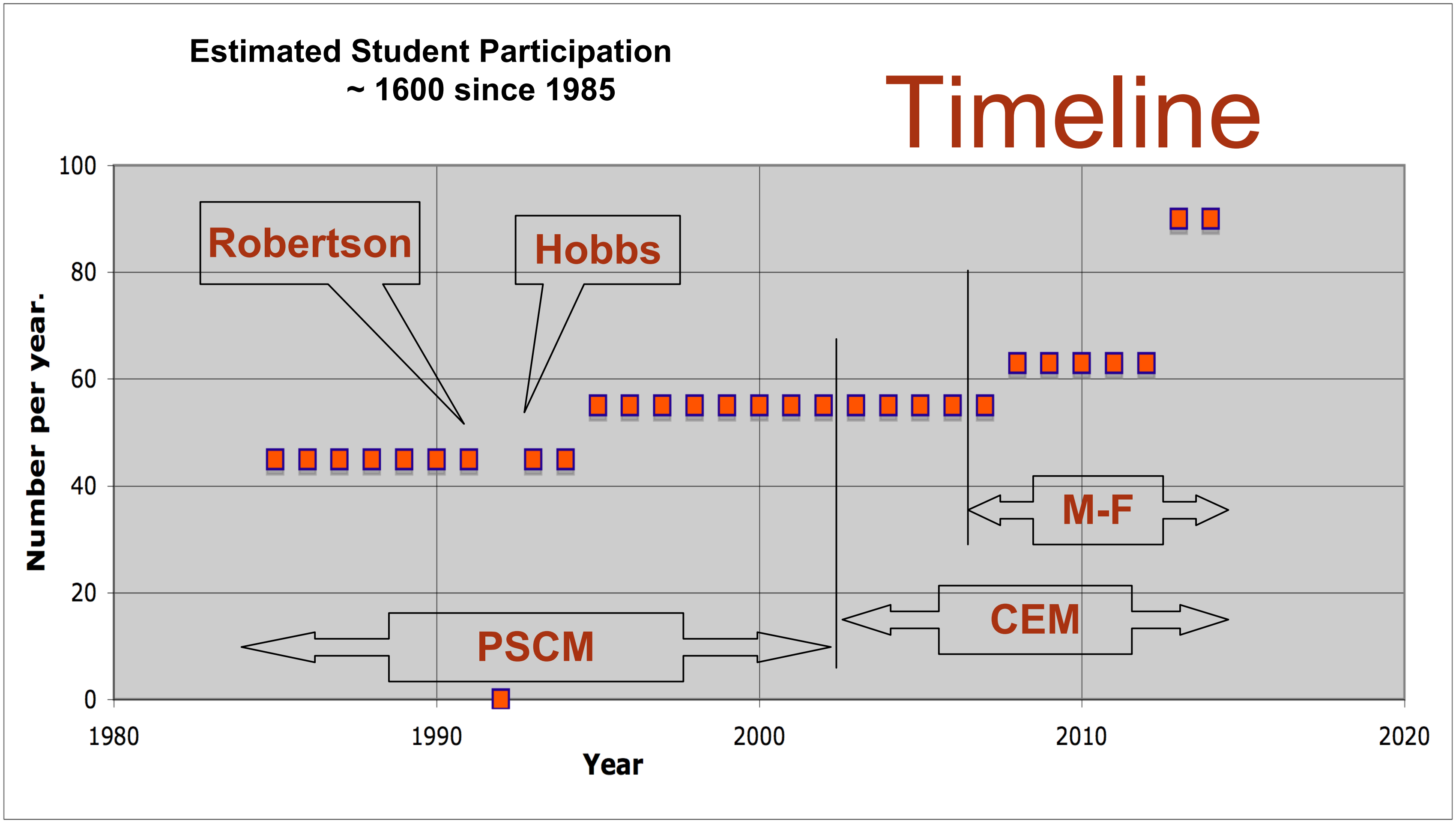
From replicating Eratosthenes to Cavendish – a capstone project for all.

Hands-on term projects in the introductory course.



