# The Effect of Using Spreadsheets as a Deployment Method for Understanding Physics Models

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# Introduction

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- How can spreadsheets be used as a deployment tool to help students gain a better grasp of physics models in Newtonian mechanics?

# Literature Review

- The Modeling Cycle includes (Halloun, 2004):
  - Model development
  - Model deployment
- Modeling focuses on models and conceptual understanding, not mathematical equations (Jackson, Dukerich, & Hestenes, 2008)
  - May mean fewer opportunities for real-world applications and computational problem-solving

# Literature Review

- Next Generation Science Standards (Achieve, Inc.)
  - **Using Mathematics and Computational Thinking**
  - "Computers and digital tools can enhance the power of mathematics by automating calculations [and] approximating solutions to problems that cannot be calculated precisely…"
  - "Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system."

# Literature Review

- Computer applications and simulations can become “mindtools” that require students to think deeply about the problem at hand (Jonassen, 1996) (Land & Hannafin, 1996).
  - Computation intimately exposes students to relationships between variables (Arons, 1997)
- VPython programming has been used in physics education
  - Learning syntax is hard (Caballero et al., 2011)
  - Only one-third of students were successful on a VPython assignment in Aiken’s 9th grade physics course (2013)
- Spreadsheets have been successfully implemented in middle and high school (Lee, Chu, & Ip, 2005)

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READY 100%

# The Treatment

- Each teacher taught the standard modeling curriculum & introduced 5 treatments with a spreadsheet theme.
  - Students created spreadsheets to strengthen models by
    - Applying models to physical phenomena.
    - Answering questions about relationships between variables.
    - Interpreting graphical representations.
    - Making predictions.

# Our Treatment

1. Constant Velocity Spreadsheet
2. Speeder-Patrolman Problem
3. Model Rocket Project & Spreadsheet
4. Projectile Motion Spreadsheet
5. Energy Spreadsheet

# School Demographics

| | Treatment Group 1 | Treatment Group 2 |
|---|---|---|
| Total School Enrollment | 2200 | 160 |
| Free/Reduced Lunch (%) | 35 | 90 |
| African American | 14 | 76 |
| Asian | 8 | 1 |
| Caucasian | 45 | 24 |
| Hispanic | 32 | 0 |
| Other | 1 | 0 |

# Treatment Groups

| | Treatment Group 1 | Treatment Group 2 |
|---|---|---|
| Type of Class | AP Physics C: Mechanics | Regular Physics |
| Number of Students | 30 | 8 |
| Grade of Students | 10, 11, 12 | 12 |
| Schedule | 1.5 hours, every other day | 53 minutes daily |
| Math Level | Concurrent Calculus 1 | Concurrent Pre-Calculus |

# Speeder & Patrolman Problem

- "A speeder driving down the road at a constant 20 m/s, passes a patrolman parked on the roadside. The patrolman waits 3 seconds, then pursues the speeder, accelerating at a constant 4.0 m/s$^2$. When the does the patrolman catch the speeder?"

Constant Velocity Model

Uniform Acceleration Model

Sheet1

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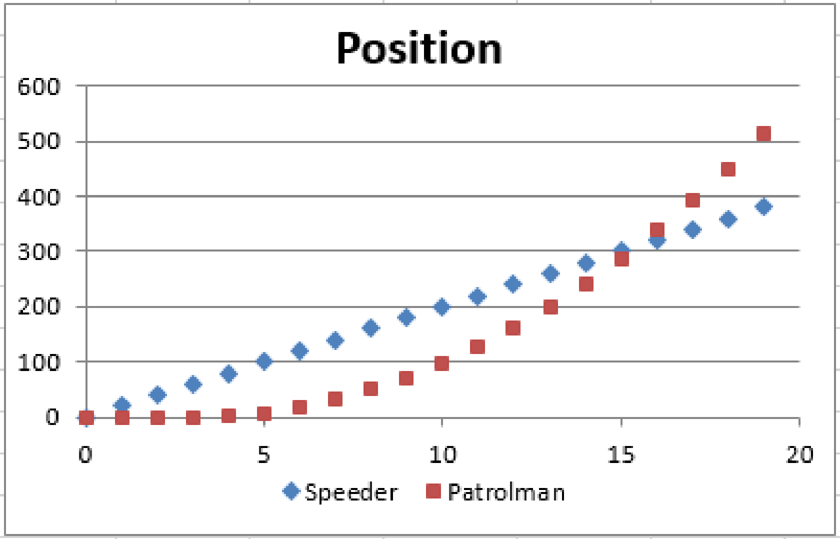
# Speeder & Patrolman Problem

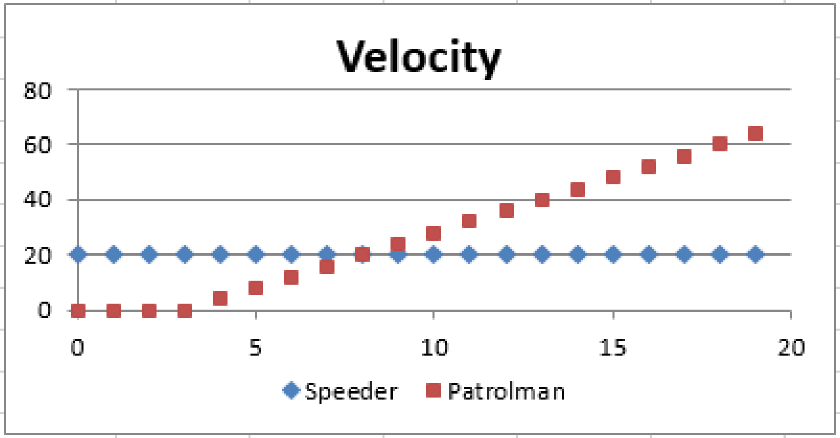
- Students were beginning to get comfortable using Excel to calculate values
- Groups used several different methods to solve the problem (algebraic, graphical, numerical)
- Students found the 3-second delay was the most difficult item to account for in their Excel equations

# Completed Spreadsheet

| | | | | | | |
|---|---|---|---|---|---|---|
| starting p | 0 | m | patrolman's | | | |
| velocity | 20 | m/s | acceleration | 4 | m/s/s | |

| | Speeder | | Patrolman | |
|---|---|---|---|---|
| Time | Position | Velocity | Position | Velocity |
| 0 | 0 | 20 | 0 | 0 |
| 1 | 20 | 20 | 0 | 0 |
| 2 | 40 | 20 | 0 | 0 |
| 3 | 60 | 20 | 0 | 0 |
| 4 | 80 | 20 | 2 | 4 |
| 5 | 100 | 20 | 8 | 8 |
| 6 | 120 | 20 | 18 | 12 |
| 7 | 140 | 20 | 32 | 16 |
| 8 | 160 | 20 | 50 | 20 |
| 9 | 180 | 20 | 72 | 24 |
| 10 | 200 | 20 | 98 | 28 |
| 11 | 220 | 20 | 128 | 32 |
| 12 | 240 | 20 | 162 | 36 |
| 13 | 260 | 20 | 200 | 40 |
| 14 | 280 | 20 | 242 | 44 |
| 15 | 300 | 20 | 288 | 48 |
| 16 | 320 | 20 | 338 | 52 |
| 17 | 340 | 20 | 392 | 56 |
| 18 | 360 | 20 | 450 | 60 |
| 19 | 380 | 20 | 512 | 64 |

