Journal of Literacy and Technology
Volume 25, Number 2: Summer 2024
ISSN: 1535-0975

STEAM Literacy: Classical and Counterintuitive Pendulum Activities with Ideas for Java Code

David Devraj Kumar
david@fau.edu

Ronald Charles Persin
rpersin@fau.edu

Susannah Louise Brown
Sbrow118@fau.edu

Victoria Brown
Vbrown22@fau.edu

Florida Atlantic University
College of Education
Department of Curriculum and Instruction
3200 College Avenue
Davie, Florida 33314

Correspondence concerning this article should be addressed to:
Dr. David Devraj Kumar
Email: david@fau.edu

Abstract

Simple to construct, and easy to do, pendulum laboratory activities (one classical and one counterintuitive), combined science and mathematics concepts to provide a good opportunity to practice literacy and STEAM skills. The STEAM pendulum project laboratory activity applies technology using Java code, integrates design thinking and uses computational thinking towards meaningful learning experiences. Built into the opportunities are post-lab discussion and reflection based on a series of higher-order thinking questions. The information provided in this article will assist educators in applying the classical and counterintuitive strategies with reference to

STEAM literacy. Hopefully, a new awareness of the importance of the pendulum in the foundation and development of the processes of science and mathematics education, and its central positioning in the many facets of not only science, but also technology, engineering, arts, and mathematics literacy will emerge.

Key words: Computational thinking, pendulum, frequency, vibration, oscillation, period, classical, counterintuitive, Java, STEAM literacy, arts integration

Why Pendulum Activities to Promote Literacy?

The influence of the pendulum in the development of Western science and culture is immense (Matthews et al., 2004). It was significant for determining the value of the acceleration due to gravity (g) and discovering the pumpkin-like shape of the earth based on variations in g across latitudes long before space explorations. The accuracy of mechanical clocks improved from +/- half an hour per day to a few seconds per day, thanks to the significant role of the pendulum in horology (Yoder, 1988). This leap in accuracy of measuring time paved the way for precision measurement in navigation, astronomy, and mechanics (Matthews et al., 2004). From an integration of science and mathematics perspective, the important role of mathematics in science experiments received more substantiation from the Galilean-Newtonian paradigm, as illustrated by Newton as an interaction between science and mathematics. More interestingly, Newton in his studies has used pendula to verify his second and third laws (Matthews et al., 2004).

The pendulum activity has all the elements for promoting Science, Technology, Engineering, Arts, and Mathematics (STEAM) literacy in educational settings. The science content governing the oscillation of a pendulum and application of mathematics are quite suitable for promoting science and mathematics literacy. Including Java scripting encourages the use of computational thinking while connecting to technological literacy skills. The design aspect, as a part of STEAM through the arts influence, of pendulum lab activities in terms of set-up and data collection helps to address skills required for engineering literacy. Creative applications of design to incorporate imagination in a problem-based learning activity integrates visual arts into the STEAM pendulum project described in this article.

According to the Department of Defense, STEM (2024), "*in today's world, STEM literacy has become increasingly important. STEM—which stands for Science, Technology, Engineering, and Mathematics—encompasses a wide range of fields and disciplines. STEM literacy is the ability to understand and apply concepts from these areas in everyday life*" (n.p.). This aligns with the *National Science Education Standards* description of science literacy as the ability to "evaluate the quality of scientific information on the basis of its source and the methods used to generate it" (National Research Council, 1996, p. 22), well before the advent of STEM education.

STEAM literacy is essential for developing critical thinking and problem-solving skills, obtaining and managing information, cultivating innovation and creative abilities, and maintaining career success (Chistyakov et al., 2023). In this paper, the researchers discuss the STEAM pendulum project which includes the classical simple pendulum activity and a counterintuitive pendulum activity which applies science and mathematics concepts, and technology using Java code, and integrates engineering and visual arts design principles through classical and counterintuitive strategies to promote educational best practices in STEAM literacy.

STEAM Literacy Approach in Educational Settings

Research indicates the significance of integrating STEM (Science, Technology, Engineering, and Mathematics) education with the arts, forming STEAM, in K-12 schools to foster creativity, real-world experiences, and enhance workforce readiness (Chistyakoy et. al, 2023). Recognizing the importance of STEAM education, policymakers established the Congressional STEAM Caucus in 2013 to emphasize the importance of arts integration in education (Congressional STEAM Caucus, 2013). This initiative promotes diverse knowledge expression, fostering higher-order and creative thinking (Congressional STEAM Caucus, 2013). Additionally, the President's Committee on the Arts and Humanities (2011) advocates for arts integration in United States schools, highlighting its role in enhancing student learning and engagement across the curriculum. Additionally, educators guided by Gardner's theory of multiple intelligences (1999), recognize the importance of tailoring teaching methods to accommodate diverse learning styles through different highly engaged activities. An integrated curriculum provides opportunities for learners to engage in discussion in small groups or beyond the classroom into the community (Marshall, 2016). While curriculum integration is not a new concept, in this article, the researchers aim to discuss best educational practices for the K-12 STEAM curriculum, which in turn promotes student learning in these respective fields. This discussion also contributes to the larger education field including STEM education and identifies effective practices for implementing K-12 STEAM through pendulum activities.

