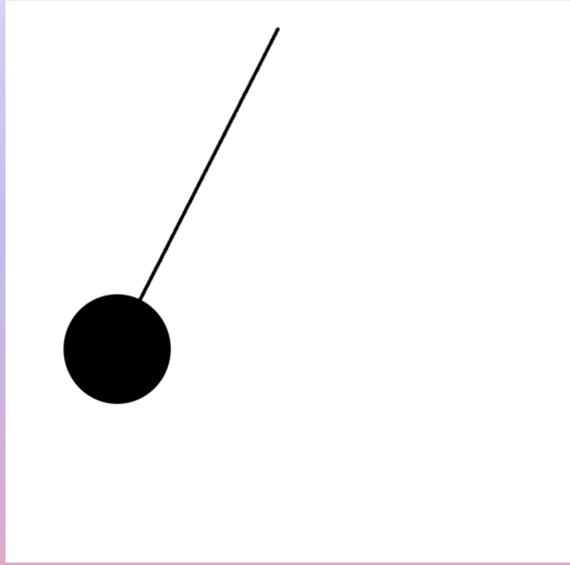
# Pendulum Motion Through Fluids: Experimental and Predictive Analysis

Sammy Stollman

# INTRODUCTION

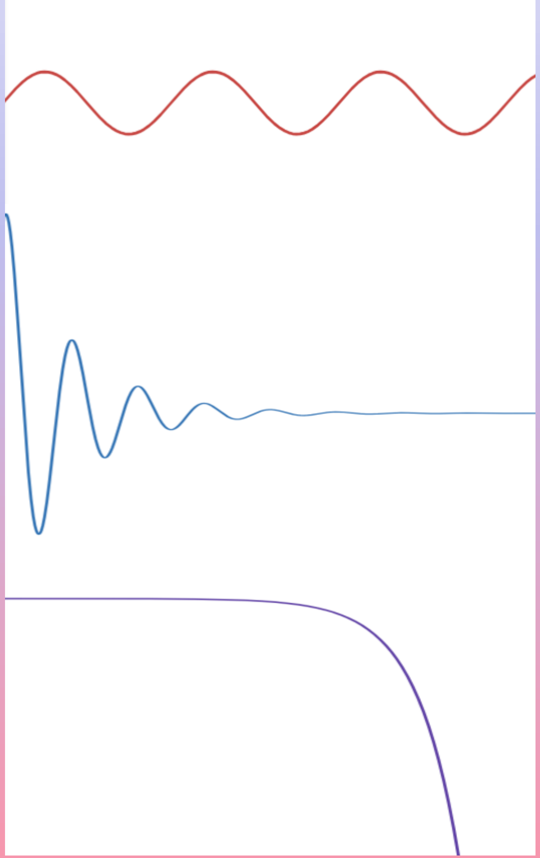
# Pendulums



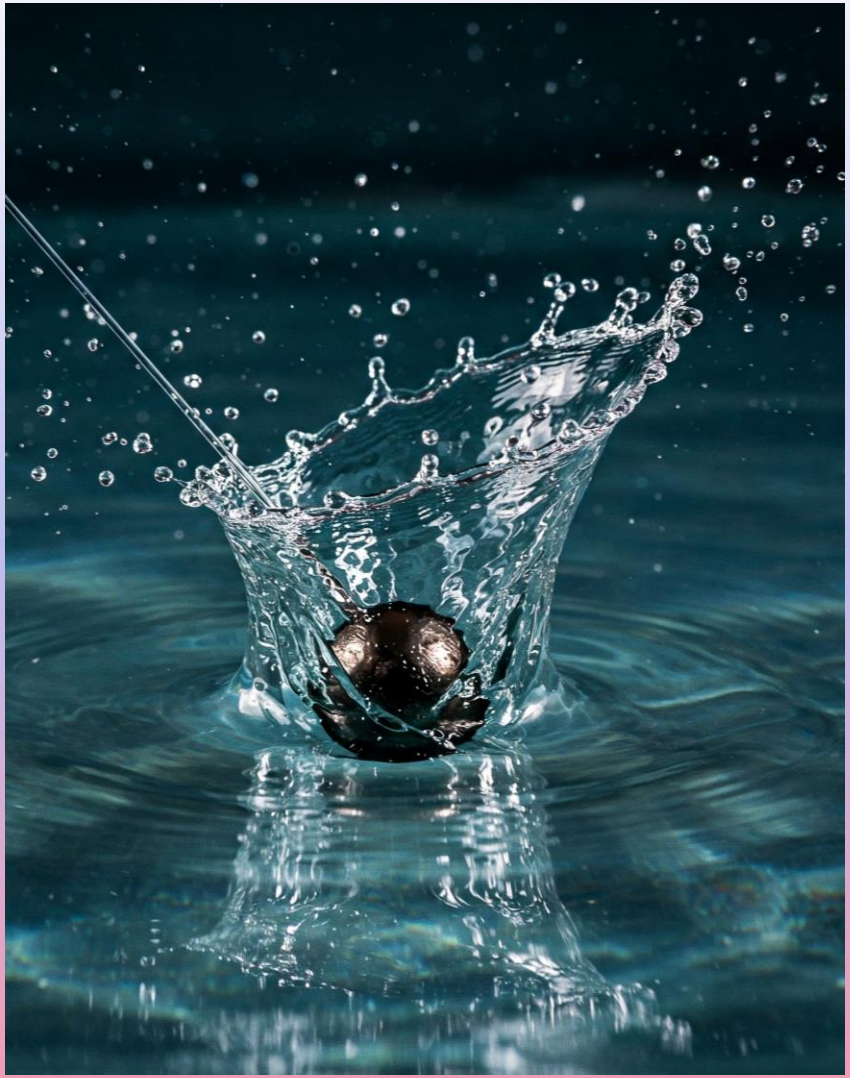
Pendulums are simple oscillators

Illustrate concepts such as:

- Simple harmonic motion
- Dampening
- Energy loss



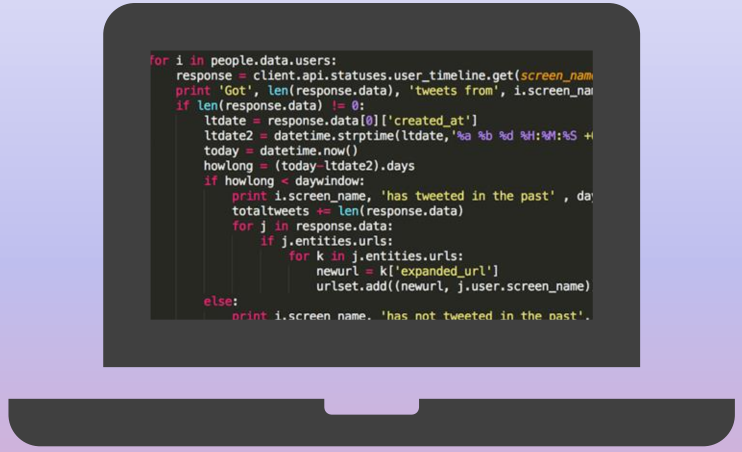
# What makes pendulum swing differently in different mediums?



