Using Open Source Intelligence Techniques to evaluate Physics Calculations

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Abstract. Checking the answer at the end of a calculation is an oft neglected part of a calculation, and getting students to engage in this behavior can be difficult when they are already intellectually tired. The paper briefly describes a graphing, linearization, and control of variables activity related to pendulums, couched as "swingset" design. After a reliable $swingtime \sim \sqrt{length}$ model has been established, students apply the model to a youtube video to predict the height of a bridge. Then, to reinforce the ideas of multiple representations, and multiple lines of evidence within an argument, students are asked to use Google Maps and other online resources to estimate the height of the bridge. Looking for overlap between online estimations and physical models from the lab is powerful. At the end of the exercise, students have had a brief introduction to "Open Source Intelligence" techniques that are commonly used by news and intelligence organizations.

1. Swingset Exercise

Early in a Physical Science or Introductory Physics-Mechanics class, we introduce and practice control of variables, graphing, and linearization concepts by asking students to think about designing a new swingset for an elementary school playground. An exciting swingset takes a long time to swing back and forth and we call this "swingtime" the output variable we want to be able to predict. Formally, a swingset is typically modeled as a pendulum with period $T \sim \sqrt{L}$ [1] but as this activity usually occurs in the first few weeks of the class, we avoid any mention of the technical story that for small oscillations a pendulum's period is $T \simeq 2\pi\sqrt{L/g}$.

When asked about possible input variables on which swingtime might depend, students will often talk about mass, weight, initial height and angle, whether you start from rest or with an initial push, and length. After breif investigations, the students typically settle on initial angle, mass, and length as the most important variables needed to predict swingtime. With further data collection, the class can narrow down the length of the swing's cable as the most important variable.

Data from a past class is given in figure 2. Thus far, all of the students' data has been collected with metal washers and string, with none of the swingsets larger than

Figure 1. In North America, a "swingset" or "swing" is a mass-rope pendulum system that people enjoy using. Swings have a long history of recreational use throughout many human cultures [3].

about $100cm$ in length. The data in figure 2 looks fairly linear, and when asked to predict the swingtime for a $200cm$ length, students typically either draw a line or use a

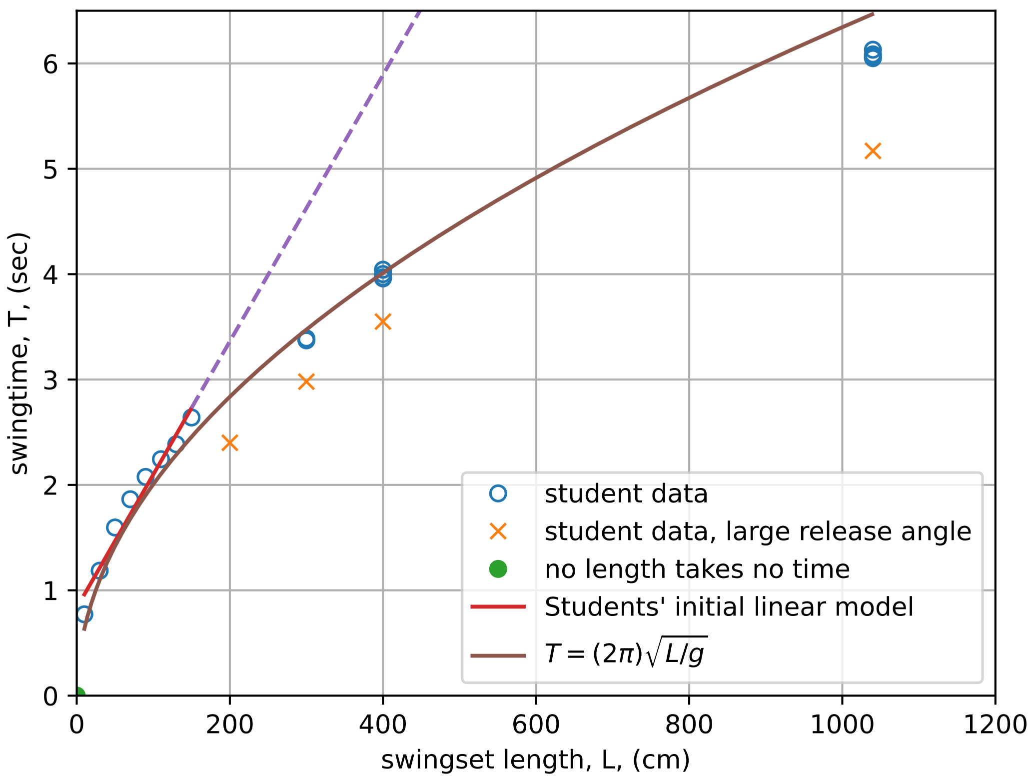

Figure 2. Typical student data, using metal washers and string to model the motion of a swingset. Students are coached to measure the time associated with multiple "there and back" swings and then divide to find an average time so that their reaction times (typically $\approx 0.3 seconds$) can be ignored.

linear math model, also shown in figure 2.

This linear model fails at longer swingset lengths. Resolution comes via two pieces of data. First, if a swingset has "almost no length" students will generally volunteer that it takes "almost no time" to swing back and forth. This means that the $length = 0$, $swingtime = 0$ intercept is physically real and should be included in fitting efforts.

Second, when results from swingset lengths of $200cm$, $300cm$ and $400cm$ are included in the graph, students can be coached to reccollect that the data reminds them of a parabola that has been rotated to open towards the positive x-axis of the graph. In Pre-Calculus or Algebra 2 classes this mathematical form is often written as a $y^2 = x$ or $y = \sqrt{x}$ relationship.