Design thinking through the arts enhances the STEM approach to education to become STEAM. Design thinking merges analytical thinking with intuitive thinking to promote creativity within the problem-solving and project-driven activities both in the classroom and in real-world situations (Henriksen, 2017). Design thinking consists of five elements that interact through an iterative process that involves empathizing, defining, ideating, prototyping, and testing (Plattner, 2015).

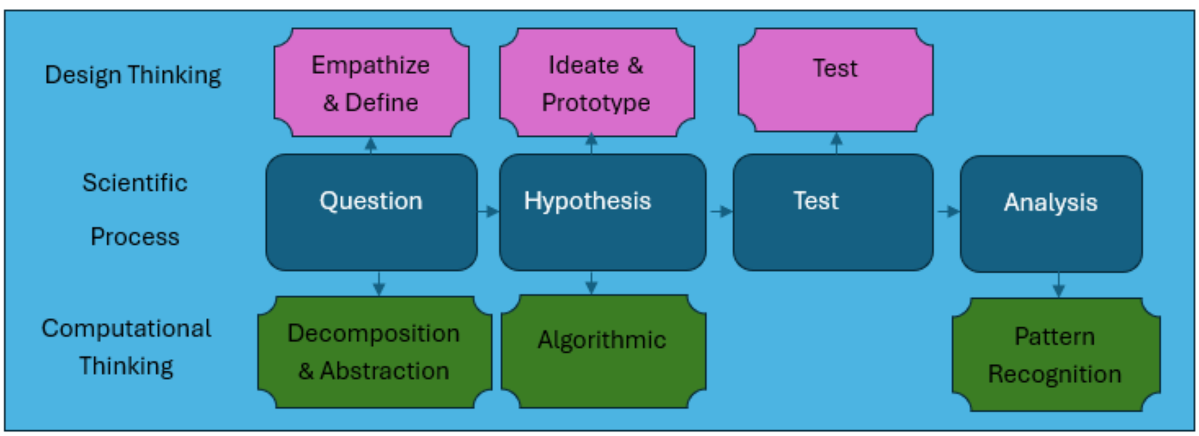
The STEAM pendulum activities outlined in this article offer straightforward, hands-on methods for delving into pendulum exploration through inquiry lab activities and a Java code simulation. These activities aim to enhance STEAM literacy by visually demonstrating the inter-connectedness of science, technology, engineering, arts, and mathematics. Specifically, the pendulum projects utilize a graphing activity on the board that demonstrates the results of the pendulums created by students, thereby illustrating the integrated relationship between these disciplines.

Integration of Computational Thinking into the STEAM Scientific Process

Underlying STEAM is the use of computational thinking to solve problems and create solutions. Computational thinking bridges hard science to the design thinking within STEAM. Computational thinking not only promotes thinking used by computer science but is integral to analytical thinking supports problem-solving, designing systems, and understanding human behavior (Wing, 2006). The purpose of computational thinking is to promote the identification of a problem and design the steps required for a solution. Computational includes decomposition by breaking down the problem, pattern recognition through the identification of similarities, abstraction by focusing on the essential information, and algorithms in the development of step-by-step solutions.

Computational thinking is included throughout scientific investigation and complements design thinking. In the identification of the question for investigation, the design thinking elements of empathize and define are the first step. To define, the computational thinking of decomposition and abstraction narrows the information to identify the question. To develop the hypothesis the design thinking skills of ideate assist in seeing possible solutions which can lead to the creation of the prototype. At the same time, algorithm thinking creates the steps required to implement the experiment. The use of pattern recognition skills enables the researcher to analyze the data gathered during the test phase (See Figure 1).

Figure 1
Integration of Computational Thinking, Design Thinking, and Scientific Process

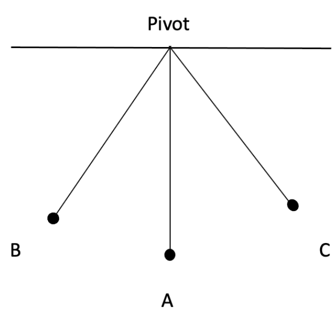


A Simple Pendulum

Designing a simple pendulum involving the STEAM approach to curriculum aligns with several educational standards. A pendulum activity aligns with the Next Generation Science Standards (2013) 3--PS2--2. *Make observations and/or measurement of an object's motion to provide evidence that a pattern can be used to predict future motion* (n.p.), with National Science Education Standards (National Research Council, 1996) *Teaching Standards B, C, and D; Assessment Standard B; 5-8 Content Standards A and B; and Program Standard C,* Pendulums (page 146-148). The National Council of Teachers of Mathematics (NCTM) (2000) lists standards in Measurement that connect to the pendulum projects including: *Apply appropriate techniques,* *tools, and formulas to determine measurements* (n.p.). The International Society for Technology in Education (ISTE) (2024) standards for K-12 students apply to the pendulum projects through the 1.4 Innovative Designer strand including: 1.4.a *Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts, or solving authentic* problems (n.p.). The Technology and Engineering Educators Association (TEEA) (2024) supports standards for students in engineering principles as applied to STEM education. Standards for Technology and Engineering Literacy 7 addresses the ability for students to *apply a broad range of making skills to their design process* (TEEA, 2024, n.p.). The National Core Arts Standards (NCAS)for Visual Arts connect through the Creating Anchor Standard 1: *Generate and conceptualize artistic ideas and work* (NCAS, 2014, p. 1) and Connecting Anchor Standard 10: *Synthesize and relate knowledge and personal experiences to make art* (NCAS, 2014, p. 8). It is important to note that throughout all the pendulum projects general safety measures include safety goggles and assistance with proper handling of the materials (paper clips, scissors).

