Modeling Power in Batteries with Linear Regressions

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Host Organization: Stanford

ETP Type: *classroom*

Subject/Grade: Physics Grades 11/12

Abstract

A fundamental aspect of how Deep Learning systems work is that they make predictions about how a function should fit some test dataset, evaluate the errors from that function to the test dataset, and modify that function to reduce the errors. In science, we also do this when thinking about the best ways to design an experiment, or to probe relationships between different variables. In this lesson, students will vary the number of batteries in an electrical circuit, and compare the expected amount of power to the actual electrical power. By varying the type of battery, students can gain a familiarity with how input power does not equal output power. Next, they will use a linear regression to interpolate and extrapolate power outputs of batteries. Finally, they will also explore the "bias" inherent in their model (that they used data about AAA batteries, and so it might not be a very good predictor for 9V batteries), and relate that understanding to how deep Machine Learning and Deep Learning algorithms function and are affected by their data sources.

Focal Content & Supporting Practices

SEP: Using mathematics and Computational Thinking

- Electrical current, voltage, resistance, and power
- Graphing points
- Graphing lines of best fit
- Calculating MSE

Sub PE: Create a computational model to calculate the change in the energy of one component in a system when the change in the energy of the other component(s) and energy flows in and out of the system are known

21st Century Skills and Applications (1 - 2 bullets)

Problem Solving

- Produces thorough analysis of effects and tradeoffs for various alternatives

Students will compare the internal resistance of different batteries, and how those internal resistances come about from intentional design choices that engineers made when designing the battery.

Measurable Objective(s)

- Students will be able to calculate the MSE for a dataset
- Students will be able to use a linear regression to make predictions about an unknown quantity
- Students will be able to evaluate the reliability of their regression

Formative Assessment(s)

- Warm-ups ("Do Nows")
- Progress checks
- Turn and talks

Summative Assessment(s)

- Lab write-up showing graphs of data
- Calculation of linear regression over their data, used to make predictions
- Analysis questions about reliability of their regressions

Fellowship Description (300-500 words)

The Autonomous Systems Lab (ASL) at Stanford, led by Dr. Marco Pavone, is interested in developing systems for controlling systems autonomously in uncertain, rapidly changing environments using robotics, control theory, and machine learning (ML). The subgroup I am working with has partnered with NASA to develop a simulator of an airplane (Xplane) to write algorithms to enable autonomous taxiing on a runway. The algorithms use ML processes (linear classifications, convolutional neural nets) to interpret images from cameras in the simulator to predict the distance from the center line given certain lighting and weather conditions, and then to adjust the plane's heading. Furthermore, they are partnering with the organization AI4ALL at Stanford to make their research with Xplane and ML accessible to high school students. In my fellowship, I am probing the XPlane Simulator (How do starting conditions affect the performance of the neural net? How does dataset acquisition and processing affect the neural net? How do other components of the NN affect downstream performance of the taxiing of the airplane? What is "good enough"?) to develop a learning module that teaches fundamental neural net concepts through "solving" a deep learning problem using the XPlane simulator (like taxiing). Learning outcomes for this module would be to increase student engagement and familiarity with ML techniques, practices, and mindsets (for example, manipulating large datasets, understanding how neural nets process datasets) in the hopes that ultimately students feel like incorporating ML into their futures is possible. ML is a very broad set of skills that ultimately opens up a lot of opportunities for students in scientific, engineering, computer science, and other related technical fields; if a field generates large amounts of data, and wants to process it to sort, categorize, or make predictions, you will frequently find someone who wants to apply ML techniques to that data. The ASL at Stanford has had partnerships with a variety of tech companies and government organizations, like NASA, to develop controls for systems like future satellites and robots, and even commercial organizations planning out how and where to place electric vehicle charging stations in a rapidly changing grid environment. Understanding how to optimize these kinds of complex systems, and what tradeoffs different optimizations have, allows everyone from engineers to city planners to develop systems that are adapted to, and responsive to, their environments.

Fellowship Connection to School/Classroom (300-500 words)

Although ML techniques require some high level mathematics that students in high school don't have broad experience with, there are certain elements of it that are accessible for students and relevant to a chemistry and physics course. As a part of ML algorithms, one of the fundamental aspects of these algorithms is that they make a predicted function to describe the data that it's given. At first, this function is incredibly inaccurate; basically random. However, the algorithm then compares its function expected values with the true values from the data, and by evaluating these errors, it's able to adjust its weights on the function it uses to make predictions, and then it makes another attempt with the new weights. This process is repeated many times over large datasets in order to develop a functional model that accurately describes the test data, and can then be used to make predictions on unseen similar data. Naturally, this is similar to when students explore mathematical relationships in science; for example, if a student were to vary the current and voltage across a resistor, they would be able to write a function that describes their data, and use that function to predict the voltage across a resistor given a certain current. Using metrics like the Mean Squared Error would allow students to evaluate how well their function fits their data. Furthermore, by training students to use computer processes to evaluate their data, they are better able to process their data and focus on the mathematical relationships between variables, rather than the mechanics of graphing, plotting lines of best fit, and measuring error. This will better enable them to see the connection to the algorithmic process that ML techniques follow.

Instructional Plan

Lesson Plan
Exemplars and Rubrics
Slides

Additional Supports

- Google Sheets Short Slideshow (with videos)
- CER Sentence Starters
- Talking like a scientist table tent
- Distance Learning Modifications

Materials
Include links to all files within this ETP

Student Facing Materials
Task Card: Modeling Power
Part 1: Student Lab
- Battery holder(s) to attach up to 6 AAA batteries in series
- Digital Multimeters (DMM)
- 6 AAA batteries
- 1 9V battery
- 1 DC motor
- Alligator clips to connect the battery holder to the motor
- 1 pulley that can be attached to a lab table
- Length of string (~1 meter long)
- Meter stick
- Timer/stopwatch (okay to use cellphone timer)
- 50 g weight
- Chromebooks

Part 2:
- Dead 9V battery (to take apart)
- Chromebooks

Part 3:
- Chromebooks

Teacher Facing Materials (including scaffolds)
Lesson Plan
Slides
Exemplars and Rubrics
Google Sheets Short Slideshow (with videos)
CER Sentence Starters
Talking like a scientist table tent

References

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Keywords

Regression, Electricity, models