To test this "curvy" relationship between swingtime and length, we ask the students to create the graph shown in figure 3 in which the data has been "linearized" by plotting $\sqrt{L}$ instead of L. In our experience, many students have not seen a non-linear proportionality "in the wild" before, and this can be a challenging concept to discuss – particularly when thinking about the units involved in linearized trendlines!

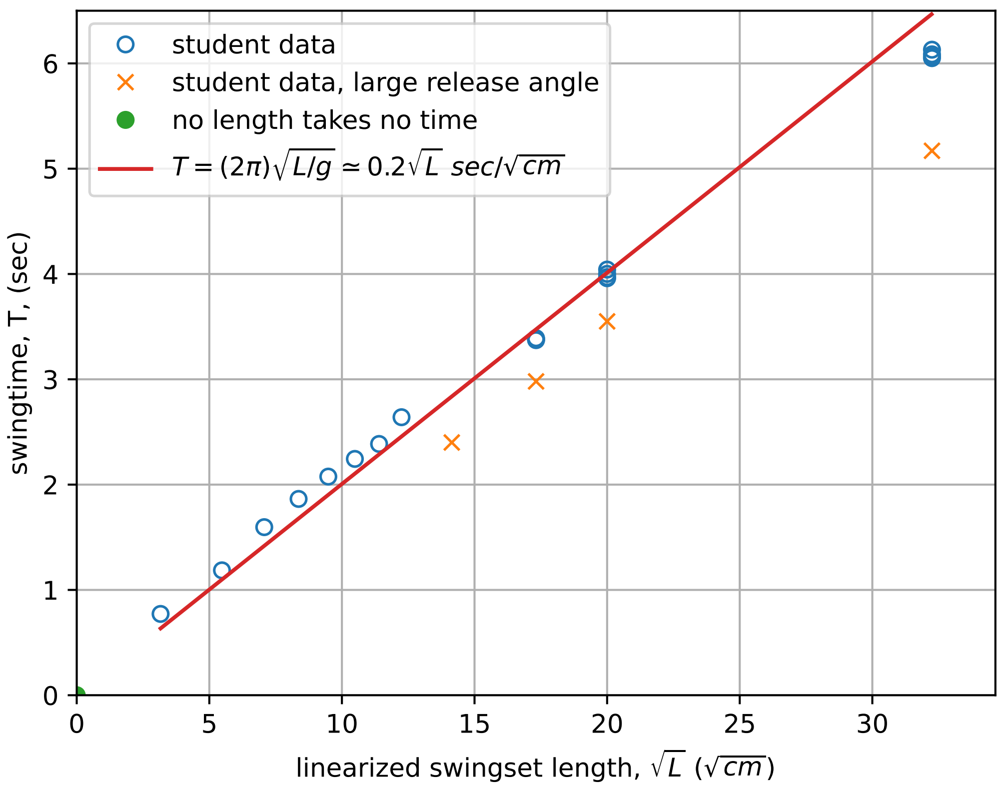

Figure 3. Linearized swingset data from a class. Note that $200cm$, $300cm'$ and $400cm$ lengths are included and described well by the $\sqrt{L}$ trendline – so long as the intial relase angle is small. The "almost no length" swingset that takes "almost no time" to swing is also nicely included.

A nice final test of the linearized model for swingtime is to use a $10m$ surveyor's tape measure as a 3-story high swingset. As seen in figure 3, even this data is reasonably described by the linearized model. Note, most of this work depends on the students using a relatively small initial release angle. If students decide to release a swingset from horizontal, the $\sqrt{L}$ dependance will be harder to see, which is again visible in figure 3.

2. Predicting the height of a swingset

With a reliable model for swingsets developed, a common follow-up assignment is to estimate the height of a bridge or arch from video of people swinging below it. Two specific examples we've used one in Sault St. Marie, [4], and another near Moab, [5], are available on youtube.

At this point, from their data analysis, students know that swingtime, T, and swingset length are described by an expression similar to the following (with slightly different slopes, depending on student measurements)

$$T \simeq \left(0.20 \frac{seconds}{\sqrt{cm}}\right)\sqrt{L}, or \tag{1}$$

$$L \simeq \left(25 \frac{cm}{sec^2}\right) T^2. \tag{2}$$

Then, if a student is able to meansure the time corresponding to half or a quarter of a swing from the video, they can use the model to predict the swing's height. As an example, the man in the Sault Ste. Marie video seems to take about 5 seconds to make half a swing (from 0:36 to 0:40 in the video)[6]. With a period of $T = 8s$, students can predict a swingset length of about $1600cm = 16m$. The video in Moab can be similarly analyzed.

3. Evaluating answer using Open Source Intelligence

3.1. screen grab and scaling

3.2. geographic searching

- wrong bridge in Sault St. Marie

3.3. shadows

3.4. geographic clues

Moab arches

References

[1] College Physics 2e 16.4 The Simple Pendulum https://openstax.org/books/college-physics-2e/pages/16-4-the-simple-pendulum

[2] https://commons.wikimedia.org/wiki/File:Fragonard,_The_Swing.jpg Jean-Honoré Fragonard: The Swing 1767

[3] https://en.wikipedia.org/wiki/Swing_(seat) Swing (seat)

[4] https://www.youtube.com/watch?v=arxiDyDouHo Sault Ste Marie's Biggest Swing Set Dylan Mcintomney Oct 29, 2014

[5] https://www.youtube.com/watch?v=4B36Lr0Unp4 World's Largest Rope Swing devinsupertramp (Devin Graham) Feb 15, 2012

[6] If you download the video from YouTube and import it into Vernier's LoggerPro, it looks like a half swing runs from 36.603s to 39.973s, a $T/2 = 3.37s$ or $T \approx 6.74s$.