A simple pendulum is a mass suspended from a fixed point so that it could swing freely. (see Figure 2).

Figure 2
Pendulum (A – rest, B and C – swing)



The length of a pendulum (L) is the distance from the fixed point to the center of the mass. The time it takes for a pendulum to complete one forward and backward motion (swing, also known as oscillatory motion, that repeats itself regularly) from point C to B and back to C is called the Time Period of a pendulum (T). Time Period (T) of a pendulum depends on the length (L) of the pendulum and acceleration (g) due to gravity.

$$T = 2\pi\sqrt{\frac{L}{g}} \qquad \text{Squaring, we get, } T^2 = \frac{4\pi^2 L}{g}$$

Graph between T^2 (y-axis) and L (x-axis) is linear.
The equation of a straight line is

$y = mx + b$

That is, $y = T^2$

$x = L$

$m = \frac{4\pi^2}{g}$, constant slope

b is the y intercept, which, in this case, is zero

During the activity the students are introduced to challenges and questions which guide them in computational thinking including: What is the shape of a graph between T^2 and L?

The frequency (f) of a simple pendulum is the reciprocal of the period (T). Therefore, it also depends upon its length (L) and acceleration (g) due to gravity.

$$f = \frac{1}{T}, \quad \text{then, } f^2 = \frac{1}{T^2} = \frac{1}{\frac{4\pi^2 L}{g}} = \frac{g}{4\pi^2 L}$$

Equation of a straight line, y = mx + b

Now, $y = f^2$

$m = \frac{g}{4\pi^2}$

$x = \frac{1}{L}$

$b = 0$

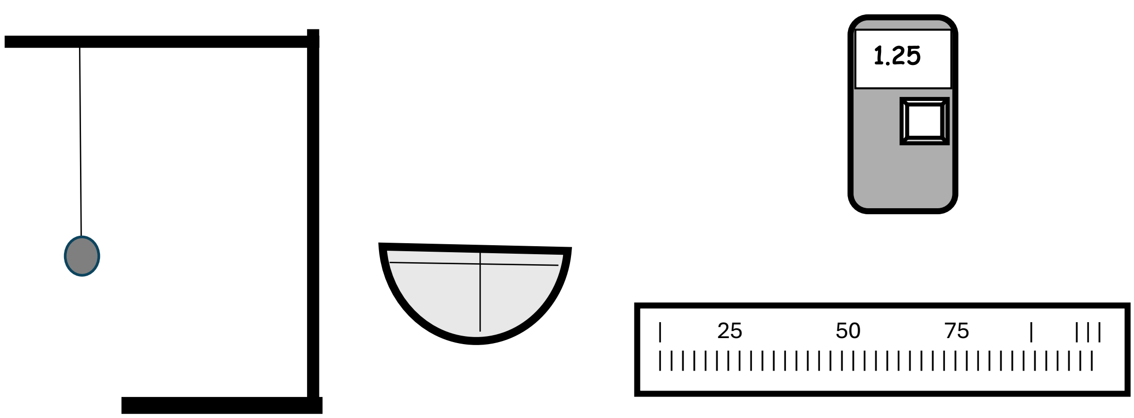
Graph between f^2 (y-axis) and $\frac{1}{L}$ (x-axis) is linear.

Another challenge for student discussion includes: What is the shape of a graph between f^2 and L? Usually, in class activities involving a pendulum, the time period, “T” for the various lengths are measured.

Classical Pendulum Lab Activity

An object attached to a string and allowed to swing back and forth over the same path is a simple pendulum. It models Simple Harmonic Motion (SHM) because the speed of the object is zero at the endpoints of the path and maximum through the center (Persin, 2017). During this activity the length is varied while timing 10 vibrations (oscillations/swings, that is one forward and backward movement) for each length. From this, the students and the teacher will try to determine the relationship between the time for 1 vibration, known as the period of the pendulum, given by T, and the length, given by L. The materials needed for the classical pendulum lab activity include retort stand, pendulum bob, thread, protractor, metric rule, and stopwatch (see Figure 3).

Figure 3
Pendulum (setup, and materials)



Journal of Literacy and Technology
Volume 25, Number 2: Summer 2024
ISSN: 1535-0975

Procedures for the Classical Pendulum Lab Activity

The students or the educator assembles the apparatus as shown in Figure 2. Be sure to clamp the stand to the table. Start with the shortest length possible (≈ 10.0 cm). The length is the distance from the center of the mass to the point of support. Displace the mass (bob) to one side at about 20º and observe its motion (SHM). One vibration is one forward and backward movement. The students will be timing 10 vibrations.