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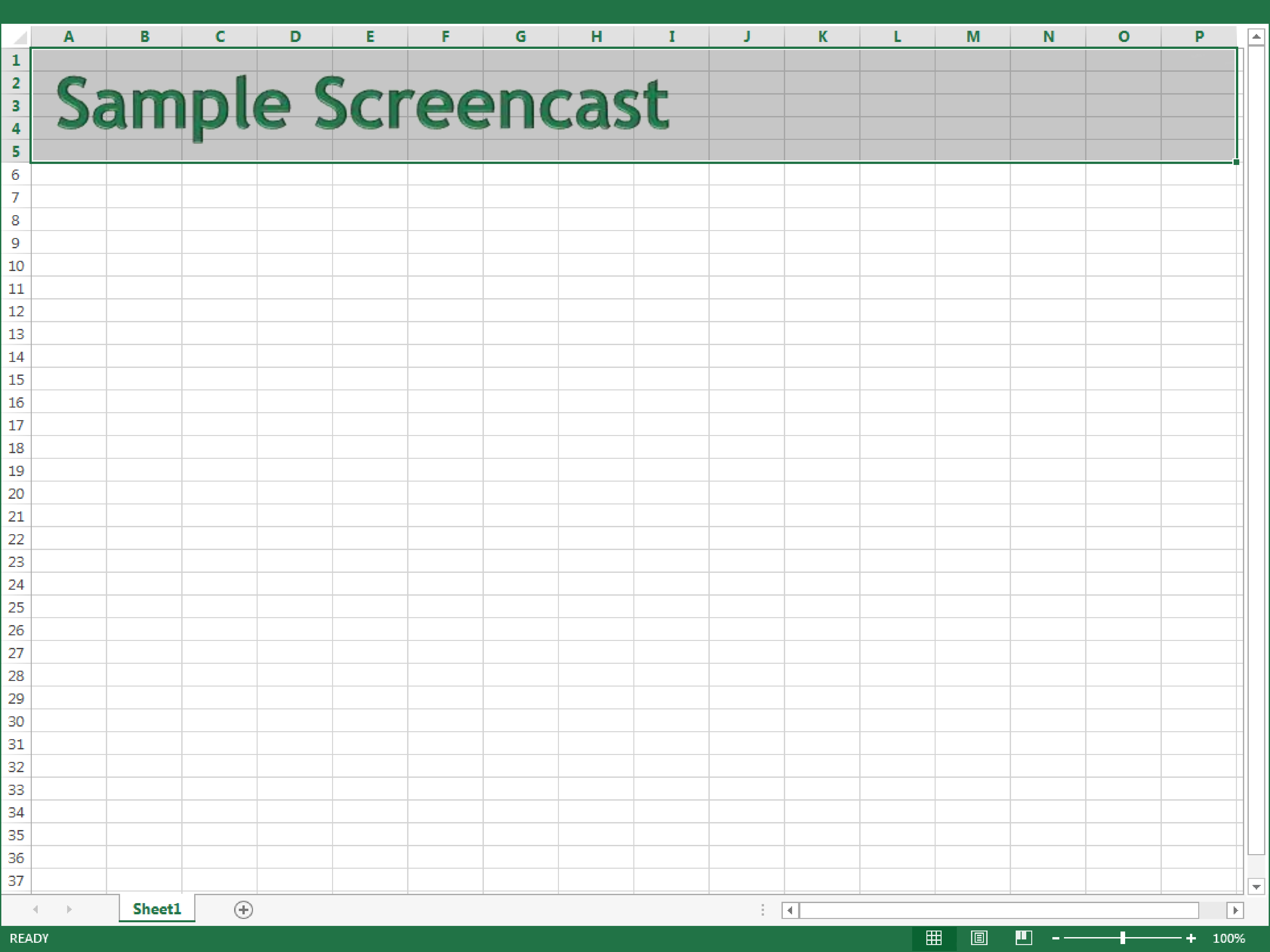
Sample Screencast
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# Screencasts

- Almost all groups had correct solutions
- Students' explanations revealed their depth of understanding of the models
  - Within groups, it was clear not every student had a complete understanding of their solution
- Several groups used the spreadsheet to present their solution, rather than using the spreadsheet to solve the problem
- Many students were choosing to use Excel for further physics problem-solving

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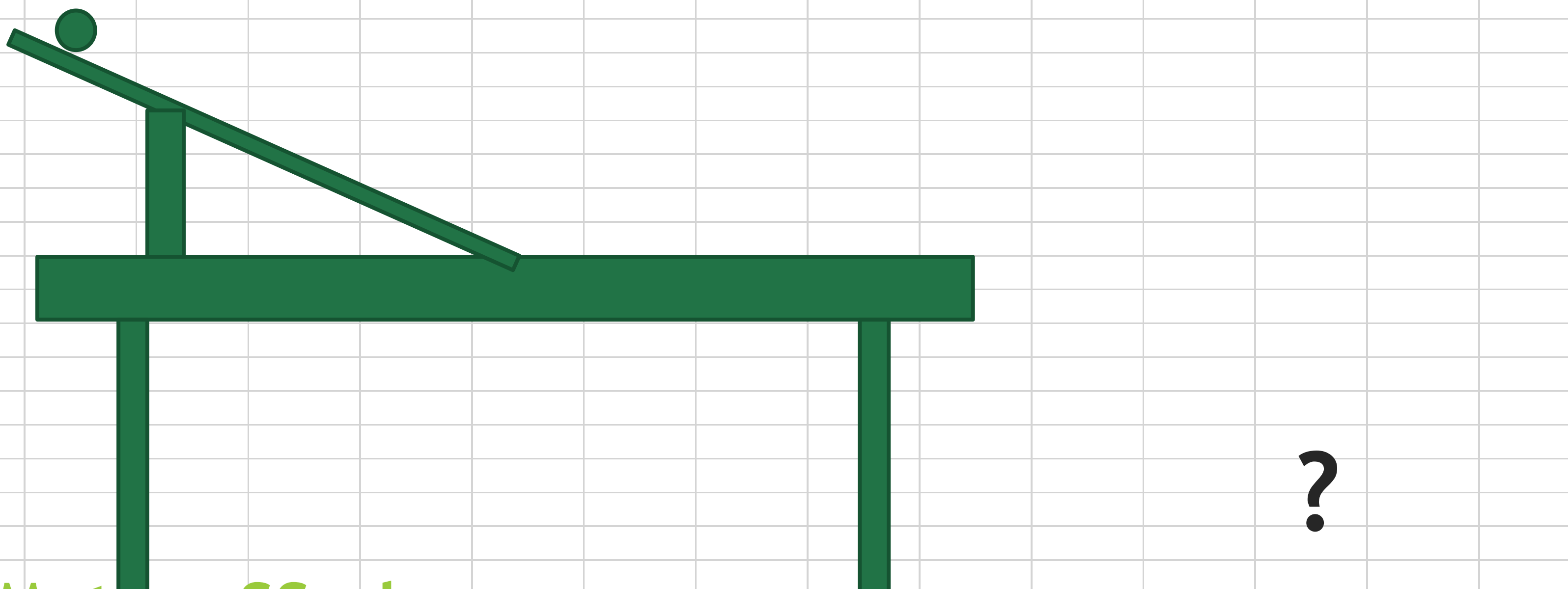
# Two Dimensional Motion

- Two dimensional problem.




2D - Motion SS.xlsx

# Two Dimensional Motion

*Doubling the horizontal velocity will double the range of the marble… The faster one is traveling more meters in one second that the slow one and they both fall at the same speed. When I plugged in 10 for the horizontal velocity the range for two seconds was 20 and when I doubled the velocity the range at two seconds changed to 40. - Donnie*

*(Investigator 1 Field Notes)*

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# Two Dimensional Motion

When asked about objects moving at different horizontal velocities….

*"Actually, they should both take the same time to drop, assuming they're dropped from the same height (and the same planet). Horizontal velocity has no effect on the y-position, the only things that affect the time to impact is the initial height."* - Matt

# 2D Motion Summary

- Spreadsheet was a natural fit.
- Helped students apply old models to new situations.
- Helped students to understand independence of two models.
- It was fun and competitive!

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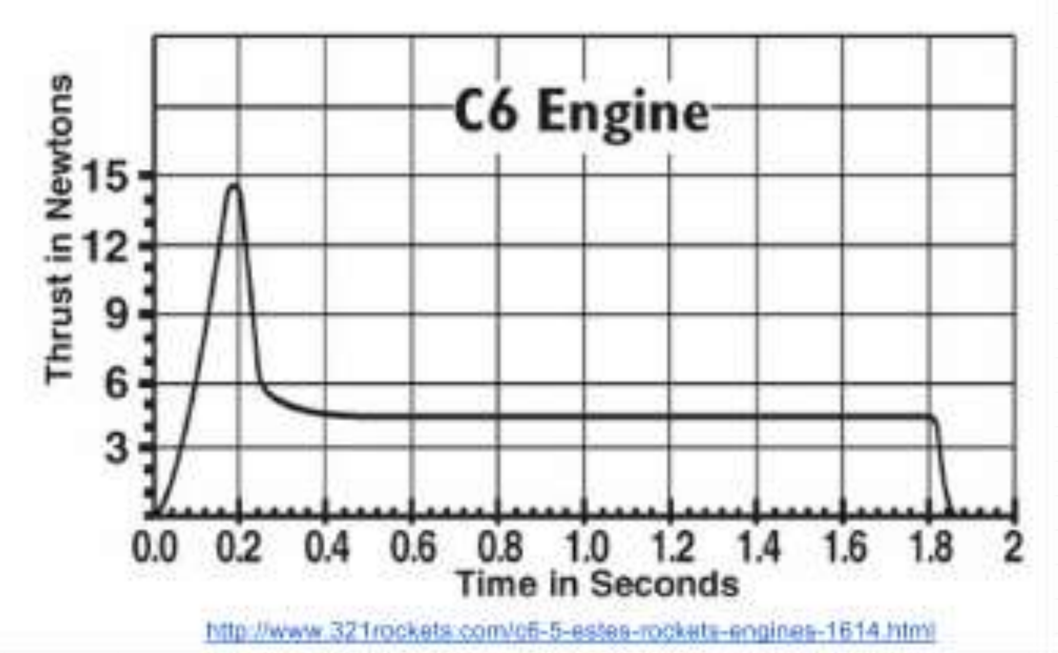
# Model Rocket Project