- PSCM = Pacific Science Center model
- Motives for change
- CEM = Capstone Experiment Model

Two Assignments

- Pacific Science Center Proposal Model (PSCPM)
  - "The project will be presented as a proposal for a demonstration or science display to the staff of the Pacific Science Center." (or formal physics experiment)
  - Working model required for presentation at an open meeting
  - Plan for full installation, cost, and target audience must also be described.
- 2003 Capstone Experiment Model (CEM).
  - Make an observation to directly measure some physical quantity or behavior. (<u>Simple</u> is best!).
  - Design and perform an experiment that is compared to a theoretical model.
  - Re-design and repeat based on an analysis of the first experiment.
- 2012 Poster Presentations implemented.

- 3-dimensional photography
- A/D converter
- AC pendulum generator
- Blood flow calibrator
- Boomerang
- Brachistochrone
- Cavendish experiment
- Charge by spraying
- Colliding water waves
- Collisions of marbles
- Cratering, momentum vs energy
- Diffraction - Holography
- Diffraction intensities
- Doppler effect
- DVM with alarm system
- Eratosthenes reprise
- Electrical generator
- Electronic ignition
- Electrostatic precipitator
- Energy stored in a capacitor
- Fail safe alarm
- Fluid flow around

Comparing Models

- PSCPM
  - Greater diversity of topics
  - Support required was very demanding.
  - Demonstration equipment retained.
- CEM
  - Greater focus on experimental skills and reasoning.
  - Resource demands reduced

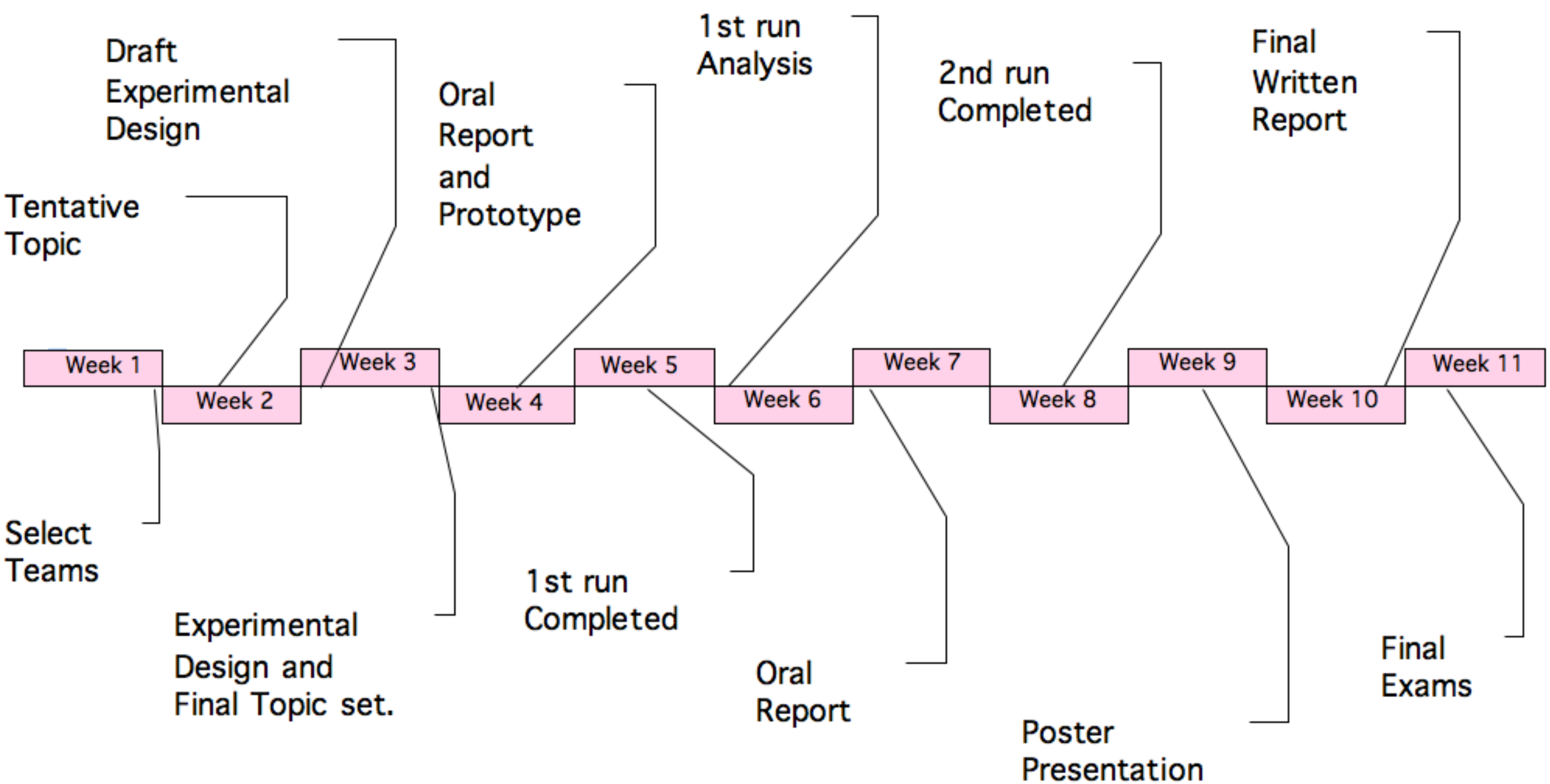
- Monkey Hunter
- Motional EMF see-saw
- Planck's constant
- Plant nutrients
- Refraction of microwaves
- Robotic arm
- Rotating atmosphere
- SHM in three dimensions
- Soap bubbles
- Space/time wave forms
- Spatial filtering
- Speech synthesizer
- Speed of light
- Stop action photography
- Tracking solar collector
- Turbidometer
- Viscosity
- Water spout light pipe
- Wave form of trumpet
- Wind tunnel
- 3 Phase Motor