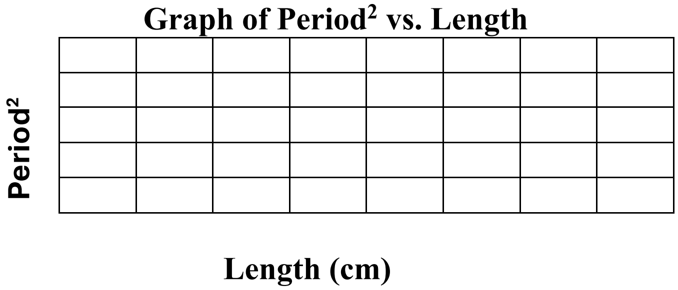
When ready to take data, displace the bob to one side at ≈20º and start the stopwatch the instant it is let go. Turn-off the stopwatch at the end of the 10^{th} vibration. Record the length and the time in the data table (see Table 1). Then increase the length by ≈10.0 cm, and again time 10 complete vibrations. Repeat steps 5-7 so that the last trial is ≈50.0 cm pendulum. Calculate the Period (T) of the pendulum by dividing the total time by 10. Square the value to get the Period^2. Graph of the Period^2 vs. the Length and tell what it indicates. (See Table 1).

Table 1

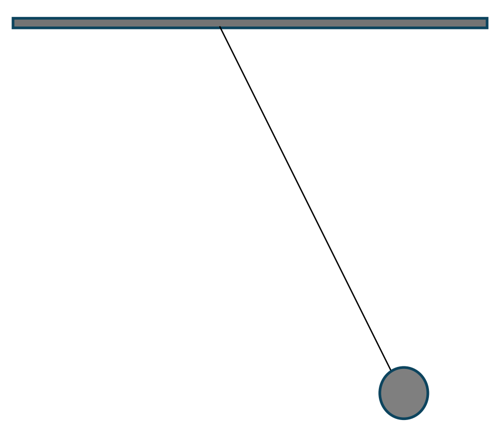
Sample Data Sheet, Grid for the Graph, and Freebody Diagram

Length (cm)	Time, 10 vib. (s) Run 1	Run 2	Run 3	Average (s)	Period (s)	Period^2 (s^2)
10						
20						
30						
40						
50						

Graph of Period^2 vs. Length



Freebody Diagram



Interpretation and Questions for Post-Lab Discussion

Journal of Literacy and Technology
Volume 25, Number 2: Summer 2024
ISSN: 1535-0975

Independently or in small groups, students answer and discuss the following questions after completing the classical pendulum lab activity. The questions guide the students in the use of computational thinking of decomposition, pattern recognition, and abstraction.

1. Describe the shape of the graph and what it shows.
2. What force caused the pendulum to: (a) move?
   (b) Stop, and change direction?
3. At what point in its motion is the bob moving fastest?
4. Where is it moving slowest and what is its speed there?
5. From the graph, interpolate to find the length of a “seconds” (T = 2.0 s) pendulum.
6. Using the equation, $T = 2\pi\sqrt{\frac{L}{g}}$, solve for L to check #5. Let $g = 9.8\ \frac{m}{s^2}$ Show all work below.
7. Complete the free-body diagram.

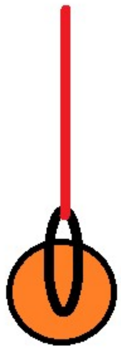
Counterintuitive Pendulum Activity

In the activity outlined in this section, it is quite counterintuitive when the length and the Number of Swings of the pendulum are the respective independent and dependent variables while keeping the time constant. An activity or event is counterintuitive if it goes against what a person intuitively thinks likely to happen due to a slight mismatch between the person’s current experience base (Kumar, 2017). The science concepts addressed include the factors influencing periodic motion, and the number of swings of pendulums. The science skills include identifying, controlling, and defining variables, and mathematics skills of graphing, averaging, rounding, range, and number. Materials for the activity include paper clips, string, coins, removable tape, and timer.

Procedures for the Counterintuitive Pendulum Activity

Construct five (5) pendulums of length 10 cm, 20 cm, 30 cm, 40 cm and 50 cm each.
An easy way to make a pendulum is to clip a coin (penny) to one end of a paper clip and to other end of the paper clip tie a string (see Figure3). Instead of paper clips, use a tape to tape one end of a string to a coin. Students can also make a swinging pendulum and conduct the two kinds of experiments discussed in this paper using Java code.

Figure 3
Pendulum Constructed Using a String, Coin and Paper Clip



Students practice swinging the pendulum and determine the number of swings of the pendulum in 10 seconds (Berlin and White, n.d.). To swing the pendulum, suspend it from the edge of a table, pull the bob (coin) to one side around 30° angle and leave it. Start a stop clock when releasing the coin and use a timer or the timer function in cell phones. For recording the data, use the sample data sheet (see Table 2).