- Viscosity
- Density
- Resistance/Dampening

# Why This Interests Me

- Computer Science
  - Computational Physics
  - Data Collection
  - Machine Learning
  - Mathematical Techniques
- Dynamics and Study of Motion



# Learning Outcomes

### Physics

- Mechanics
- Dampening
- Fluid Dynamics

### Data Science

- Data Collection
- Modeling
- Machine Learning

### Programming

- Python
- Jupyter Notebook

# Importance in Lab Setting

Prediction Methods

Computational Physics

# End Goals of Experiment

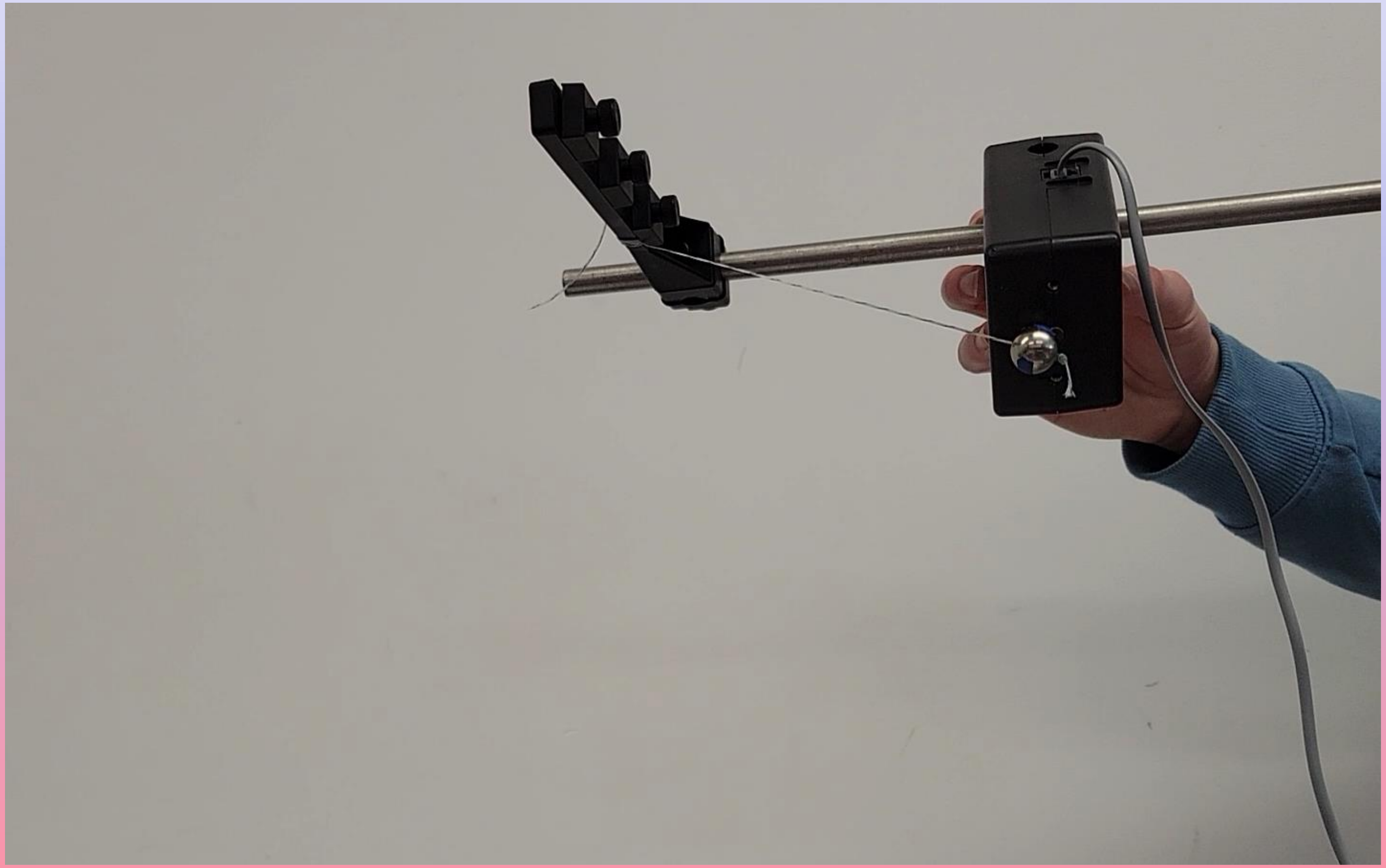
- Videos
- Use The Model
- Predictions
- Benefits/Drawbacks
- Question How we can Improve Model

# Materials and Methodology

# Fluids

- Air
- Water
- Oil
- Syrup

# Video Clips of Pendulum in Fluid



# Video Clips of Pendulum in Fluid

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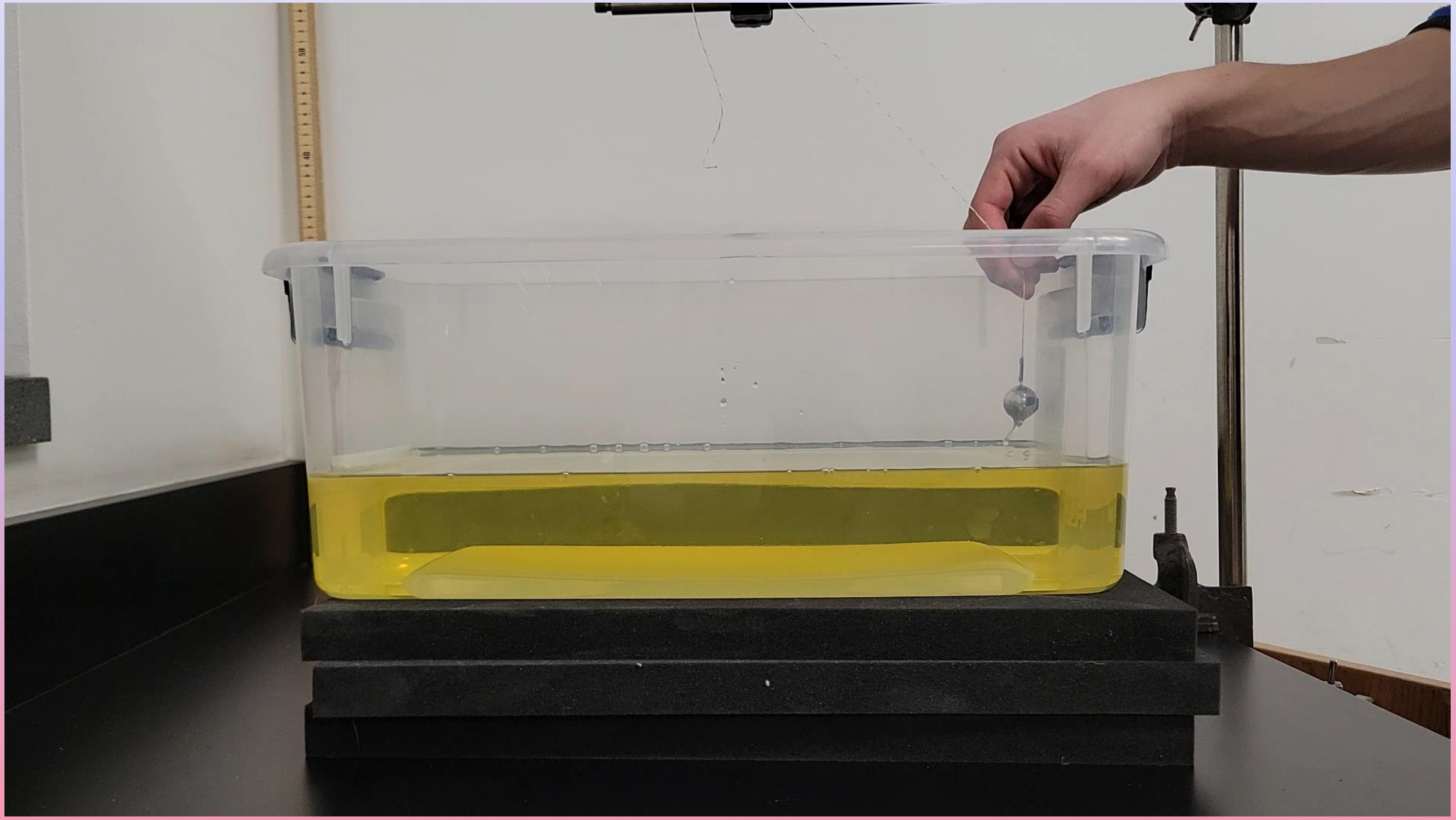