Comparing Outcomes

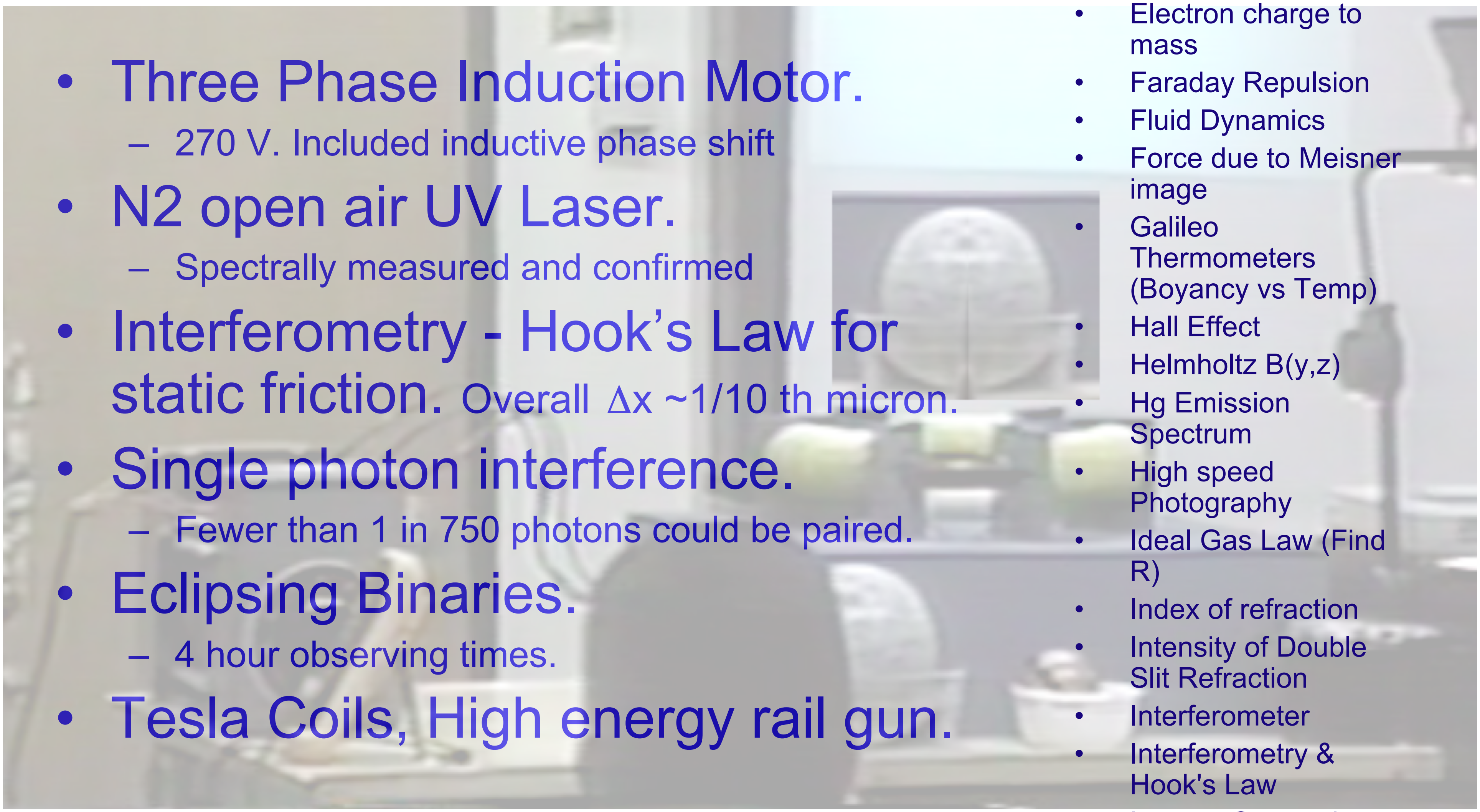
- PSCPM
  - Students follow their interests.
  - More simple “show and tell” type projects.
- CEM
  - Weakness with skill sets apparent.
  - Appropriate coaching during topic selection is essential.