## Phase One: Frictionless

- Students modeled the flight of a 100-g rocket
- The thrust profile of the engine was provided

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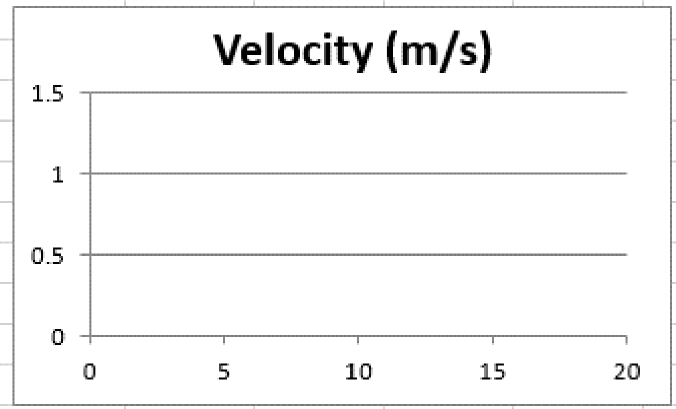
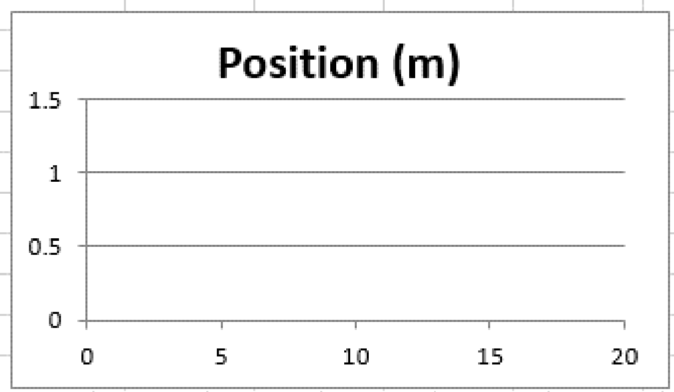
# Model Rocket Project

## Phase One: Frictionless

| Mass | 100 | g |
|---|---|---|

| Time (s) | Thrust (N) (N) | Acceleration (m/s2) | Velocity (m/s) | Position (m) |
|---|---|---|---|---|
| 0 | 0 | | | |
| 0.04 | 1.20 | | | |
| 0.08 | 4.50 | | | |
| 0.12 | 8.00 | | | |
| 0.16 | 12.50 | | | |
| 0.20 | 14.00 | | | |
| 0.24 | 6.00 | | | |
| 0.28 | 5.00 | | | |
| 0.32 | 4.80 | | | |
| 0.36 | 4.50 | | | |
| 0.40 | 4.40 | | | |
| 0.44 | 4.40 | | | |
| 0.48 | 4.40 | | | |
| 0.52 | 4.40 | | | |
| 0.56 | 4.40 | | | |
| 0.60 | 4.40 | | | |
| 0.64 | 4.40 | | | |
| 0.68 | 4.40 | | | |
| 0.72 | 4.40 | | | |
| 0.76 | 4.40 | | | |

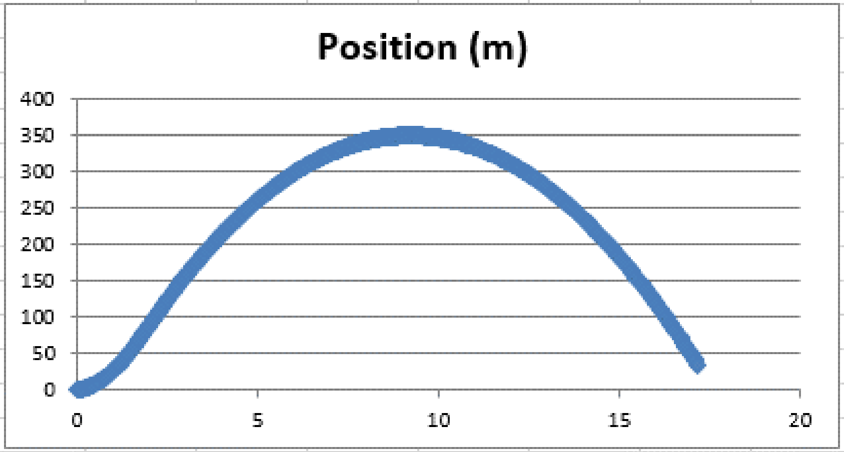


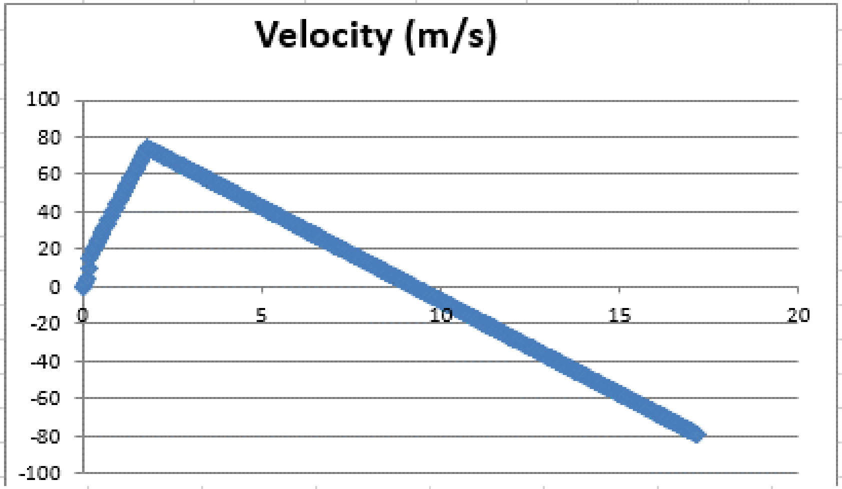



# Model Rocket Project

## Phase One: Frictionless

| Mass | 94.8 | g | | | |
|---|---|---|---|---|---|
| **Time (s)** | **Thrust (N) (N)** | **Force G (N)** | **Acceleration (m/s2)** | **Velocity (m/s)** | **Position (m)** |
| 0 | 0 | 0.948 | | 0 | 0 |
| 0.04 | 1.20 | 0.948 | 2.66 | 0.11 | 0.00 |
| 0.08 | 4.50 | 0.948 | 37.47 | 1.61 | 0.07 |
| 0.12 | 8.00 | 0.948 | 74.39 | 4.58 | 0.25 |
| 0.16 | 12.50 | 0.948 | 121.86 | 9.45 | 0.63 |
| 0.20 | 14.00 | 0.948 | 137.68 | 14.96 | 1.23 |
| 0.24 | 6.00 | 0.948 | 53.29 | 17.09 | 1.91 |
| 0.28 | 5.00 | 0.948 | 42.74 | 18.80 | 2.66 |
| 0.32 | 4.80 | 0.948 | 40.63 | 20.43 | 3.48 |
| 0.36 | 4.50 | 0.948 | 37.47 | 21.93 | 4.36 |
| 0.40 | 4.40 | 0.948 | 36.41 | 23.38 | 5.29 |
| 0.44 | 4.40 | 0.948 | 36.41 | 24.84 | 6.29 |
| 0.48 | 4.40 | 0.948 | 36.41 | 26.30 | 7.34 |
| 0.52 | 4.40 | 0.948 | 36.41 | 27.75 | 8.45 |
| 0.56 | 4.40 | 0.948 | 36.41 | 29.21 | 9.62 |
| 0.60 | 4.40 | 0.948 | 36.41 | 30.67 | 10.84 |
| 0.64 | 4.40 | 0.948 | 36.41 | 32.12 | 12.13 |
| 0.68 | 4.40 | 0.948 | 36.41 | 33.58 | 13.47 |
| 0.72 | 4.40 | 0.948 | 36.41 | 35.04 | 14.87 |
| 0.76 | 4.40 | 0.948 | 36.41 | 36.49 | 16.33 |
| 0.80 | 4.40 | 0.948 | 36.41 | 37.95 | 17.85 |
| 0.84 | 4.40 | 0.948 | 36.41 | 39.41 | 19.43 |
| 0.88 | 4.40 | 0.948 | 36.41 | 40.86 | 21.06 |
| 0.92 | 4.40 | 0.948 | 36.41 | 42.32 | 22.76 |