Table 2
Sample Data Sheet for Number of Swings versus Length of the Pendulum

Length of Pendulum (cm)	**Number of Swings in 10 seconds**			
	Run 1	**Run 2**	**Run 3**	**Average**
10				
20				
30				
40				
50				

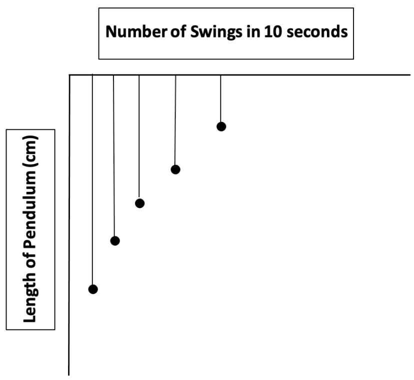
Students conduct the experiment three (3) times for each pendulum length. Students average the three-runs (using a calculator) and record to the nearest whole number. The teacher working with the students determines a range of results by the students/groups calling out their results for each length of the pendulums and drawing coordinates on the white board. Horizontal axis (x-axis) is the Number of Swings in 10 seconds, and the vertical axis (y-axis) is the length of the pendulum in centimeters. Note, move the x-axis to the top of the board.

Students come to the white board and hang their pendulums on the number line at the position corresponding to the Number of Swings in 10 seconds for their respective pendulums. They can

Volume 25, Number 2: Summer 2024
ISSN: 1535-0975

post their pendulums on the board using removable tape. Now, students have created a graph on the board with actual pendulums. Or, they can paste their pendulums on the board using removable tape. Now students have created a graph on the board with the pendulums they made. By observing the graph, the bobs as points on the graph, students will notice the Number of Swings of each pendulum increased with decreasing length of the pendulum. Using a marker, make a mark on the board where each bob rests on the board. When all the marks/points are connected, it will end up generating a graph. See Figure 4 for representative sample.

Figure 4
Number of Swings versus Length of Pendulum Graph



Variables such as the number of coins/bobs (mass), and the angle of release that is, the length of the arc of the swing could be experimented using the same procedure above. This pendulum activity could be carried out individually or in groups.

Post-Lab Discussion of the Classical and Counterintuitive Pendulum

Individual and group reflection of the pendulum lab results for both the classical pendulum and counterintuitive pendulum activities assists with a deeper comprehension of the science and mathematics concepts. Students can consider the learning aims of each lab activity and discuss in small groups.

Classical Pendulum

The key aims of a classical pendulum experiment are: to examine and study the motion of a simple pendulum; secondly, to collect data and graph, third is to learn the relationships between the period and length of a simple pendulum by examining the graph, and lastly, to determine the acceleration due to gravity using simple pendulum lab data (Simple pendulum experiment report, n.d.).

Counterintuitive Pendulum

As noted above, an activity or event is counterintuitive if it goes against what a person intuitively thinks likely to happen due to a slight mismatch between the person's current experience base. It is quite counterintuitive when the length and the number of swings of the pendulum are the respective independent and dependent variables while keeping the time constant (Berlin and White, n.d.).

Sources of Error in the Classical and Counterintuitive Methods

Generally, for both approaches, the pendulum length usually presents errors depending on how the string is tied to the support rod, and how accurately the location of the center of mass of the bob is determined. Secondly, to ensure that there is a clear point where the pendulum starts to swing, there may be some error in determining a constant angle of displacement from the equilibrium position for each run. Then, for the classical approach, there could be inaccurate timing of the periods simply due to not turning the stopwatch on and off at the exact times when the bob starts to swing and then completes the 10^{th} vibration (Heckenberg, n.d.). For the counterintuitive, since the time is held constant to measure the number of vibrations in a 10.0 s interval, uncertainty may occur when determining a precise fractional part of a vibration. Through computational thinking, students can identify these errors and use design thinking to improve the results of the experiment.

Agreement in the Classical and Counterintuitive Results

The linear graph of the Period^2 vs Length of the pendulum resulting from the classical approach illustrated the square root relationship between the Period and Length, which was given by the equation, $T = 2\pi\sqrt{\frac{L}{g}}$. For the counterintuitive, a graph of the Length of the Pendulum vs the Number of Swings in 10 seconds, corresponding to the frequency, f, was created on the board with actual pendulums.

By observing the graph, with the bobs as points on the graph, students will indeed be able to notice the Number of Swings of each pendulum increased with decreasing Length of the Pendulum. Points for the graph can be produced using a marker to make a mark on the board in line where the center of mass of each bob contacts the board. Therefore, when all the marks/points are connected, it will end up generating a graph of an inverse proportion between the length and the frequency. As shown earlier in this paper, since $f = \frac{1}{T}$, then, $f^2 = \frac{1}{T^2} = \frac{1}{\frac{4\pi^2 L}{g}} = \frac{g}{4\pi^2 L}$ or $f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$ again illustrating an inverse relationship between the length and the frequency.

STEAM Integration

Including technology, engineering, and art in the pendulum activities increases student engagement by providing learning options or choices. By increasing the creative options, students realize the real-world implications for the STEAM pendulum projects.