- Mass Spectrometer
- Math curves
- Monkey Hunter
- Nitrogen Laser
- Photovoltaics
- Rail Gun
- Reference Frames
- Ruben's tube
- Seismograph
- Shielding- Skin Depth
- Sono-luminescence
- Spectra, Interference
- Speed of light from e and mu
- Sphere and Hoop
- Standing Wave
- Stereo Optics
- Tesla Coil
- Theremin
- Tidal Generator
- Trebuchet
- Tube amplifiers
- Two Source Interference
- Wind Generation
- Wind Tunnel
- Wine Glass Resonance

Timeline / Structure



Extreme Values



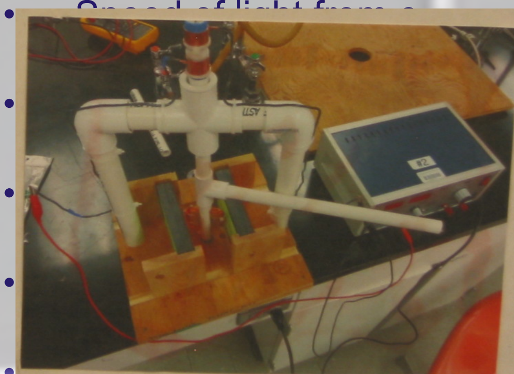
- Three Phase Induction Motor.
  - 270 V. Included inductive phase shift
- N2 open air UV Laser.
  - Spectrally measured and confirmed
- Interferometry - Hook’s Law for static friction. Overall Δx ~1/10 th micron.
- Single photon interference.
  - Fewer than 1 in 750 photons could be paired.
- Eclipsing Binaries.
  - 4 hour observing times.
- Tesla Coils, High energy rail gun.

- Doppler Effect
- Dynamics of a trapeze swing.
- Eclipsing Binaries
- Electron charge to mass
- Faraday Repulsion
- Fluid Dynamics
- Force due to Meisner image
- Galileo Thermometers (Boyancy vs Temp)
- Hall Effect
- Helmholtz B(y,z)
- Hg Emission Spectrum
- High speed Photography
- Ideal Gas Law (Find R)
- Index of refraction
- Intensity of Double Slit Refraction
- Interferometer
- Interferometry & Hook's Law
- Inverse Square law
- Lift and drag
- Linear Induction

Surpassing Expectations

- Cantilever beam shape
  - Fourth order differential equation
- Single photon interference
  - Fewer than 1 in 750 photons could be paired.
- Torque in a current loop
  - Multiple experiments.
- Band Pass Filter
  - Multiple experiments
- Frames of reference.
  - Hand built with complex controls.

