						
C	Trial 2: 10 periods in seconds						
D	Trial 2: 1 period in seconds (divide row C by 10)						
E	Trial 3: 10 periods in seconds						
F	Trial 3: 1 period in seconds (divide row E by 10)						
G	Total time for all three trials of the pendulum (add rows B, D, and F)						
	Average time for three trials of the period of the pendulum (divide row G by 3)						

Graph the results using the x-axis for the length of the string (in cm) and the y-axis for the period of the pendulum (in sec). What type of graph below does this model?

- A linear function: $y = mx + b$
- A quadratic function: $y = x^2$
- A cubic function: $y = x^3$
- An exponential function: $y = a \cdot b^x$
- An inverse variation function: $y = \frac{1}{x}$
- A square root function: $y = \sqrt{x}$

The formula for the period of the pendulum is

$$p = 2\pi\sqrt{\frac{L}{g}}$$

where p is the period of the pendulum, L is the length of the string, and g is the acceleration due to gravity (9.8 m/s^2, or 32.2 ft/s^2).

Graph the inverse of the results above. Let the x-axis be the period of the pendulum and the y-axis be the length of the string. What function above does this model? The formula for the period of the pendulum is also:

$$L = g\left(\frac{p}{2\pi}\right)^2$$

Appendix B
Poe problem summary

In the actual story, "The Pit and the Pendulum," Edgar Allan Poe writes that the pendulum is 30-40 feet long. He says that he thinks there are 10-12 swings left and that he thinks he has about 1 to $1\frac{1}{2}$ minutes to escape. Use the formula for the period of the pendulum to complete the table below. (Hint use 32.2 ft/s^2 instead of 9.8 m/s^2 for gravity)

Length (ft)	Time (1 period)	Time (10 periods)	Time (12 periods)
40			
35			
30			
25			
20			
15			
10			
5			

Does the prisoner in "The Pit and the Pendulum" have time to escape? Given his assumptions, are there times when he will be able to escape and other times when he will not? Is Edgar Allan Poe really a mathematician? Based on the information extracted from the story (look for details), if he does escape, when do you think that happens? In other words, which assumptions are true? Brainstorm here. Use charts, tables, graphs, etc.

At 25 ft, is there time for a prisoner to escape?

At what length do you think a person would NOT have time to escape? Explain your reasoning.

Will he always be able to escape if the rats chew through the rope in 1 minute? Will he ever be able to escape if it takes the rats $1\frac{1}{2}$ minutes to chew through the rope? Explain your reasoning.