Technology Integration through Java Programming Application of the Oscillating Pendulum

The main reason for using Java is that it can be used on any computer (i.e., platform independent). It provides a technology to tackle real-world challenges. What is required is an integrated development environment (IDE) which is a software application that normally consists of a source code editor, build automation tools, and a debugger. There are many to choose from including Eclipse, BlueJ, IntelliJ IDEA, and NetBeans. The use of the computer program also promotes online students to engage in activities like those conducted in the classroom while encouraging the students to use the computational thinking skills in the implementation of the scientific processes.

The Java compiler and interpreter are part of the Java Software Development Kit (SDK), which is also referred to as the Java Development Kit (JDK). Java was designed to make it much easier to write bug-free code. Because Java is simple, it is easy to read and write. The learning curve is intended to not confuse beginners.

Sources of support for teachers and students new to Java programming include: CodeMentor at https://www.codementor.io offering free "how-to" events. Codementor Events is a developer community and virtual events platform where developers learn and share new tools, technical concepts, and career tips (Codementor events, n.d.), and Java Codedex with free downloadable code modules at https://java.codedex.com that users can configure to accomplish various programming tasks (Javacodex, n.d.). In Figure 5, a resulting Java program for the simple pendulum is presented.

Figure 5
Java Code for Simulating a Pendulum

```
import java.awt.*;
import javax.swing.*;
public class Pendulum extends JPanel implements Runnable {
  private double angle = Math.PI / 2;
  private int length;
  public Pendulum(int length) {
    this.length = length;
    setDoubleBuffered(true);   }
  public void paint(Graphics g) {
    g.setColor(Color.WHITE);
    g.fillRect(0, 0, getWidth(), getHeight());
    g.setColor(Color.BLACK);
    int anchorX = getWidth() / 2, anchorY = getHeight() / 4;
    int ball = anchorX + (int) (Math.sin(angle) * length);
    int ballY = anchorY + (int) (Math.cos(angle) * length);
    g.drawLine(anchorX, anchorY, ballX, ballY);
    g.fillOval(anchorX - 3, anchorY - 4, 7, 7);
    g.fillOval(ballX - 7, ballY - 7, 14, 14);   }

  public void run() {
    double angleAccel, angleVelocity = 0, dt = 0.1;
    while (true) {
      angleAccel = -9.81 / length * Math.sin(angle);
      angleVelocity += angleAccel * dt;
```



```
    angle += angleVelocity * dt;
    repaint();
    try {
      Thread.sleep(15);
    } catch (InterruptedException ex) {
    }    }   }

  public Dimension getPreferredSize() {
    return new Dimension(2 * length + 50, length / 2 * 3);   }

public static void main(String[] args) {
    JFrame.setDefaultLookAndFeelDecorated(true);
    JFrame f = new JFrame("Pendulum Example");
    Pendulum p = new Pendulum(100);
    f.add(p);
    f.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    f.pack();
    f.setVisible(true);
    new Thread(p).start();   }}
```

Note: The above Java program will draw a line attached to a ball that oscillates from a point of support in a framed window. The oscillation of the pendulum could be modified by changing the value of the variable “angle.” Any number of oscillations can be timed by users in order to collect data and compare the results with both the classical and counterintuitive approaches.

Integrating Engineering and Technology Literacy

The two variations of pendulum activities integrate science and mathematics literacy, and with Java code they incorporate computer technology literacy. This activity requires the use of the science literacy of understanding, experimenting and reasoning based upon the observations and data. As the students begin to understand the principles which make the pendulum work using their computational thinking skills, they begin to identify new questions and modify the variables to achieve hypothesized results deepening their understanding within science literacy. As the students begin to understand the mathematics of the pendulum swing, they gain knowledge of mathematics literacy of how the variables impact the methods and processes within the mathematic problems. Using the JavaScript allows the students to change the numbers within the variables and impact upon the results. They also can see the value of writing code to help solve problems.

Engineering literacy is integrated through engineering design principles in pendulum experiments to solve problems and complete the STEAM connection. The engineering design could be as simple as designing simple pendulums with a variety of materials to designing a complex 360-degree pendulum ride reported by Elliott (2021). Keeley (n.d.) outlined how to use formative assessment probes during pre-lab discussion to facilitate students to explore variables affecting the swing of a pendulum, using an example known as a “crooked swing”, in which engineering design principles can be utilized to solve a problem. Details are provided by Konacek-Moran (2011) in the story of a swing that was attached by 2 ropes to a branch of a tree that was not parallel to the ground. Hence, the swing oscillated in a crooked manner. The engineering design application could be accomplished with demonstrations of a “crooked swing” to pique student curiosity with a “real world’ example during a pre-lab discussion. The specific engineering design principles involved would be identifying the problem, using scientific knowledge to define the problem, and generating possible solutions by brainstorming ideas. This would be followed by doing the actual pendulum lab activity which is designed for students to learn about the different variables affecting the swing of a pendulum. After the lab activity, the students could return to the “crooked swing” problem during post-lab discussion to apply what they learned.