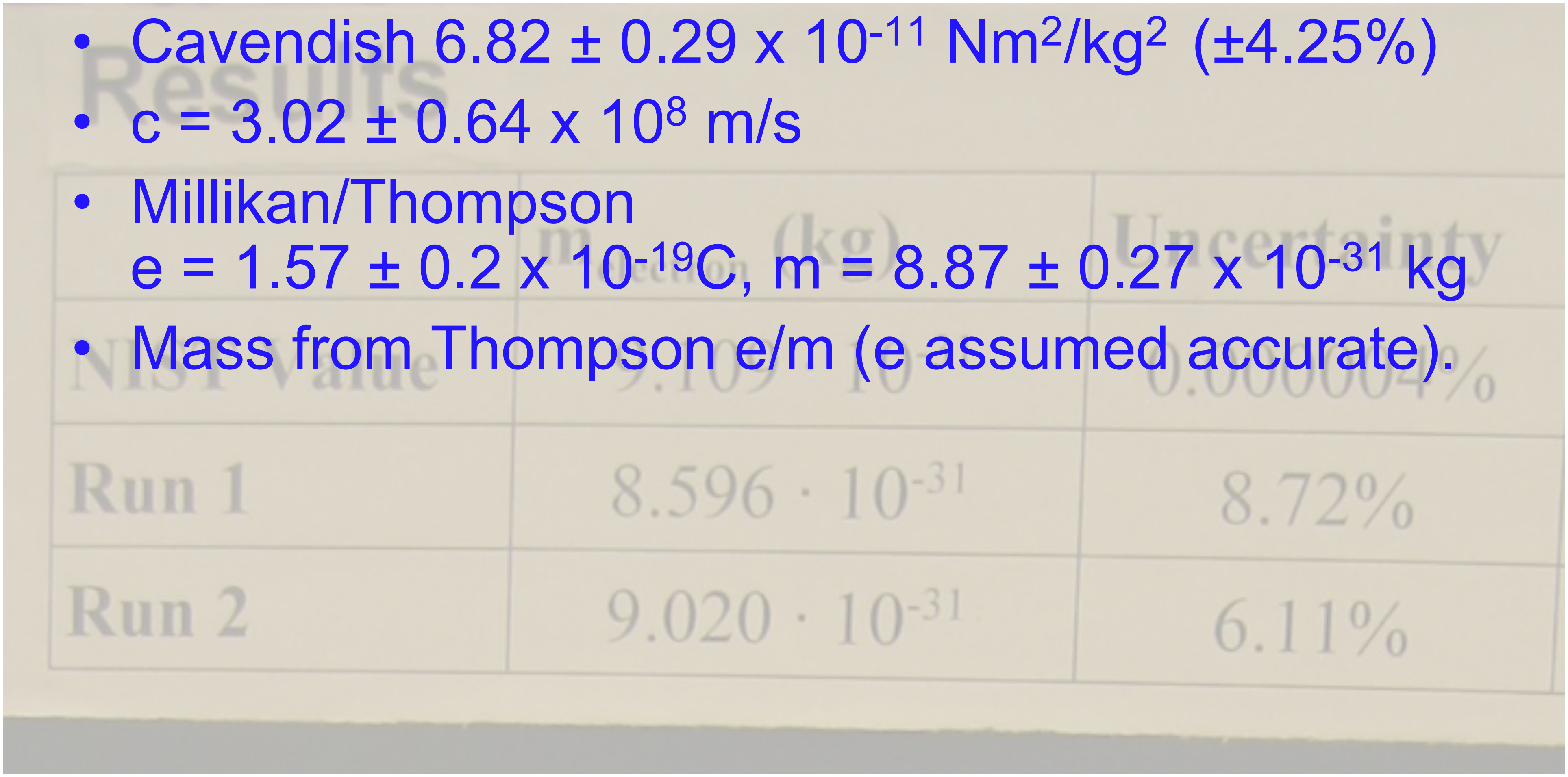
- Rotation of Polarized Light
- SHM Not a Parabola
- SHM Springs
- Single photon
- Snell's Law Corrected.
- Speed of Light direct Measurement