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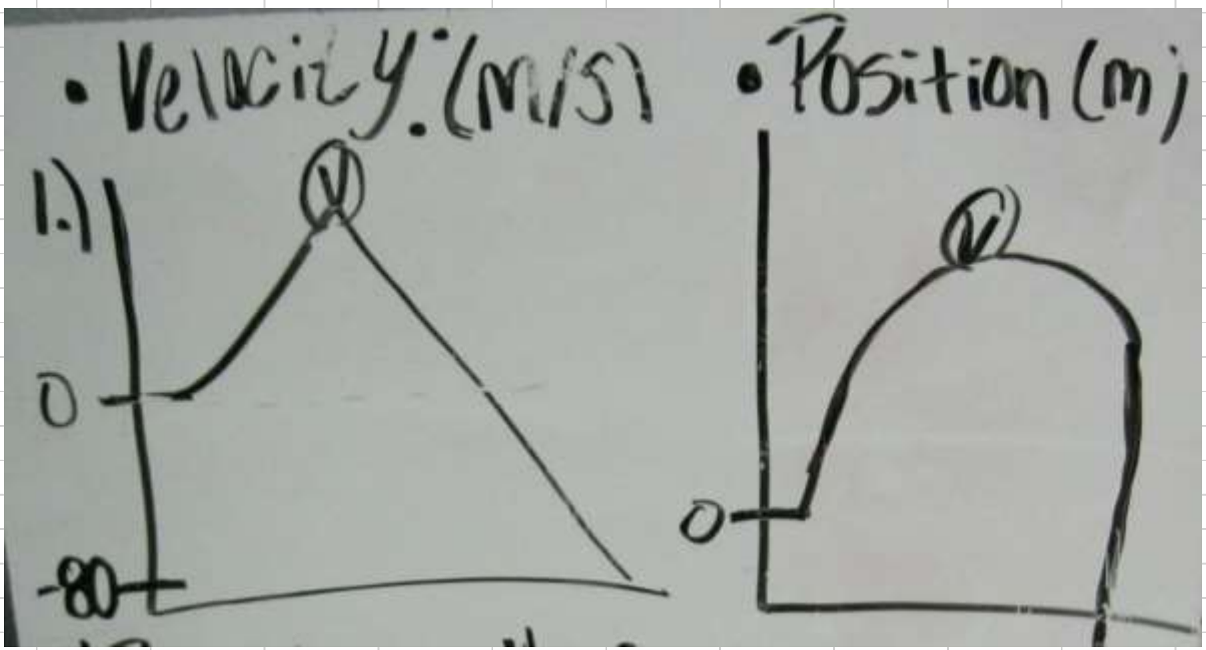
# Model Rocket Project

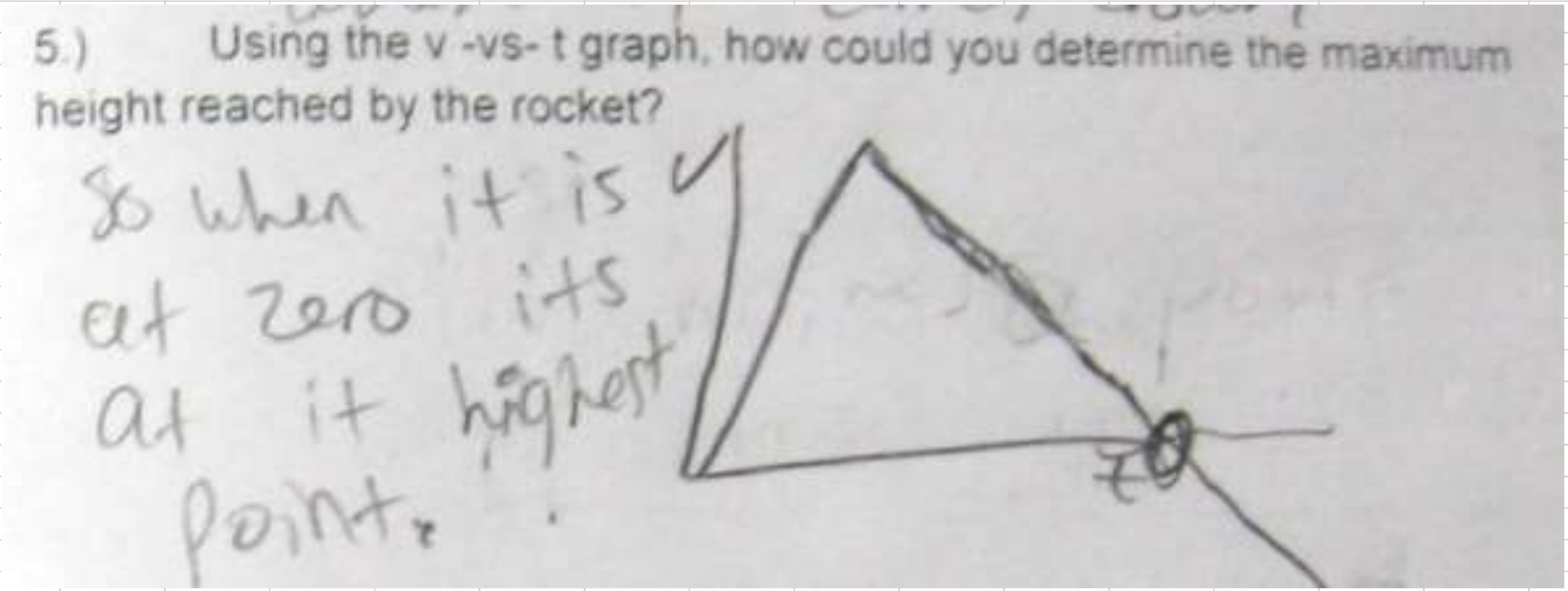
## Phase One: Frictionless

- Students sketched their graphs and were asked to place a “v” at the point where the rocket was going fastest.



# Model Rocket Project

## Phase One: Frictionless




- Students were again able to confront misconceptions and interpret graphs of motion

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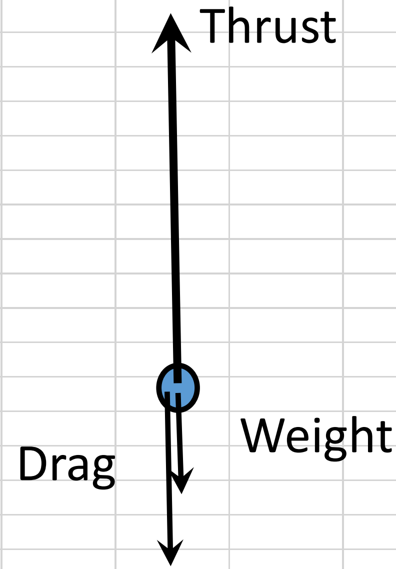
# Model Rocket Project

## Phase Two: Friction

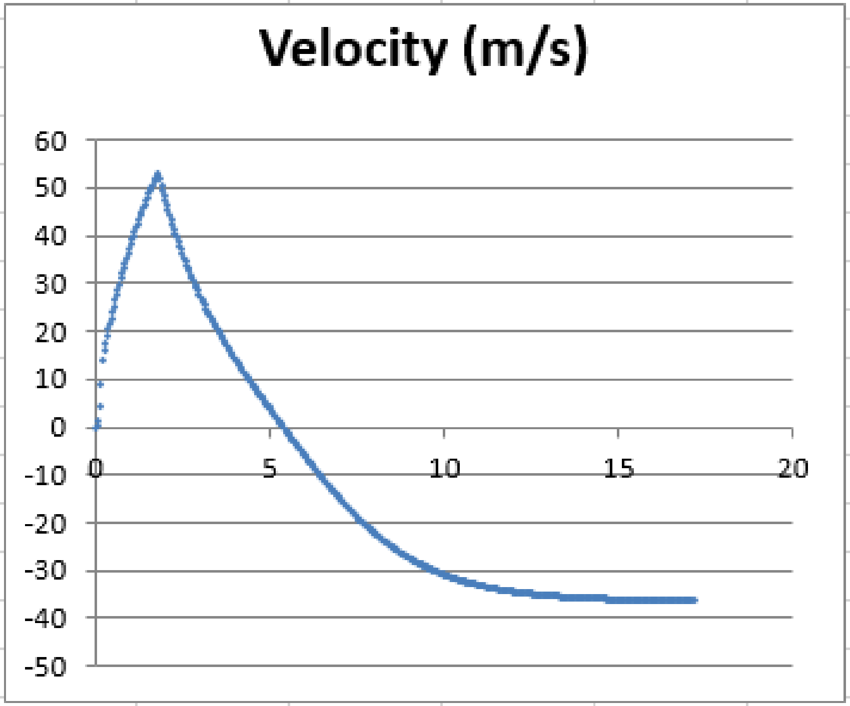
- Students now include friction in their design.