# Video Clips of Pendulum in Fluid

# Materials

Pendulum Clamp

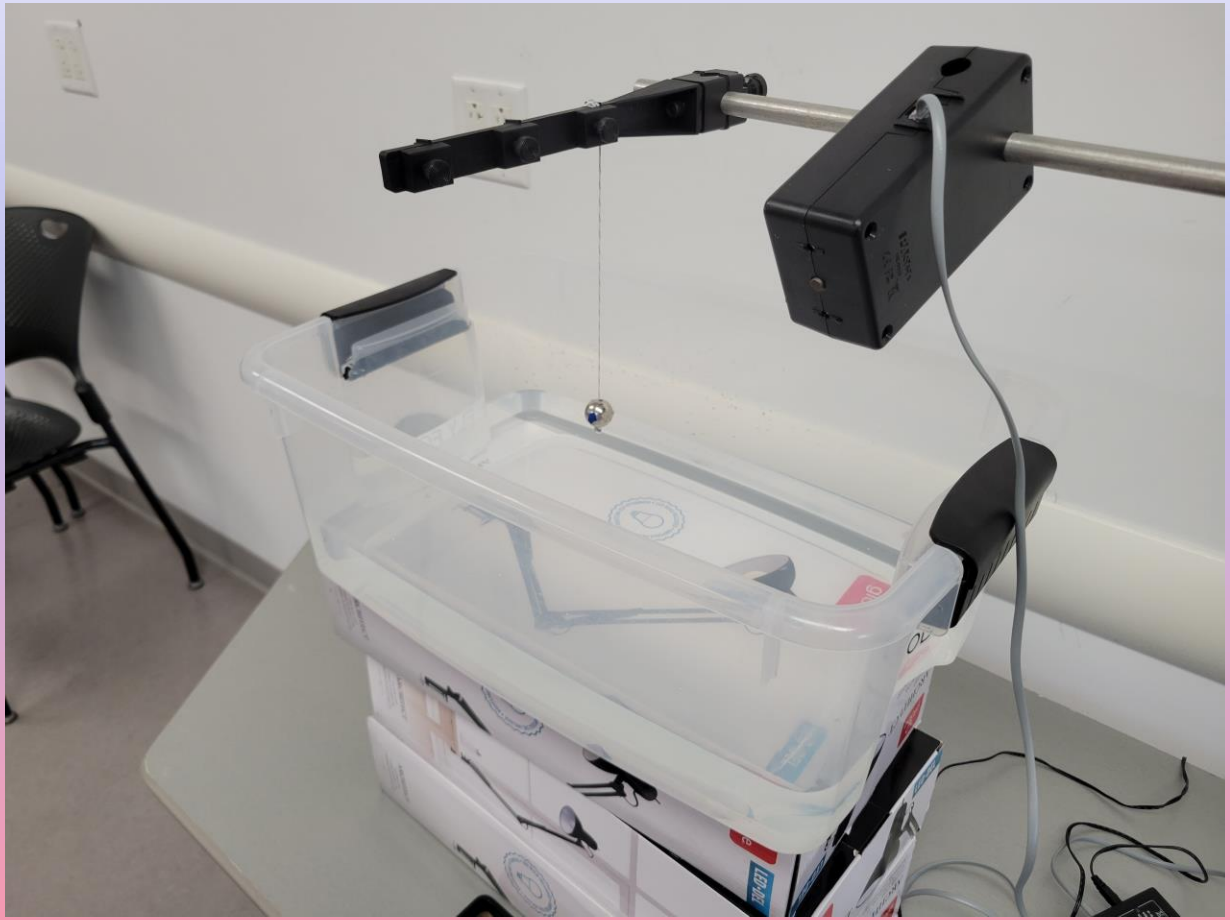
Steel Ball

String

Plastic Bin

Phone Holder

Meter Stick



Drop Box With Magnet

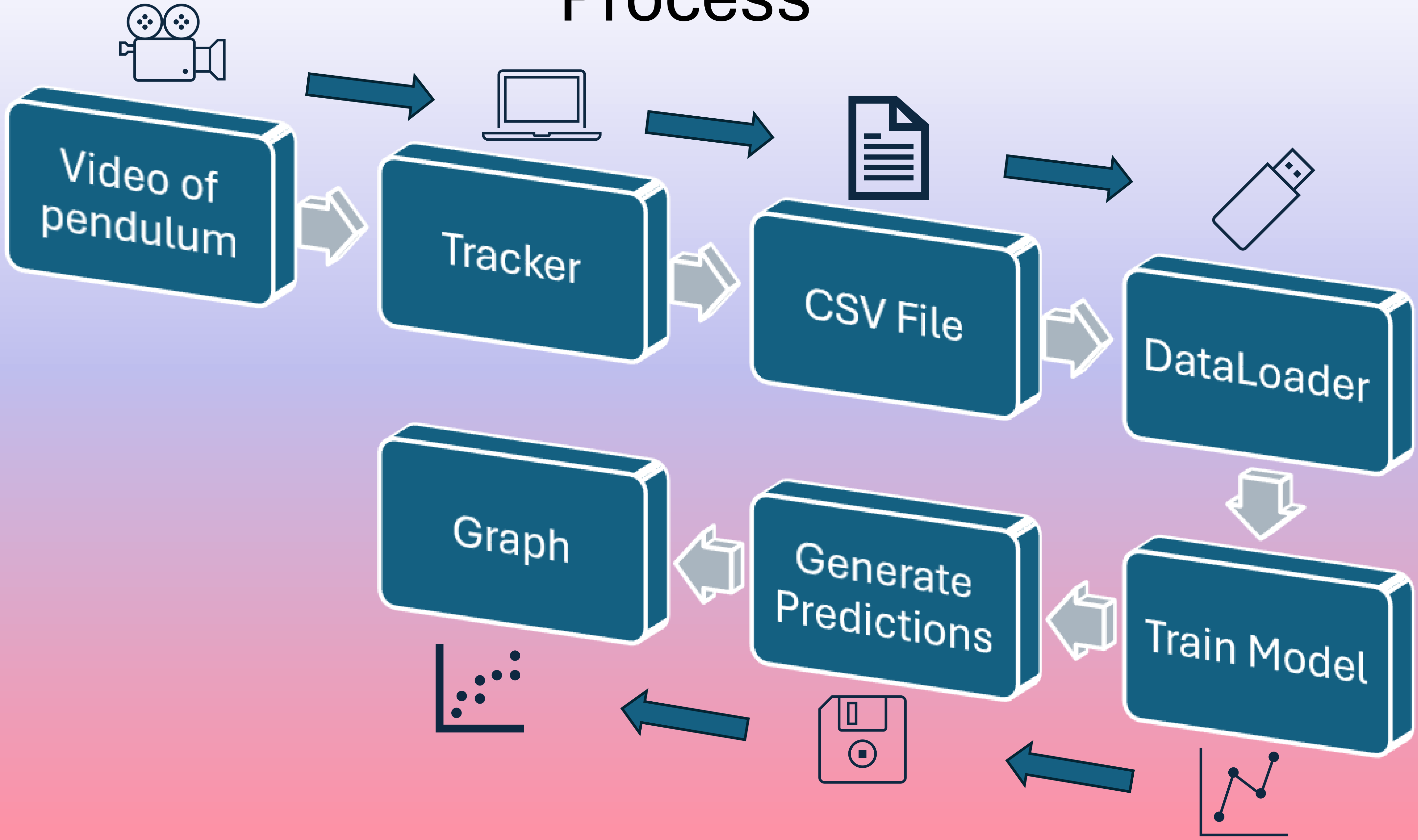
Control Box

Button

Large Table Clamp and Rod

Small Table Clamp and Rod

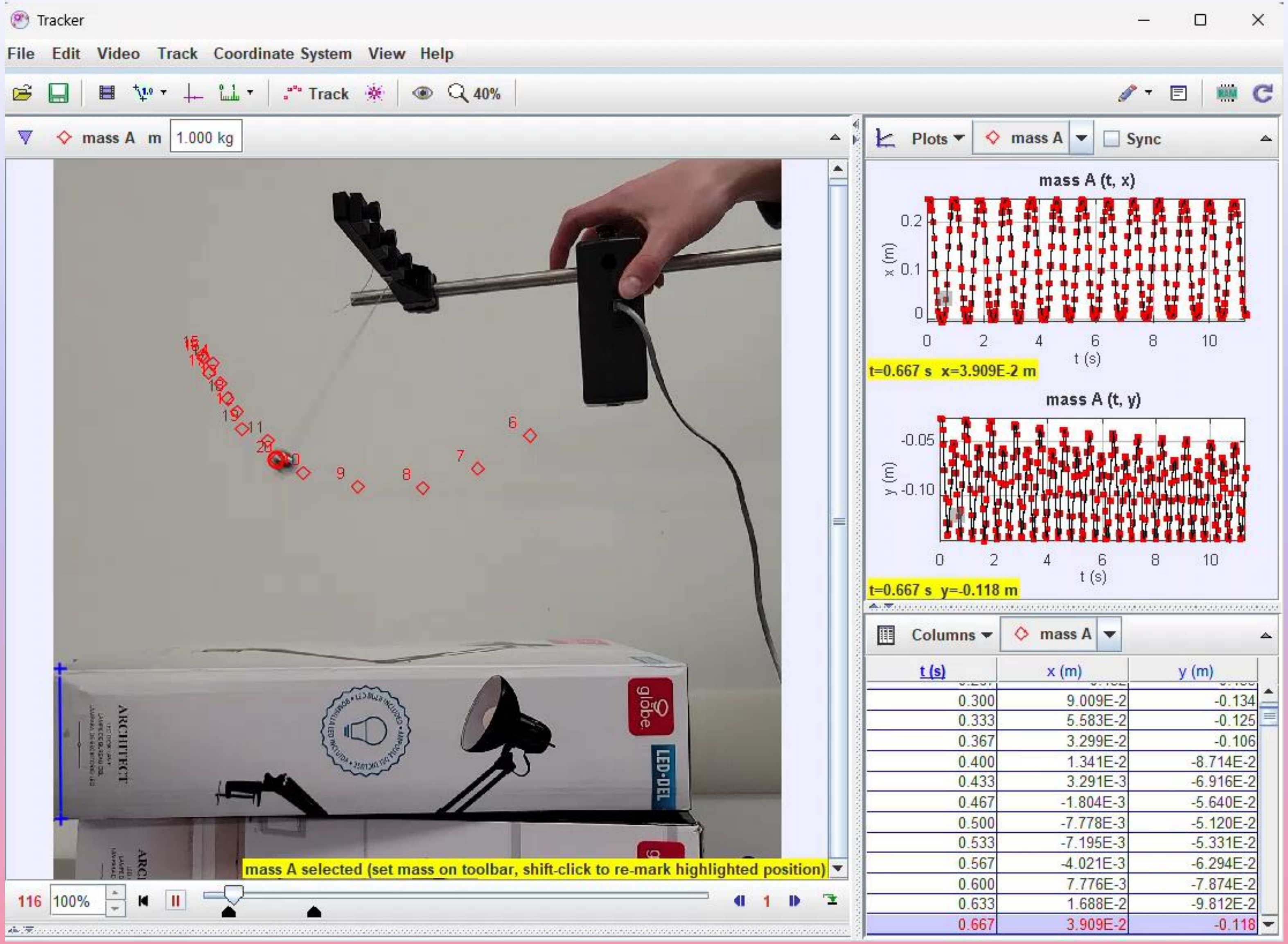
# Process


Video of pendulum
Tracker
CSV File
DataLoader
Train Model
Generate Predictions
Graph

# Data Collection

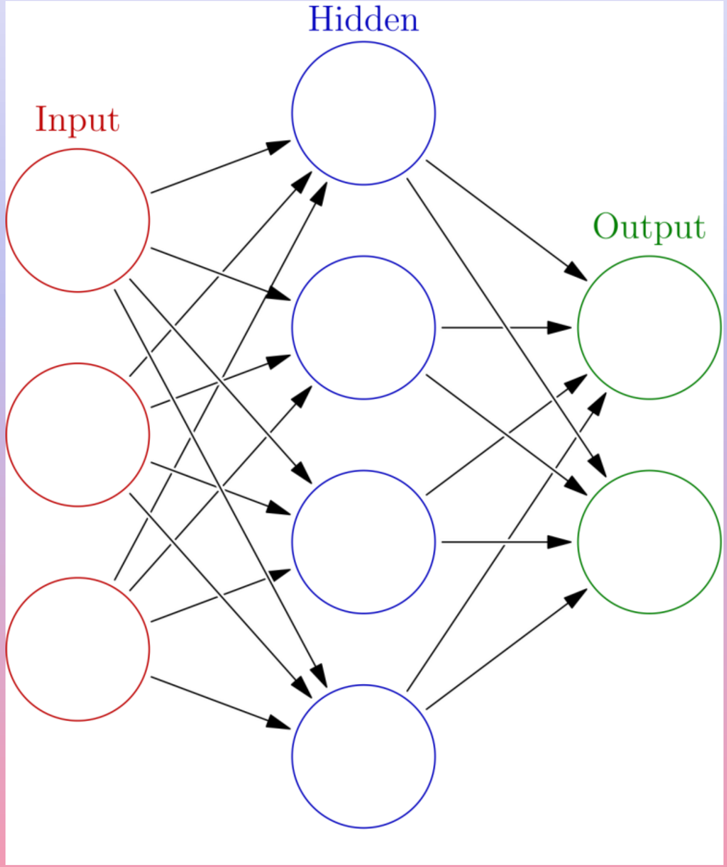
# Software

- Tracker
  - 30 fps vs 60 fps
- Python Notebook
  - Pytorch library
- CSV files



# Why Use Machine Learning for This?

- Simple pendulums can be easily modeled with traditional analytical equations
- Damped pendulums in fluids are complex
- ML can help by
  - Predicting motion without solving complex differential equations