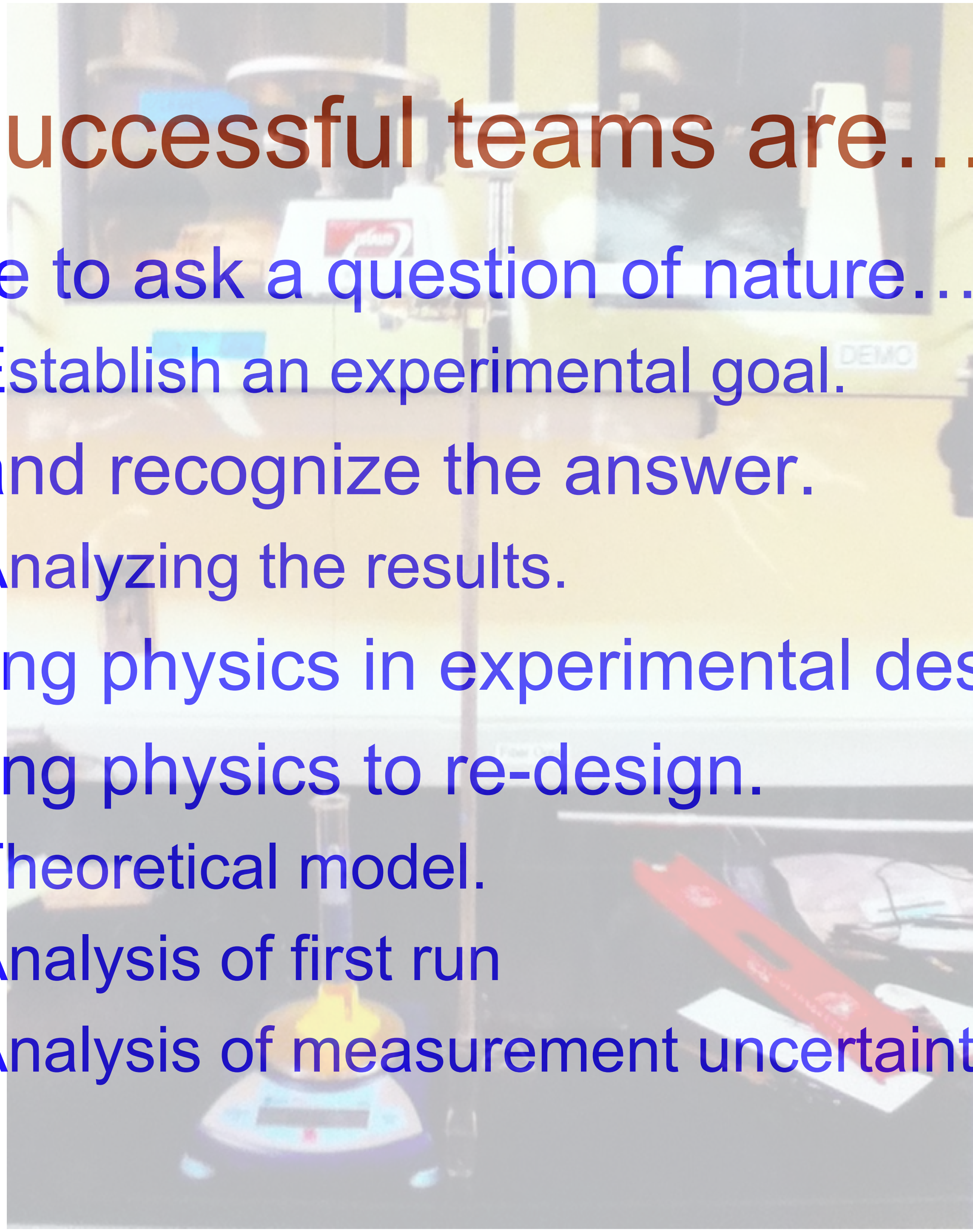
- Speed of waves on a string
- Springs in Series and parallel.
- Stokes Law (viscosity)
- T dependence Resistors
- Tautochrone Curve
- Telescope Optics
- Thermal Expansion
- Tornadoes and Wind Shear
- Torsion Constant

Quality Physics

- Cavendish $6.82 \pm 0.29 \times 10^{-11}\ Nm^2/kg^2$ (±4.25%)
- $c = 3.02 \pm 0.64 \times 10^{8}$ m/s
- Millikan/Thompson
  $e = 1.57 \pm 0.2 \times 10^{-19}C$, $m = 8.87 \pm 0.27 \times 10^{-31}$ kg
- Mass from Thompson e/m (e assumed accurate).