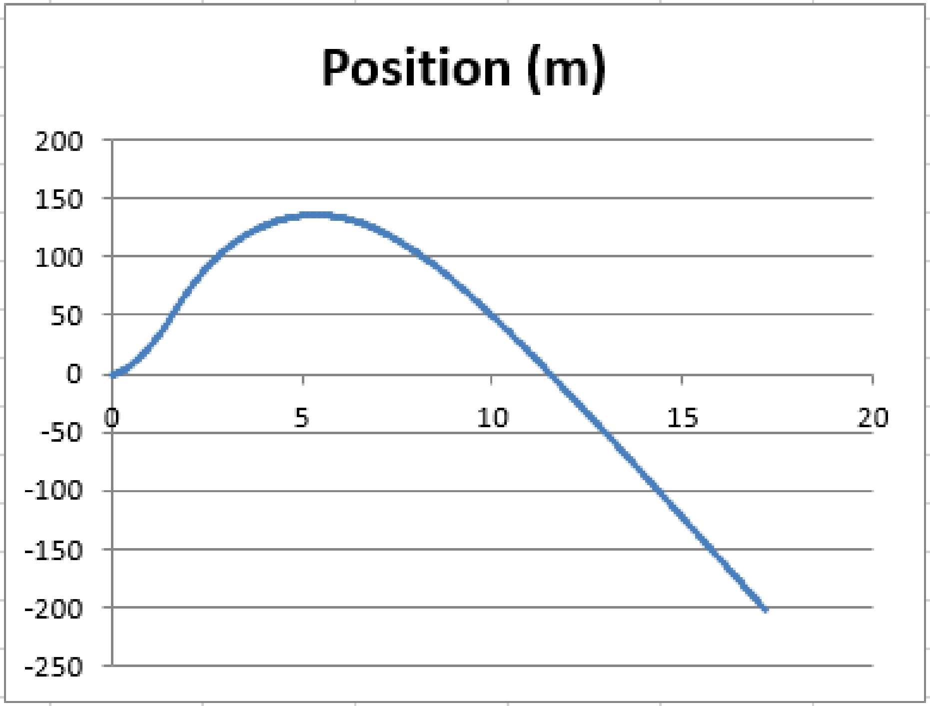



$$F_d = C_d \cdot \rho \cdot v^2 \cdot A$$

# Rockets: Phase 2

- Sample graphs from student spreadsheet.

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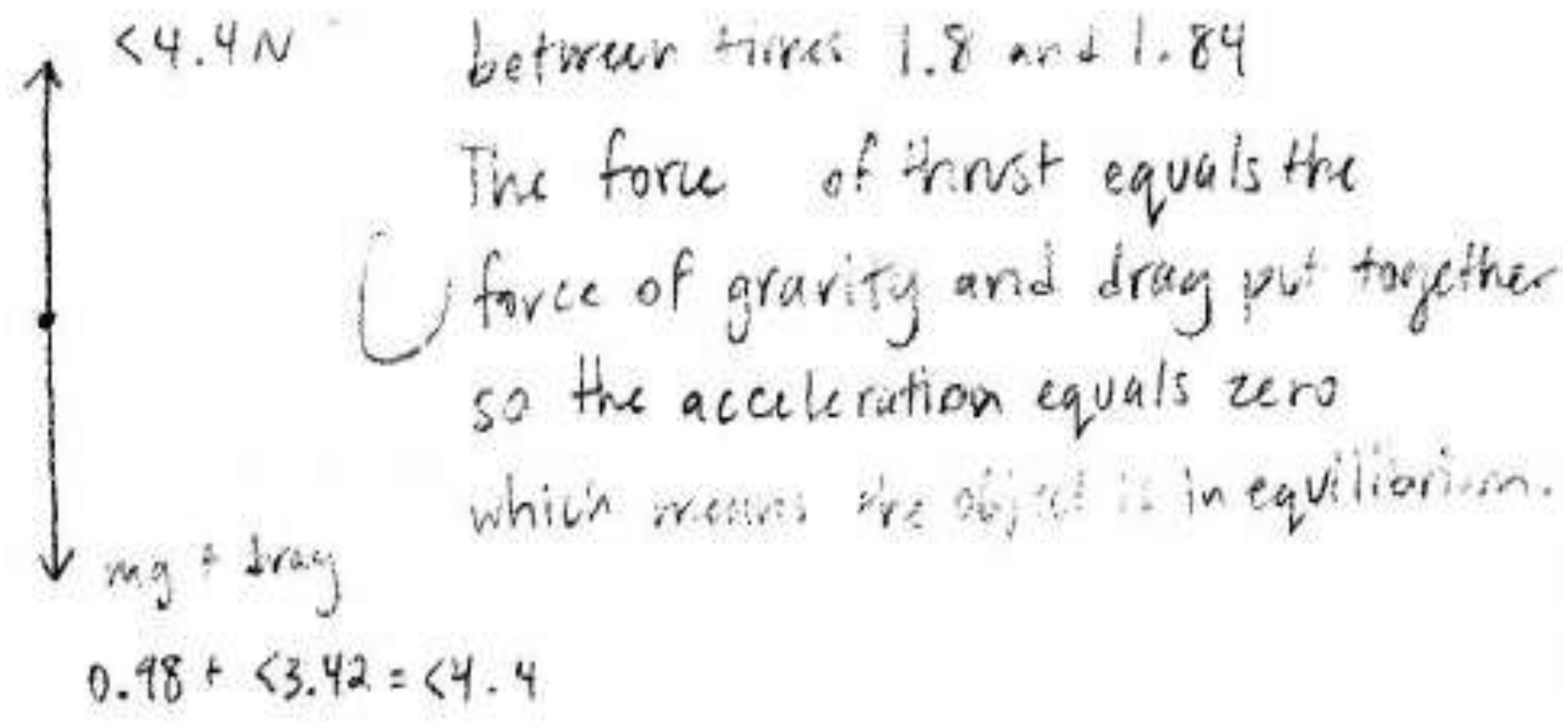
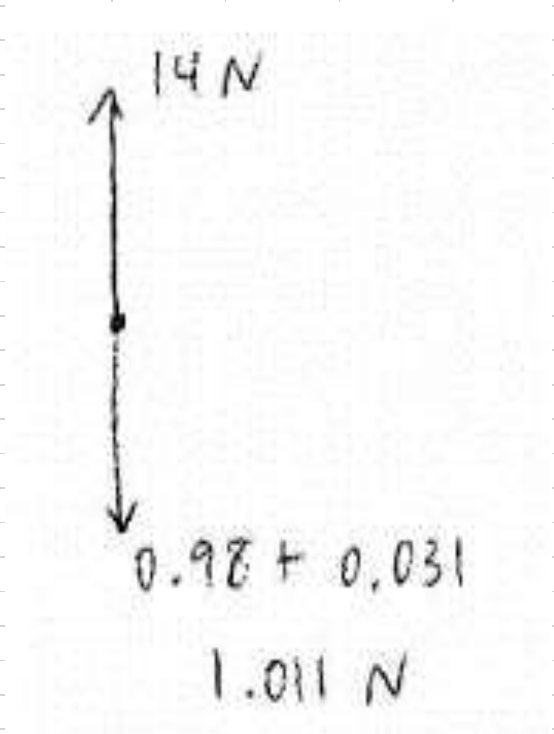
# Rockets: Phase 2

## Jamie’s Force Diagram: Equilibrium



# Rockets: Phase 2

## Jamie's Spreadsheet: Maximum Acceleration




*"At t = 0.2, a = 122.39. The upward force is the greatest at this time causing the acceleration to be the greatest at this time."*