  - Model behavior using experimental data



# Deciding How Many Data Points Are Important

- Considerations:
  - Training time
  - Computational power
- I ended up using about 5 files for each fluid
  - Each containing between 300 and 500 data points
- Very easy to modify

```
CONFIG = {
    "sequence_length":200,
    "prediction_length": 300,
    "hidden_size": 256,
    "num_layers": 4,
    "learning_rate": 0.001,
    "batch_size": 32,
    "dropout": 0.2,
    "epochs": 150
}
```

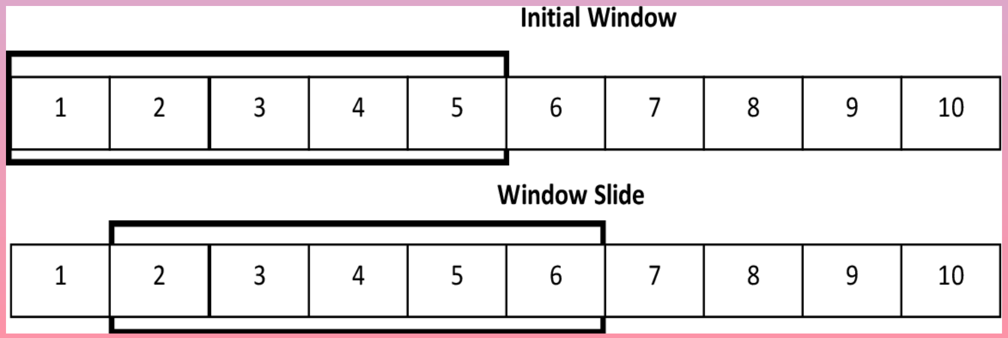
# Training one model vs training multiple

| One Model | Multiple Models |
| --- | --- |
| Learns patterns for all fluids (more adaptable) | Less data efficient |
| Only train once | Must train separately for each fluid |
| Easier to add more fluids later | No risk of fluid type confusion |
| Smaller storage space | More storage space |