Results

	$m_{electron}$ (kg)	Uncertainty
NIST Value	$9.109 \cdot 10^{-31}$	0.000004%
Run 1	$8.596 \cdot 10^{-31}$	8.72%
Run 2	$9.020 \cdot 10^{-31}$	6.11%



Successful teams are…

- able to ask a question of nature…
  - Establish an experimental goal.
- …and recognize the answer.
  - Analyzing the results.
- Using physics in experimental design.
- Using physics to re-design.
  - Theoretical model.
  - Analysis of first run
  - Analysis of measurement uncertainty..

Meta - Physics goals

- Feel that they have mastered something.
  - Hopefully the result, but sans that, there should be some element they feel is a new skill or knowledge.
- "I was there".
  - appreciate that they know something that does not rest on outside authority.
- Communicating science to others.
  - They are part of a community who share common interests, experiences, and frustrations.

Practical goals

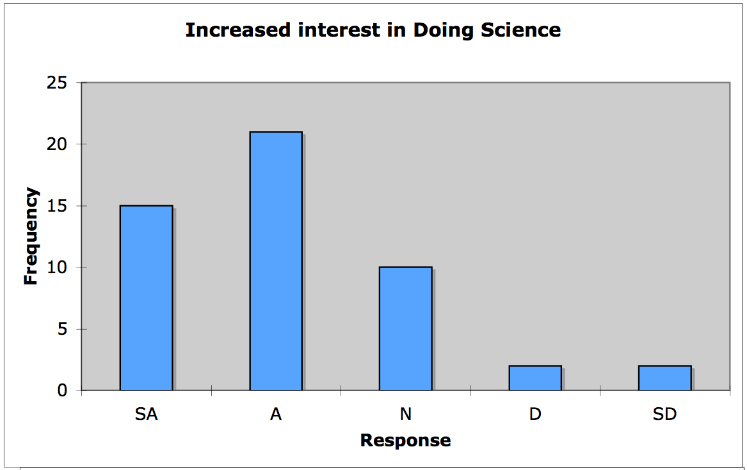
- How to observe carefully.
- How to make things.
  - How to make things that work.
- Be exposed to something beyond the norm/safe.
- Be exposed to the unexpected.

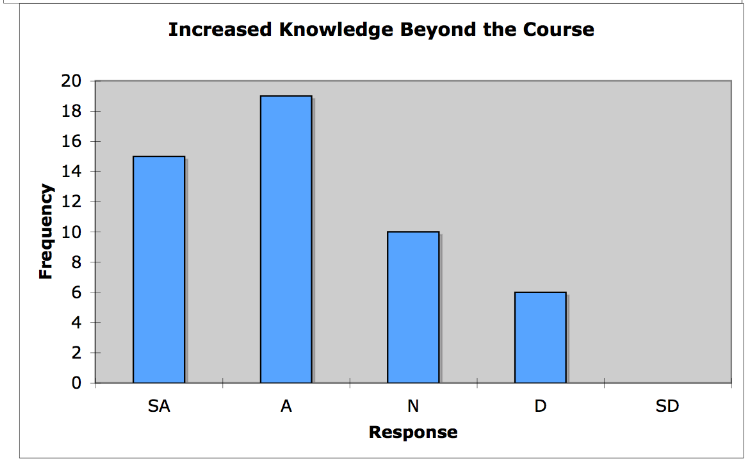
- Little assessment data available but from 2005 - 2011 four winners of the Higgs/Osborne Prize at UW have been BC students.