Visual Arts Integration: Creative Innovations

Art integration for the STEAM pendulum projects includes utilizing the principles of design for creative sculpture. Students are motivated to sculpt using modeling clay various bobs or weights that are used in the pendulum experiments. For example, instead of using the paper clip and a penny, students can create an animal shape (bird, owl, dog, cat, monkey, frog) from modeling clay and attach a paper clip into the center of the sculpture or a string directly onto the top of the sculpture (see Figure 6).

Figure 6
Sculptural Pendulum Owl Bob (Mass at the End of the Pendulum)

Other shapes dependent upon what the students are studying can be included, such as, dimensional forms of spheres, cones, and cubes. The imagination of the students becomes involved in the creative design of the bob or weight. Students select colors and create textures on the clay surface. If a penny weight is included in the sculpture by inserting the coin into the modeling clay figurine, students may research creatures that are the size of a penny. For example, many species of frogs have been discovered that are coin sized or smaller (Sullivan, 2024). By allowing the students to select the creative design, inspiration to learn more about science in the world around them can occur. Learning how to form the modeling clay (use of art materials), judge the quality of the artwork (critique and evaluation), and add to the aesthetics (sense of wonder and beauty) of the pendulum can provide motivation and opportunities for engaged discussion during the creation of the pendulums, while collecting data, and post-lab explorations.

Journal of Literacy and Technology
Volume 25, Number 2: Summer 2024
ISSN: 1535-0975

Reflections and Higher-Order Thinking Questions to Prompt Students' Discussion and Feedback

The pendulum activities described in this article are simple hands-on ways to explore pendulums with inquiry lab activities and a Java code simulation to promote STEAM literacy. They are intended to help to visually illustrate the integrated relationship between science and mathematics through the graphing activity on the board using student made pendulums. For example, as students come to the front and post their pendulums at the respective number of swings, they are constructing an actual graph connecting the length of the pendulum and the number of swings using the pendulums they constructed and experimented with. Once they realize it, they come back to the front with their cell phone cameras to take pictures of the graph they collectively helped to create on the board.

Class discussions, depending on the grade level, could include the shape of the graph when all the points touching the bobs on the board are connected, and predicting the number of swings in 10 seconds for an unknown length of a pendulum and vice versa. At higher grade levels, teachers could also initiate discussions on using the time of swing instead of the number of swings and explore the relationship to length of the pendulum, verify with a hands-on activity, and discuss the shape of the graph, the time and length relationship.

Examples of higher-order questions that can be used to extend discussion, illicit student feedback, and promote STEAM literacy at specific grade levels could include:

1. Where will the Pendulum have the greatest amount of kinetic energy? (Middle, Secondary)
2. What is the relationship between the length of a pendulum and number of swings? (Elementary, Middle)
3. Will a pendulum starting at a higher height have a greater period than a pendulum that starts at a lower height? (Middle, Secondary)
4. At what point in its motion does a pendulum have its maximum velocity? (Middle, Secondary)
5. Why does a pendulum have the same period even when starting from higher heights? (Elementary, Middle, Secondary)
6. Both a simple pendulum and a satellite orbiting the Earth are said to be examples of periodic motion. How would the formula for the period (T) of a pendulum be adjusted for a satellite? (Secondary)
7. For what applications might engineers use some of the conclusions based on the information gathered from the answers to these questions? (Middle, Secondary)
8. How would adding more mass to the bob of a pendulum affect the time for one swing? (Elementary, Middle, Secondary)
9. For what applications might artists or visual designers use some of the conclusions based on the information gathered from the answers to these questions? (Middle, Secondary)
10. Extended discussion: Pendulum data can also serve as an easy way to calculate the acceleration due to gravity wherever you find yourself. (Simple pendulum experiment report, n.d.) This can be accomplished because, as we know, the period of a simple pendulum is related to the acceleration due to gravity. Considering the equation again,

$$T = 2\pi\sqrt{\frac{L}{g}}\text{ , it follows that }\quad g = \frac{4\pi^2 L}{T^2}\,.$$

In addition to integrating science, mathematics, technology and engineering, these pendulum activities provide an opportunity to integrate arts, for example, by encouraging students to make colorful pendulums using various colorful materials and be creative in illustrating different physical pendula to enhance STEAM literacy. Integrating history by engaging students in group discussions about the historical developments of pendulums is an excellent way to bring a historical perspective to STEAM literacy. As a technology, pendulums have a prominent place in history in regulating the movement of clocks. For example, old grandfather clocks use pendulums, and by adjusting the length of the pendulum, one could adjust the clock to go faster or slower. In earlier days without air conditioners, during summer months, the length of the metal rods that passed through the diameter of the bob in pendulum clocks would increase in length due to heat, and the center of mass of the pendulum bob displaced, affecting the accuracy of the clock. To adjust the bob back to its original position, there is a nut attached to a threaded screw on the bottom end of the pendulum rod positioned just underneath the bob. By moving the nut clockwise, the center of mass of the bob could be returned to its optimum position. During cold winter months, the rod shortens in length and the screw is turned counterclockwise to readjust the bob. Another technological solution to this situation was the introduction of wooden rods to replace metal rods in pendulum clocks. This real-world connection to pendulums in grandfather clocks could bring life to developing STEAM literacy, as students see the connection between their classroom activity and the role of pendulums in the world outside classrooms.