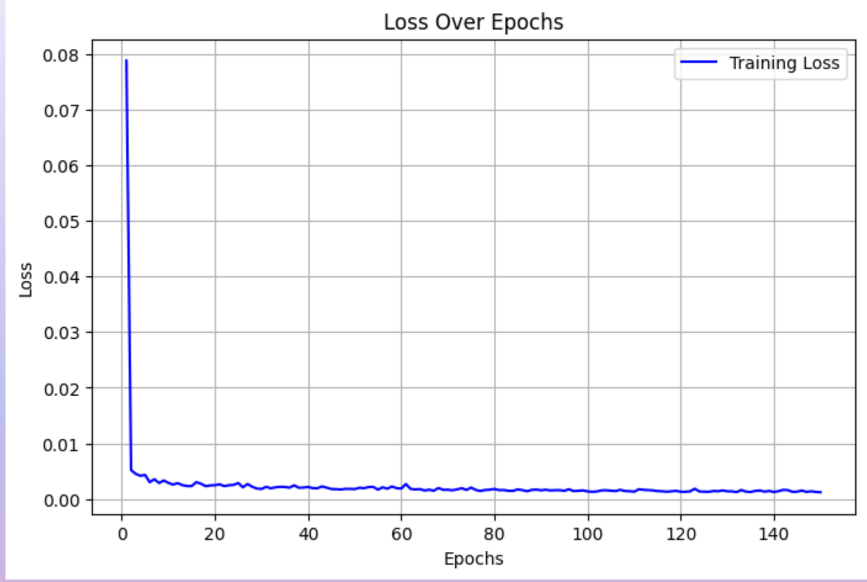
# Data Processing

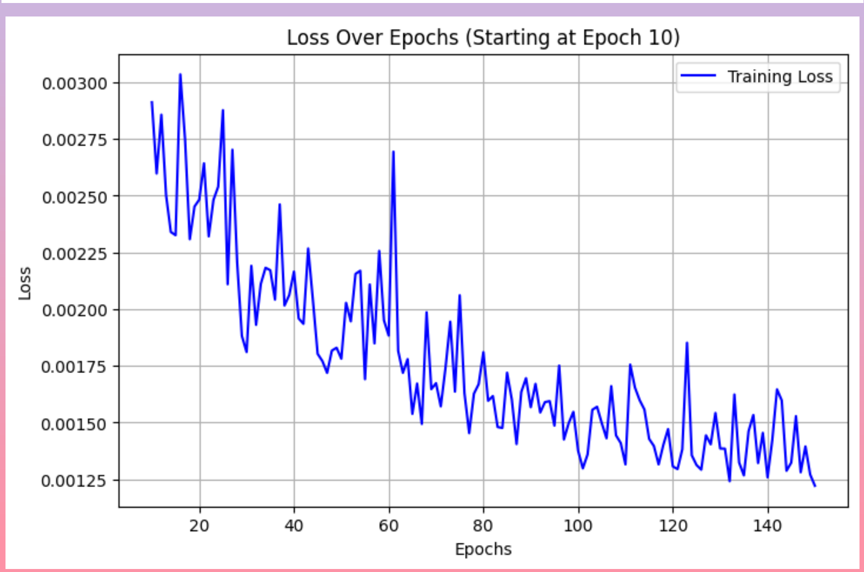
# LSTM

- LSTM stands for Long Short-Term Memory
- Models like this can store data from multiple different time periods in a dataset
- Data is classified in terms of importance for future predictions and re-evaluated at each full training run-through (Epoch)
- The primary goal of any machine learning model is to minimize loss between actual and predicted values



# Training




$$\frac{1}{\underset{\text{number of samples}}{\boxed{n}}}\underbrace{\sum_{i=1}^{\boxed{n}}\left(\overset{\text{real value}}{\boxed{Y_i}}-\overset{\text{predicted value}}{\boxed{\hat{Y}_i}}\right)^2}_{\text{sum of the errors of all samples}}$$

```
100%  77/77 [00:02<00:00, 29.06it/s]
Epoch 8/125, Loss: 0.0031301827221358945
100%  77/77 [00:02<00:00, 33.46it/s]
Epoch 9/125, Loss: 0.003398802368780719
100%  77/77 [00:02<00:00, 35.92it/s]
Epoch 10/125, Loss: 0.0030652529033892728
100%  77/77 [00:02<00:00, 35.03it/s]
Epoch 11/125, Loss: 0.0031389225434584472
79%  61/77 [00:02<00:00, 25.97it/s]
```

# Challenges

- Shaky Video
- Inconsistent Starting Point
- String Friction
- Tracking Shiny Ball
- Training Time
- Number of Data Points → The more data the better
- Cleaning up CSV Files → Deleting extra lines