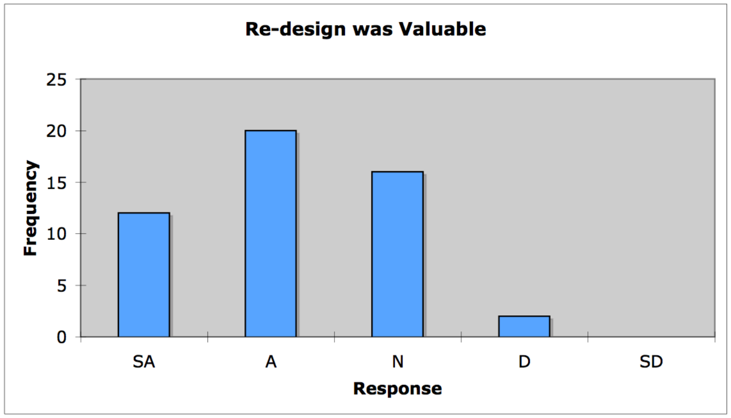
Evaluation

Student perception

- Interest in doing science increased. (72%)
- Increase knowledge beyond the course. (68%)
- Redesign was valuable. (64%)
- Attitudes shift following the presentations.







Overall Benefits

- Expert-like skills shown off in public.
  - Students quoting $B(z)_{Hoop}$ on the fly.
  - A student interpreting a complex circuit diagram in modular functional units.
  - Sophisticated analysis or reasoning skills
  - Sophisticated construction skills
- Inspire the remaining class.
- Recognizing the gap between text problems and getting something to work in the real world.

Appendicies

How to and support items for Q&A

Generic Structure

- Form Project Teams
  - Select teams by matching the team member's available meeting times.
  - Designate/select point of contact member
- Teams select and get topic approved
  - To measure something or do science is goal.
  - Make cool device for You Tube is NOT the goal.
- Prototyping and progress reports
  - Get hands dirty very early.
  - Students tend to think from theory for too long.

Generic Structure

- Preliminary result deadline
  - Most teams miss this. They frequently deceive themselves that it is not real or not enforced.
- Continued progress updates
  - Get details. Students will gloss over things or not recognize an obstacle as intractable & not note it.
- Final completion deadline
  - Most teams miss this.
  - This one they at least believe.

Generic Structure

- Presentation to peers and evaluator(s).
  - Presentations with Q&A give detailed feedback.
  - Posters demand fewer department resources.
  - Posters give larger quantity but less regulated quality feedback
- Submission of final report
  - Final report should incorporate feedback from presentation.

Measurement Capabilities

Stand alone

- meter sticks, micrometers
- scales, balances, masses
- Volumetric flasks
- timers,
- Electrometer,
- Thermometer
- multi-meters (current, voltage, resistance, capacitance.)
- Oscilloscopes - 100MHz
- frequency measurements,
- light meters,
- measuring microscope
- Sound intensity
- Wavelength (spectrometer)
- Spherocity

Computer assisted

- Position, velocity acceleration
- Angular position, velocity acceleration
- Force
- Pressure
- Temperature
- Light intensity
- Magnetic field
- Wavelength (spectrometer)
- Radiation
- Voltage
- Sound intensity
- FFT
- Image and video analysis

Apparatus and Energy.

Supplied material/Energy

- Water
- Compressed air,
- LN2
- Heat, Light, UV
- Function generators and speakers,
- Lasers
- Current to 8ADC and to 10A AC
- Voltages to 200VDC and to 120VAC,
- Van deGraaff and Wimshurst generators
- Transformers to 9000 VAC

Apparatus

- Projectile launchers,
- Force tables
- Air tracks,
- Low friction tracks/carts,
- Cavendish Balance,
- Millikan oil Drop,
- Electron Charge to Mass,
- Solenoids, Helmholtz coils.
- Optical benches and optical elements,
- Spectrometers and gratings,
- Polarizing filters, and other similar apparatus

Support Structure

- Space-empty labs and set up spaces 8’ X 12’ X 3ea
- Time-about 5 hrs/week per section
- Multiple groups during these times
- Darkable spaces
- Advising in electronics, thermo, E&M, mechanics, materials, Mathphys
- Gas, hotplates, water, air. (Not required)
- Soldering, breadboarding
- Limited carpentry and tool work (vise and drill press).
- Measuring devices
- Power supplies
- Willing chemistry, astronomy, engineering, and math faculty.