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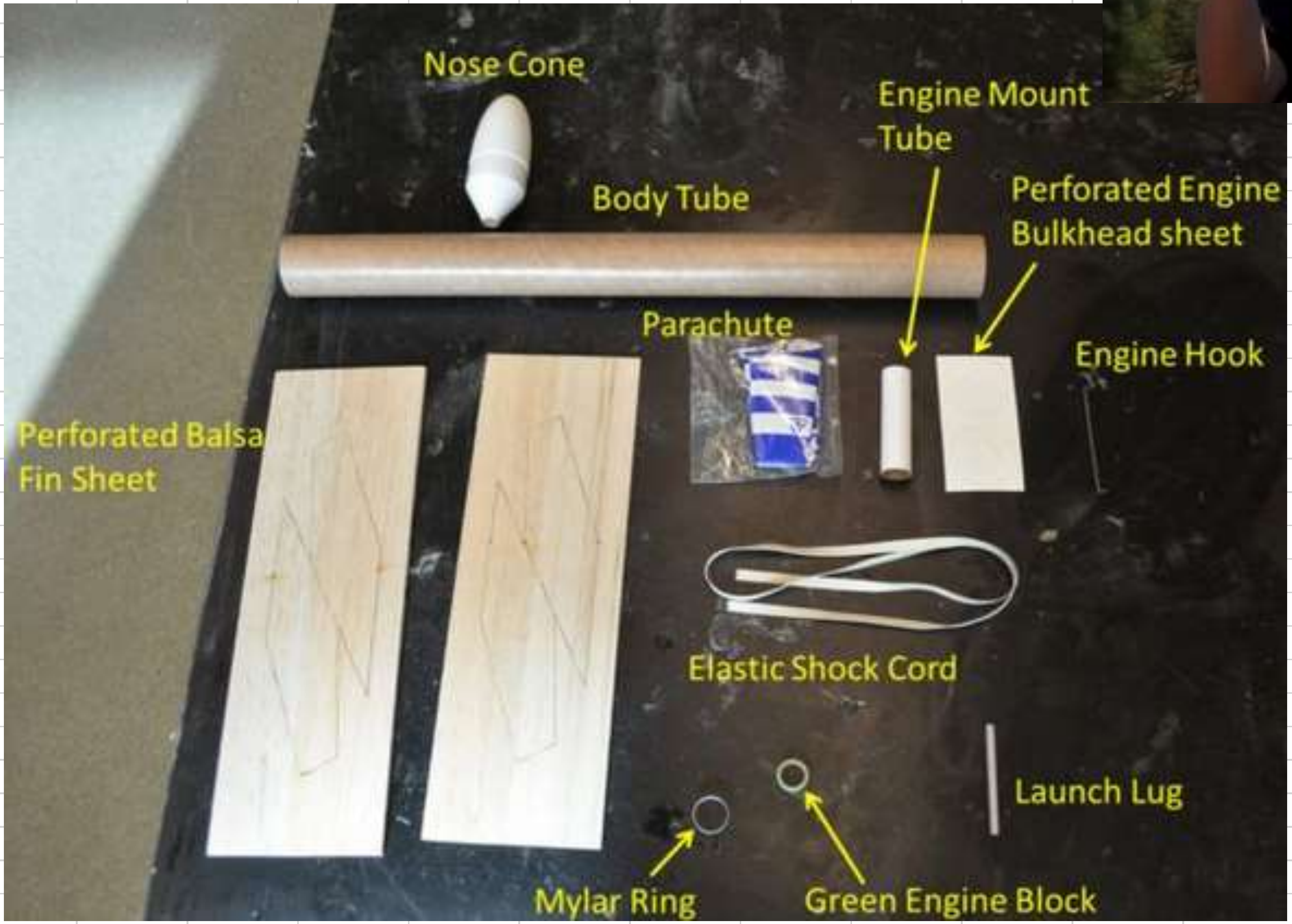
# Rockets: Phase 3

## It gets even better!!



# Phase 3: Rocket Video

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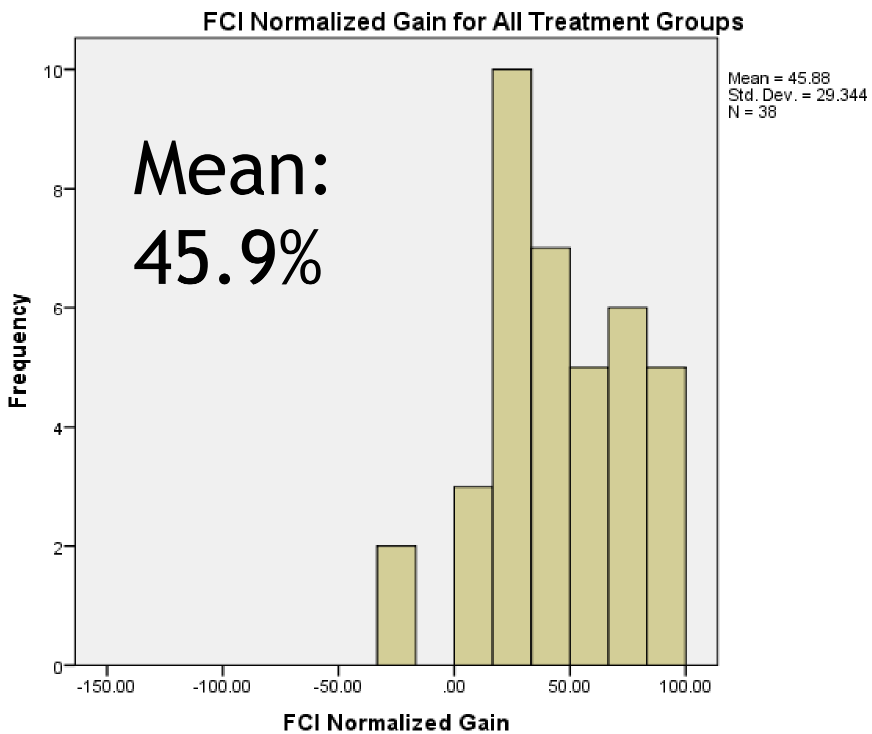
# Phase 2 & 3 outcomes

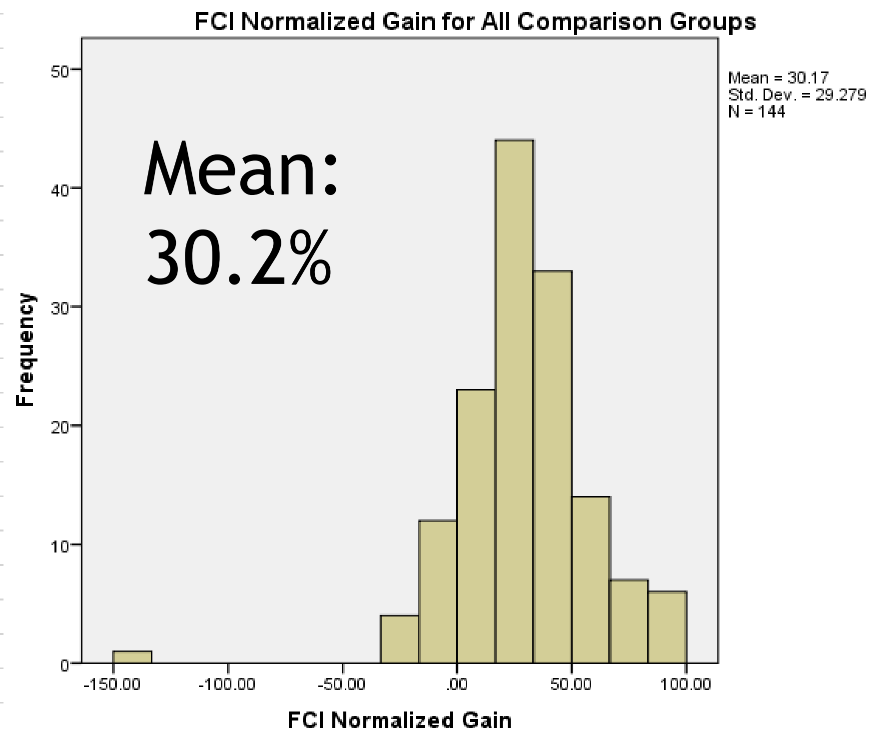
- **Challenging**
- **Model Building**
  - Constant force model
- **Complications**
  - Spreadsheet issues
    - -Circular referencing, units, drag force
- **Increased motivation.**
  - Real life application
  - Competition

# Quantitative Data & Analysis

| Group | N | Pre-CTSR (%) | Post-CTSR (%) | Pre-FCI | Post-FCI | FCI (G) (%) |
|---|---|---|---|---|---|---|
| Treatment Group 1 (AP Physics) | 29 | 67 | 77 | 8.6 | 19.3 | 50.3 |
| Treatment Group 2 (Regular Physics) | 8 | 45 | 46 | 5.1 | 13.0 | 29.5 |
| *Comparison Group 1 (Regular Physics)* | *41* | *49* | *60* | *7.0* | *11.0* | *16.9* |
| *Comparison Group 2 (Regular Physics)* | *39* | *52* | *60* | *7.6* | *12.6* | *22.7* |
| *Comparison Group 3 (AP Physics)* | *26* | – | – | *10.3* | *18.7* | *36.5* |
| *Comparison Group 4 (Regular Physics)* | *11* | – | – | *5.3* | *12.4* | *28.1* |