# Solutions

Shaky Video

CapCut Video editor stabilize feature

# Solutions

Inconsistent Start Point

Drop Box and Push Button


Drop Box

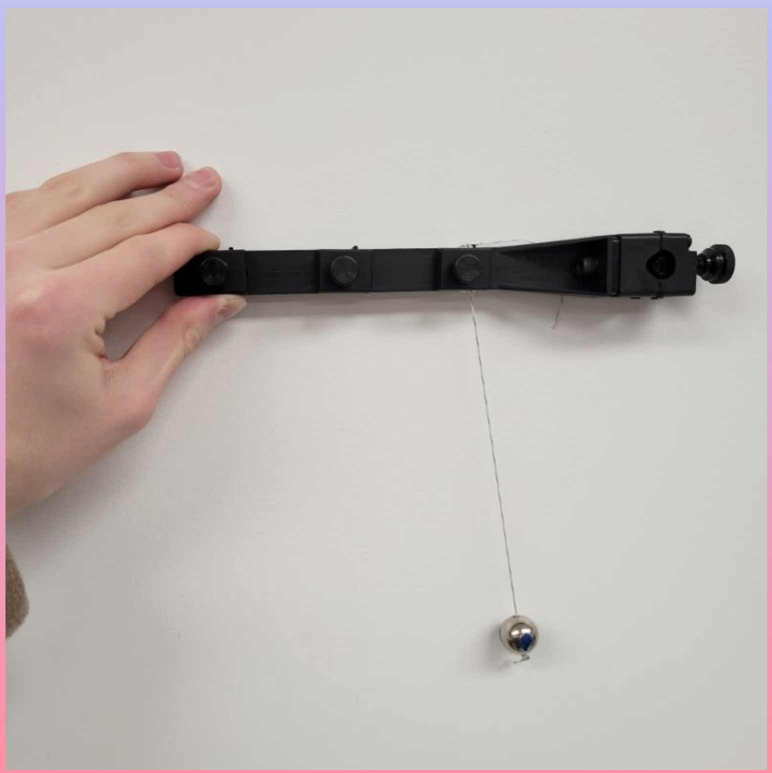

Control Box

Button

# Solutions

String Friction

Pendulum Clamp



# Solutions

Shiny Ball

Tape/Recolor

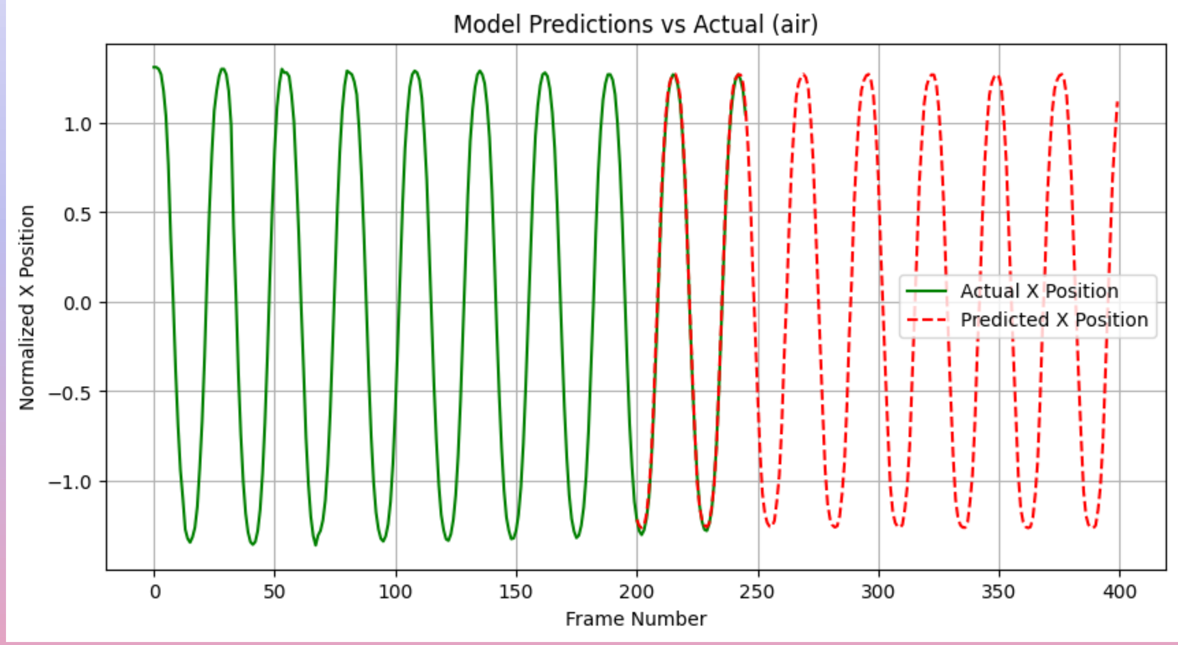
# Solutions

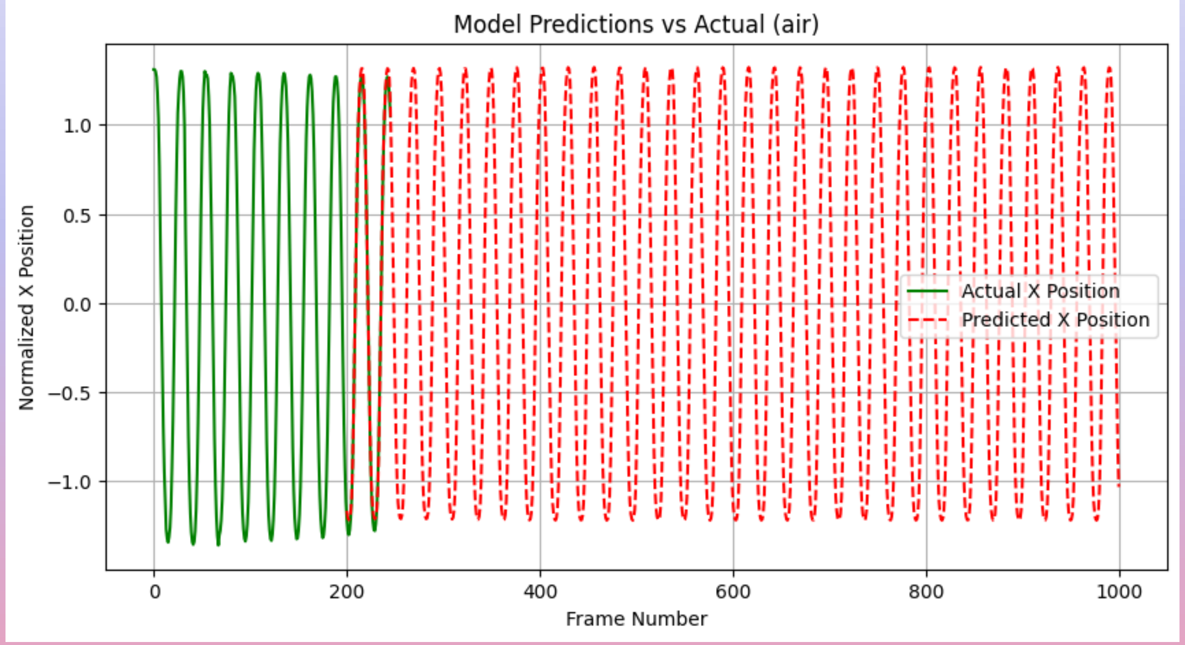
Training Time → Reduce Features

| Features: x,y,vx,vy | Features: x |
|---|---|
| **Epochs: 125** | **Epochs: 125** |
| `Training took 2230.79 seconds` | `Training took: 259.19 seconds` |
| $\frac{2230s}{60s/min} \approx 37min$ | $\frac{259s}{60s/min} \approx 4.3min$ |