Summary

The pendulum activity has been an isolated topic in elementary, middle, and secondary schools, with varying degrees of emphasis for many decades, but its full potential for learning about the nature of science, and the relationships between science, technology, engineering, arts, and mathematics (STEAM) is seldom fully developed. As discussed in this paper, there is now ample opportunity for a richer treatment of the pendulum from elementary school to high school contrasting classical and counterintuitive experimental methods, including sample laboratory activity handouts, combined with coding-up the equations of pendulum motion in a programming example. The integration of scientific processes, computational thinking with design thinking through the pendulum activity makes this a powerful teaching opportunity for the promotion of skills required beyond the classroom. It is anticipated that teachers will implement these and other pendulum lab activities to engage their students in meaningful STEM education and similar creative ways to promote STEAM literacy among preservice teachers and elementary through high school students.

References

Berlin, D. R., & White, A. L. (n.d.) *A "model" for integrated science and mathematics teaching and learning*. Columbus, OH: NCSTL, The Ohio State University.

Chistyakov, A. A., Zhdanov, S. P., Avdeeva, E. L., Dyadichenko, E. A., Kunitsyna, M. L., & Yagudina, R. I. (2023). Exploring the characteristics and effectiveness of project-based learning for science and STEAM education. *Eurasia Journal of Mathematics, Science and Technology Education, 19*(5), em2256. https://doi.org/10.29333/ejmste/13128

Codementor events (2023, May 27). Explore events. http://www.codementor.io/events/upcoming

Congressional STEAM Caucus. (2013, February 7). Americans for the arts action fund. Author. https://www.artsactionfund.org/news/entry/the-congressional-steam-caucus

Department of Defense STEM. (2024). *The importance of increasing STEM literacy now to help solve global problems later*. https://dodstem.us/meet/blog/entries/increasing-stem-literacy/

Elliott, J, W. (2021). Theoretical design of a 360 degree pendulum ride. *Williams Honors College, Honors Research Projects*. 1350. https://ideaexchange.uakron.edu/honors_research_projects/1350

Gardner, H. (1999). Intelligence reframed: Multiple intelligences for the 21st century. Basics Books.

Heckenberg, N. R. (2023, May 8). Using a pendulum to teach experiment design and error analysis. https://www.rpi.edu/dept/phys/Courses/PHYSIHonors/Heckenberg.pdf

Henriksen, D. (2017). Creating STEAM with design thinking: Beyond STEM and arts integration. The STEAM Journal, 3(1). https://scholarship.claremont.edu/steam/vol3/iss1/11

International Society for Technology in Education. (2024, March 18). *ISTE standards for students.* https://iste.org/standards/students

International Technology and Engineering Educators Association. (2024, March 18). *Standards for technological and engineering literacy.* https://iste.org/standards/students

Javacodex, (2023, May 7). Javacodex categories. https://javacodex.com/menu.php

Keeley, P. (2013). Pendulums and crooked swings: Connecting science and engineering. *Science & Children, 51*, 32-35.

Konicek-Moran, R. (2011). The Crooked Swing Story. *Yet More Everyday Science Mysteries*. NSTA Press.

Kumar, D. D. (2017). Teaching counterintuitive science. *Primary Science, 148*, 33-35.

Marshall, J. (2016). A systems view: The role of art in education. *Art Education, 69*(3), 12-19.

Matthews, M. R., Gauld, C., & Stinner, A. (2004). The pendulum: Its place in science, culture and pedagogy. *Science & Education, 13*, 261-277.

National Core Arts Standards (2014). *National core arts standards: Dance, media arts, music, theater, and visual arts.* https://www.nationalartsstandards.org/

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Author.

National Research Council (1996). *National Science Education Standards*. Washington, DC: The National Academies Press.

Next Generation Science Standards Lead States. (2013). *Next generation science standards: For states, by States.* Washington, DC: The National Academies Press.

Persin, R. C. (2017). *IB physics, Two-dimensional motion, Circular/periodic motion, and gravitation.* http://www.Lnk2Lrn.com

Plattner, H. (n.d.). An introduction to design thinking process guide. https://web.stanford.edu/~mshanks/MichaelShanks/files/509554.pdf

President's Committee on the Arts and Humanities. (2011). Reinvesting in arts education: Winning American's future through creative schools. https://www.pcah.gov/sites/default/files/photos/FCAH_Reinvesting_4web.pdf

Simple pendulum experiment report. (2023, May 8). https://gishomework.com/simple-pendulum-experiment-report/

Sullivan, W. (February 28, 2024). The world's smallest vertebrate is a tiny Brazilian frog, study finds. *Smithsonian Magazine*. https://www.smithsonianmag.com/smart-news/the-worlds-smallest-vertebrate-is-a-tiny-brazilian-frog-study-finds-180983867/

Wing, J. (2006). Computational thinking. *Communications of the ACM, 49* (3) 33-35. https://dl.acm.org/doi/pdf/10.1145/1118178.1118215

Yoder, J. G. (1988). *Unrolling time: Christiaan Huygens and the mathematization of nature.* Cambridge: Cambridge University Press.