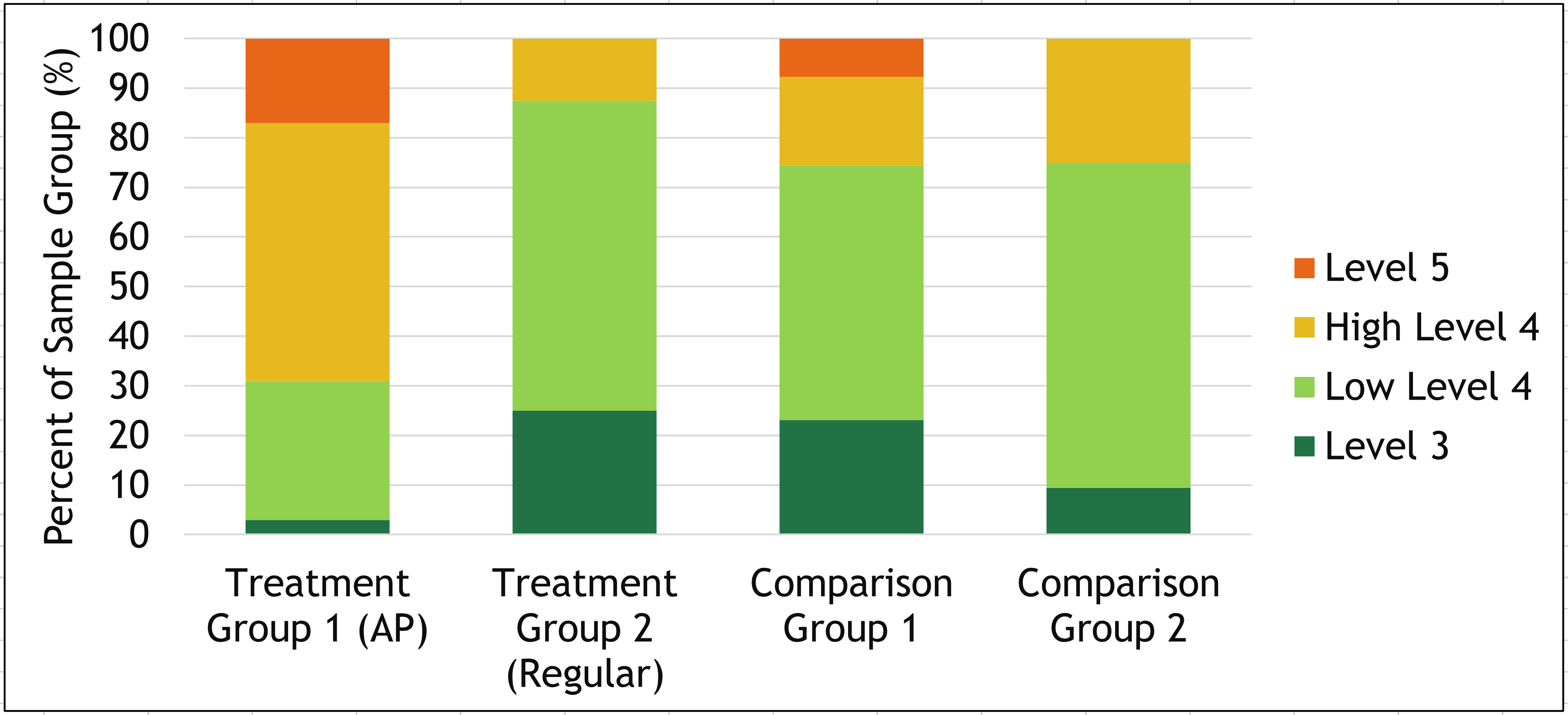
# Treatment vs. Comparison




- FCI normalized gain for all treatment groups was higher than the combined comparison groups. $t(180) = 2.941$, $p = 0.002$

# CTSR (Lawson) Scores




- Science reasoning ability varied greatly between groups

# FCI Normalized Gain

| | FCI Normalized Gain (%) | Comparison Group 1 (Regular) | Comparison Group 2 (Regular) | Same Class 2012-2013 |
|---|---|---|---|---|
| Treatment Group 1 (AP Physics C) | 50.3 | 16.9 $p < 0.001$ | 22.7 $p < 0.001$ | 36.5 $p = 0.17$ |
| Treatment Group 2 (Regular) | 29.5 | 16.9 $p = 0.08$ | 22.7 $p = 0.16$ | 28.1 $p = 0.89$ |

- At $a = 0.05$, individual treatment groups did not show statistically significant growth when compared to the most appropriate comparison groups.

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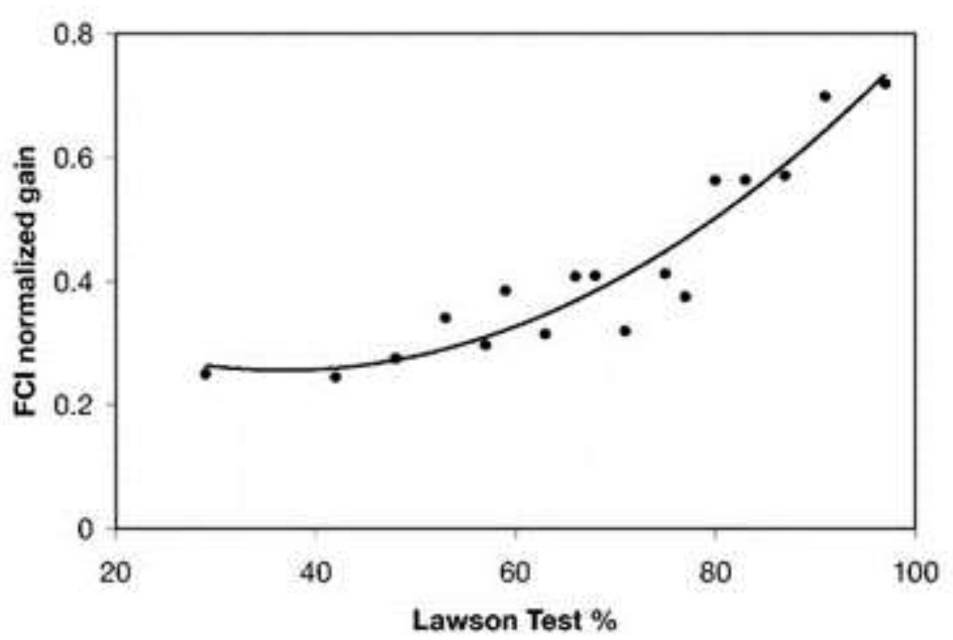
# CTSR (Lawson) & FCI (G)




Published data on expected FCI normalized gain for a given CTSR (Lawson) pretest score.
(Coletta, Phillips, & Steinert, 2007)

- Students with higher CTSR (Lawson) scores (indicating more formal reasoning skills) grow much more in their understanding of physics models.

# Treatment Group 1 (AP Physics C)

- CTSR scores and FCI normalized gain compared to expected normalized gain based on data published by Coletta, Phillips, & Steinert (2007)

| Quartile | Mean CTSR Score (%) | FCI (G) | Expected FCI (G) | Difference |
|---|---|---|---|---|
| 1 | 44 | 0.26 | 0.25 | +0.01 |
| 2 | 61 | 0.39 | 0.35 | +0.04 |
| 3 | 73 | 0.67 | 0.45 | +0.22 |
| 4 | 86 | 0.79 | 0.60 | +0.19 |

# Treatment Group 2 (Regular Phys.)

- CTSR scores and FCI normalized gain compared to expected normalized gain based on data published by Coletta, Phillips, & Steinert (2007)

| Quartile | Mean CTSR Score (%) | FCI (G) | Predicted FCI (G) | Difference |
|---|---|---|---|---|
| 1 | 27 | –0.01 | 0.25 | –0.26 |
| 2 | 33 | 0.22 | 0.26 | –0.04 |
| 3 | 37 | 0.35 | 0.26 | +0.09 |
| 4 | 48 | 0.62 | 0.28 | +0.34 |