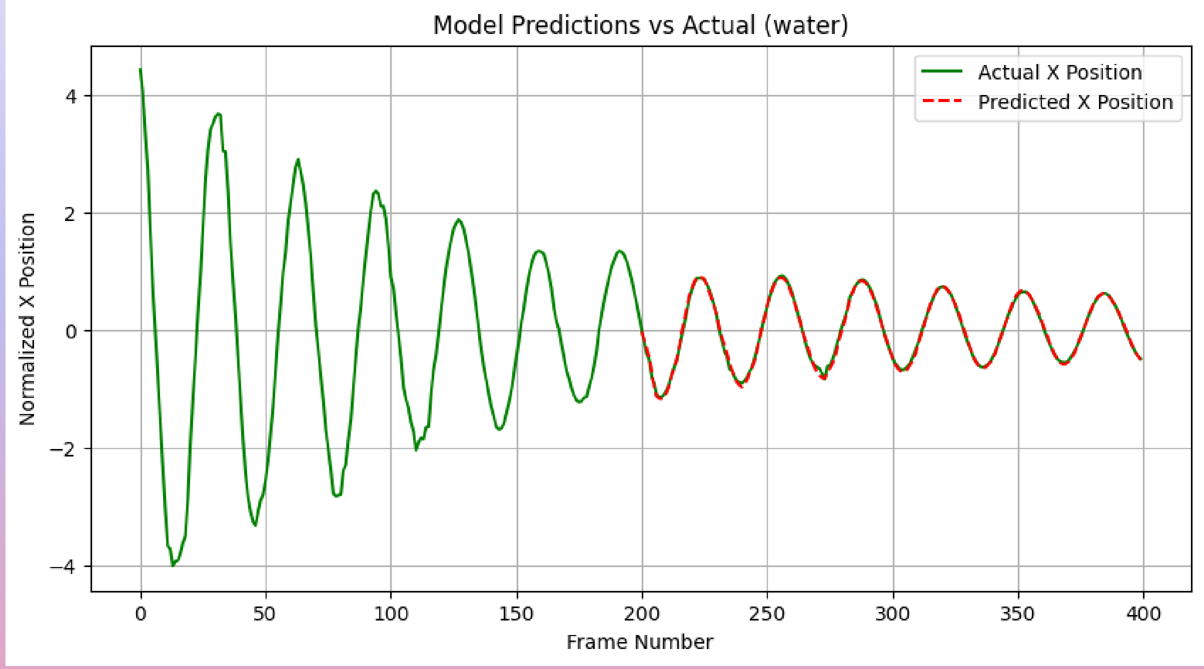
# Analysis

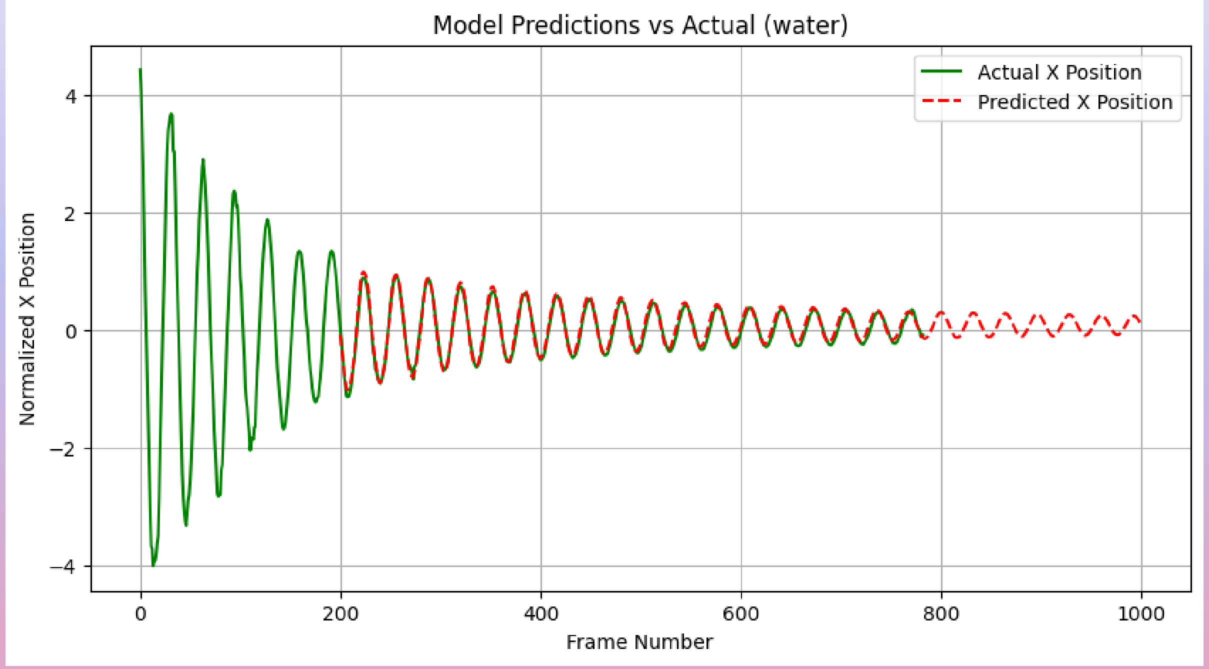
# Predictions



# Predictions



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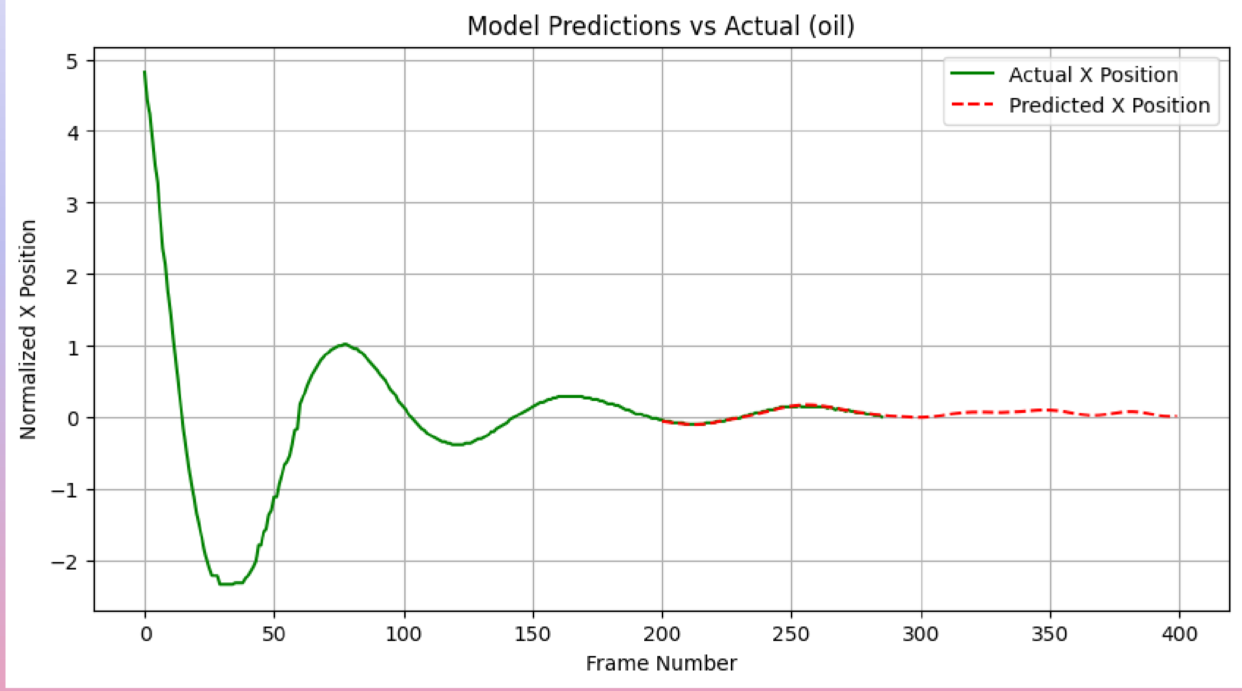
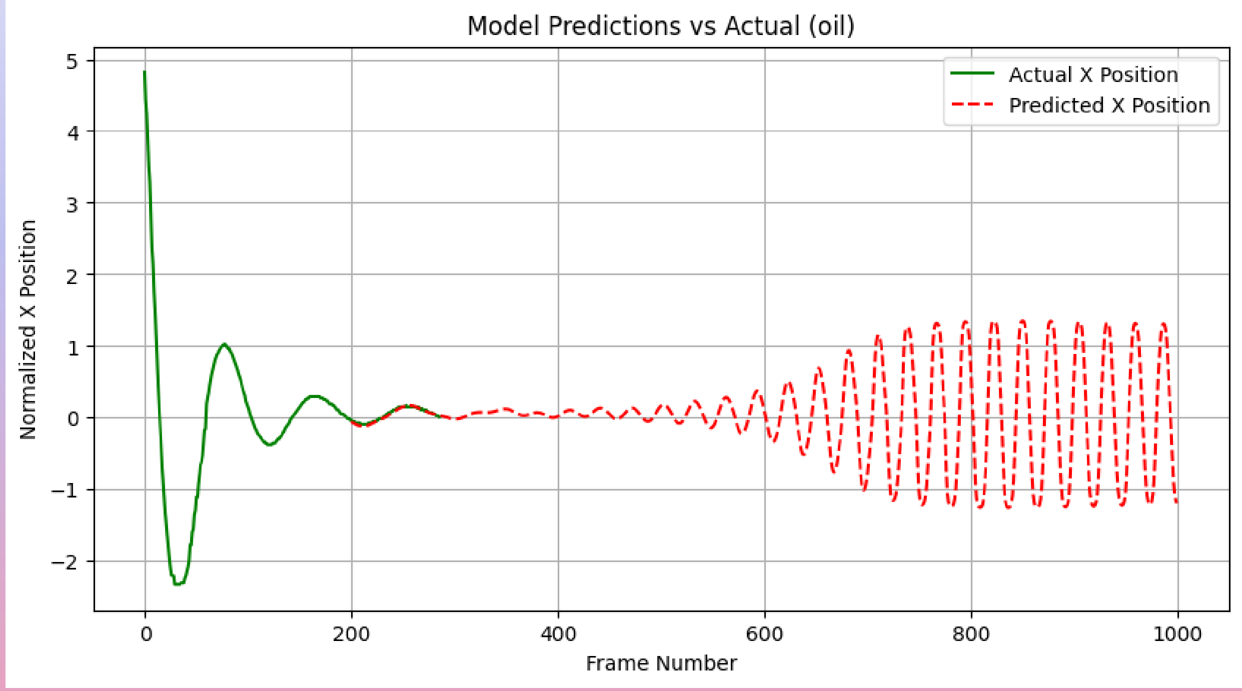
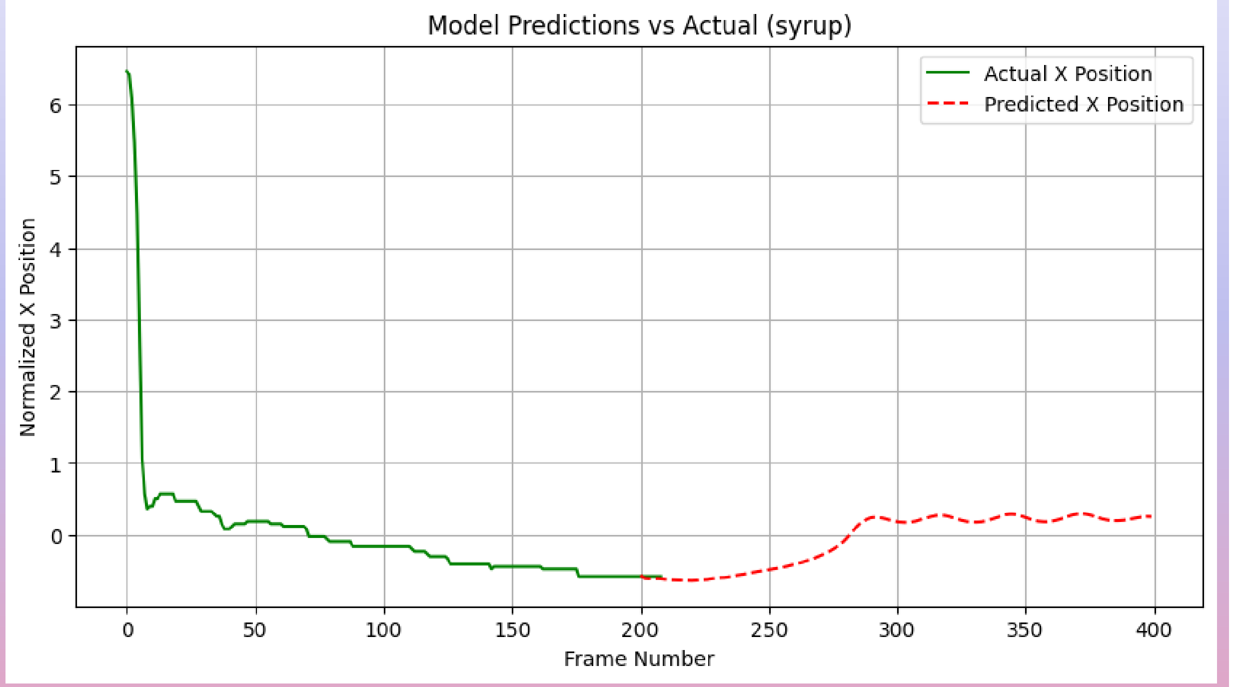
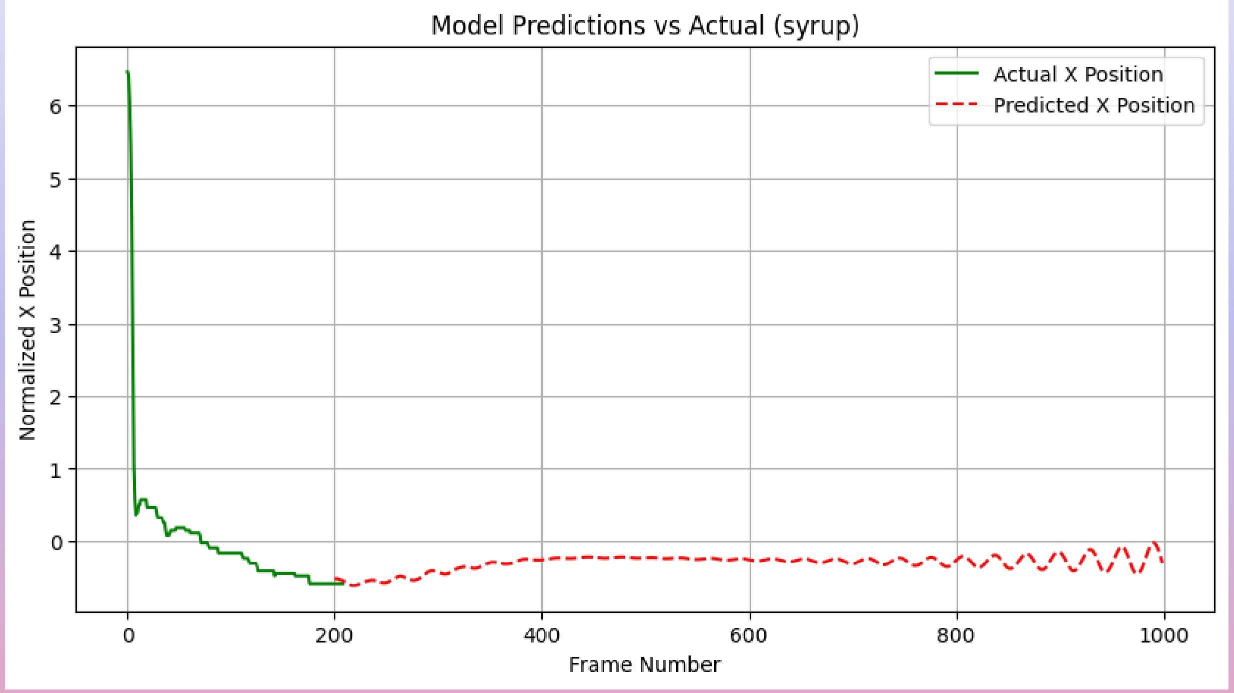


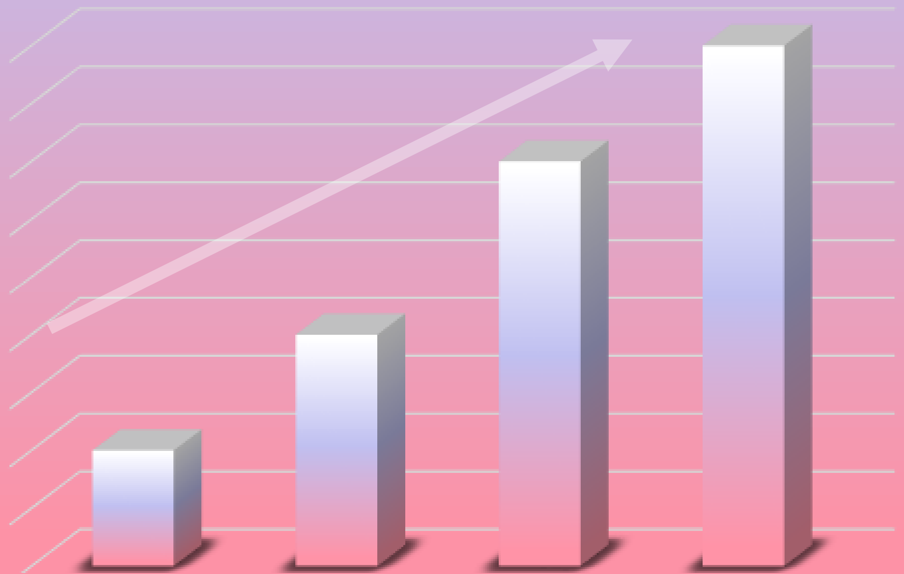
# Predictions



# Future Improvements

- Using water and water thickener to show how different amounts of thickener change viscosity and period
  - Easier cleanup
- Different Tracker Application using AI
- Increase feature size for more predictions (y, vx, vy…)



# Questions