# Comparison Groups 1 & 2 (Regular)

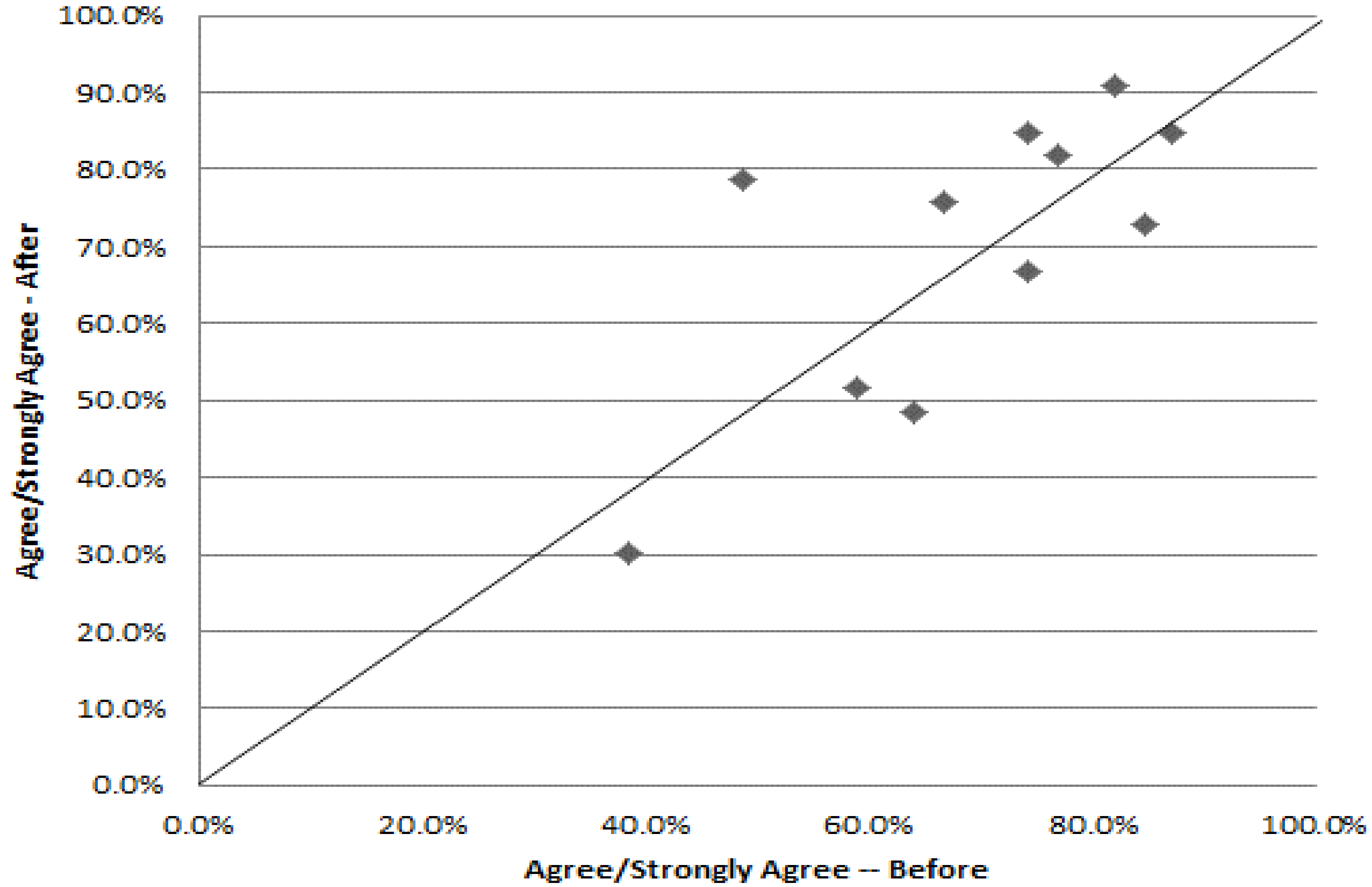
- CTSR scores and FCI normalized gain compared to expected normalized gain based on data published by Coletta, Phillips, & Steinert (2007)

| Quartile | Mean CTSR Score (%) | FCI (G) | Predicted FCI (G) | Difference |
|---|---|---|---|---|
| 1 | 31 | 0.10 | 0.25 | –0.15 |
| 2 | 44 | 0.18 | 0.27 | –0.09 |
| 3 | 54 | 0.20 | 0.30 | –0.10 |
| 4 | 72 | 0.32 | 0.45 | –0.13 |

# Quantitative Conclusions

- The FCI may not be the appropriate measure of the type of thinking promoted by spreadsheets
- Using spreadsheets in physics is promising
  - Students appeared to have a somewhat greater understanding of models, but FCI growth data is inconclusive
- Upper two quartiles of science reasoning students had extraordinary FCI gains

# Student Perceptions




Sheet1

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# Student Perceptions

| Question | Agree - Before | Agree - After | Change |
|---|---|---|---|
| I feel comfortable working with spreadsheets. | 49% | 79% | +30% |
| After using Spreadsheets in physics class, I have used a spreadsheet for something other than physics. | N/A | 39% | N/A |

| Question | Agree - Before | Agree - After | Change |
|---|---|---|---|
| Spreadsheets help me to understand physics models | 74% | 67% | -7% |

Sheet1

READY 100%

# Student Perceptions

| Question | Agree-Before | Agree-After | Change |
|---|---|---|---|
| Spreadsheets help me to understand relationships between variables. | 67% | 76% | +9% |
| Spreadsheets help me to understand graphical relationships. | 75% | 85% | +10% |
| Spreadsheets can help me to make predictions in problems. | 82% | 91% | +9% |

Sheet1

READY 100%

# Student Perceptions

| Question | Agree-Before | Agree-After | Change |
|---|---|---|---|
| Spreadsheets can make problem solving easier | 85% | 73% | -12% |
| Given a choice of tools to use (paper/pencil, calculator, etc.) I would choose to use a spreadsheet to solve a problem. | 39% | 30% | -9% |
| I can solve problems with spreadsheets that I would struggle with by hand. | 59% | 52% | -7% |
| Spreadsheets are useful for problem solving. | 87% | 85% | -2% |

# Student Perceptions - Conclusion

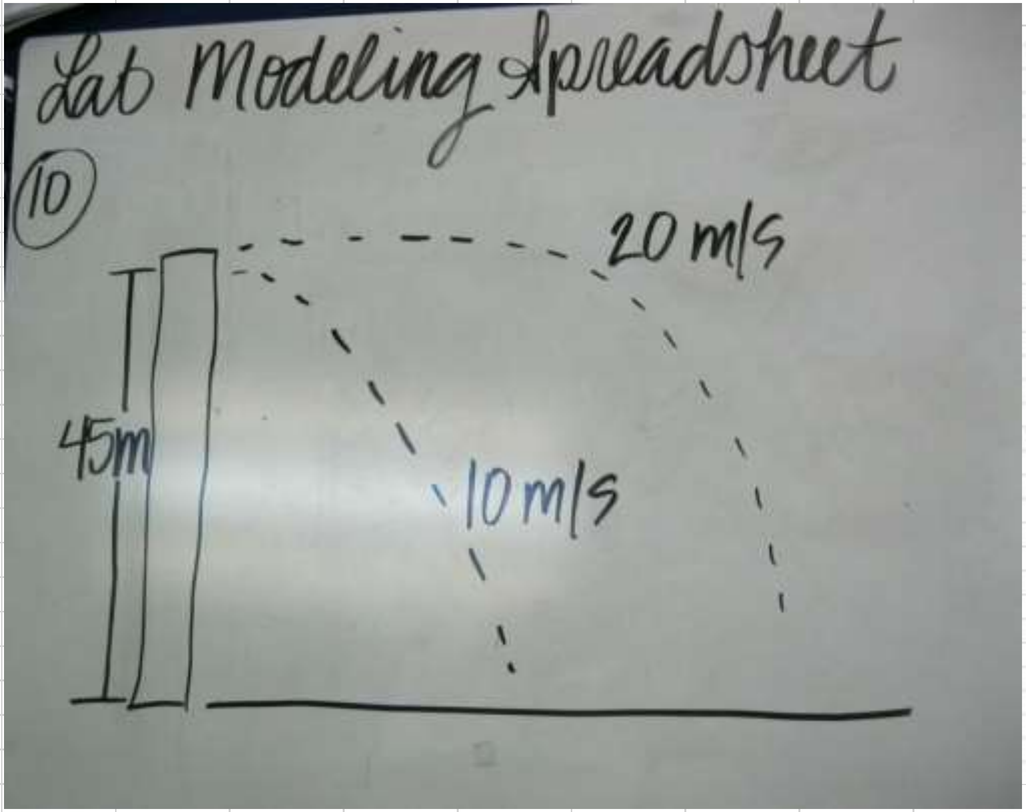
- Many of the modeling traits were prevalent
  - Relationship between variables.
  - Graphical relationships
  - Power of prediction
- Treatment was rigorous, still positive
- 82% of students suggested that we do it again next year.

Sheet1

READY 100%

# Conclusion

- Students were equipped with a new tool that is widely available and often used
  - Other classes
  - College
  - Careers
- Students were able to go much further
  - Non-constant forces
  - Non-uniform acceleration



# Conclusion

- Experience using computational modeling to evaluate the impact of parameters on a system
- Quantitative effect is promising
  - More work needs to be done!
- We will continue to use and improve these activities

# Conclusion

# Acknowledgements

- Dr. Colleen Megowan-Romanowicz
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- Our students

# Questions?