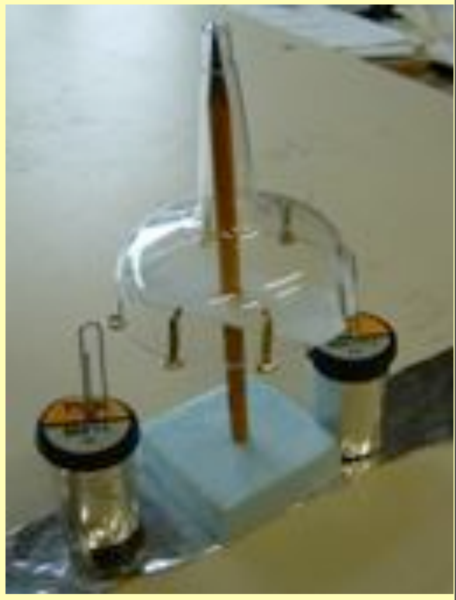


Facets of Physics Teaching & Pedagogical Engineering in the High School Classroom

Robert A. Morse
2015 Millikan Lecture
AAPT Summer Meeting
College Park, MD

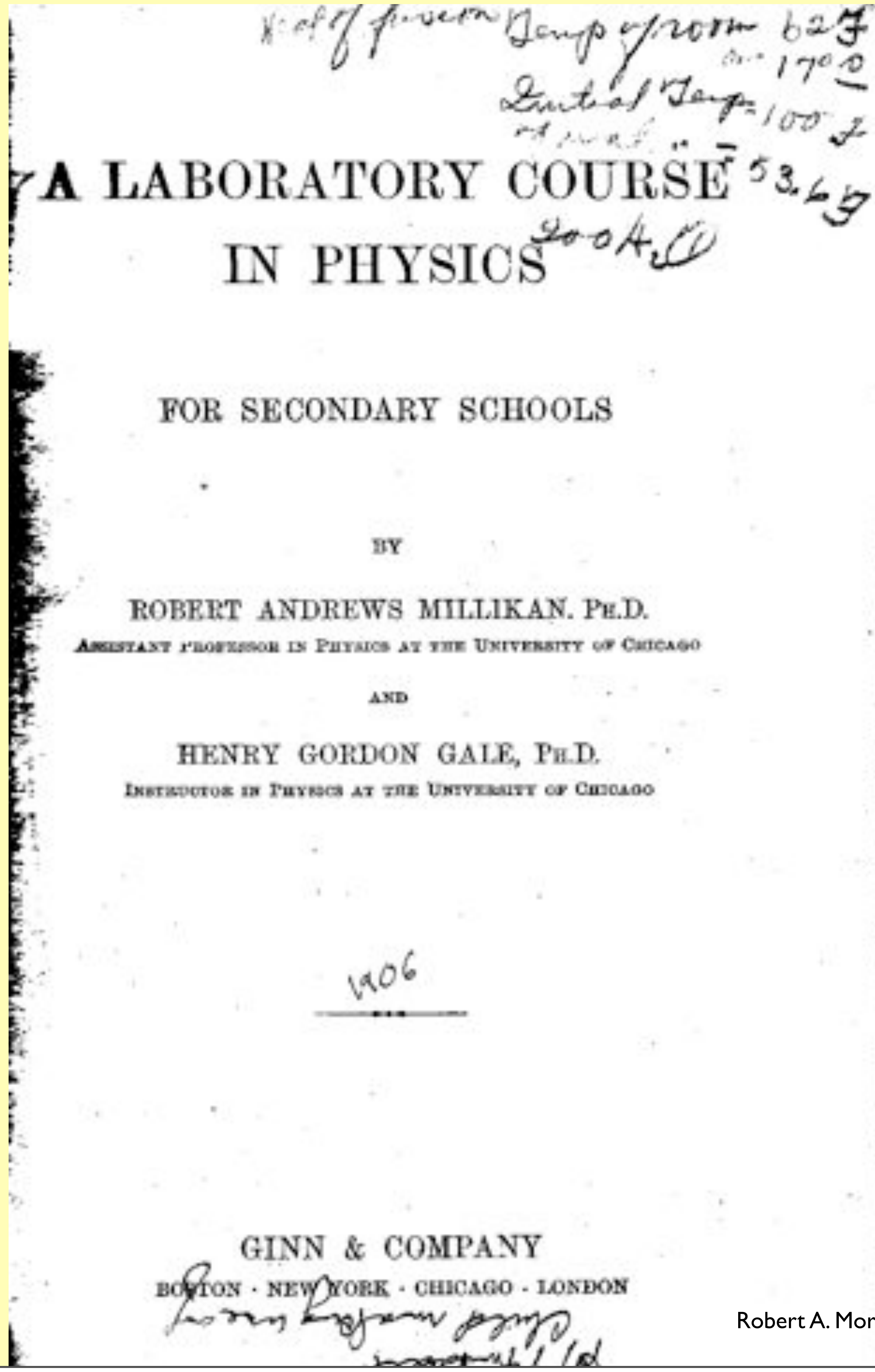
Dwain Desbien, in accepting the Halliday and Resnick Award, noted that this might be the only time you would see him in coat and tie . By contrast, the last 30 years of my teaching career, I would be dressed like this at the start of every class. Jacket, tie, shirt tails tucked in, no T- shirts allowed. Even this PTRA t-shirt would be verboten. The students were expected to arrive in the same dress code. Once I had taken attendance, which I shall skip this morning, then I would remove my jacket as a signal to students that they could remove theirs. So, Ladies & Gentlemen, you may remove your jackets.

THANKS

- Family
- Masconomet Regional HS & St. Albans School
- PTRA & John Layman
- Andy Elby
- AP Physics redesign
- AAPT colleagues and friends

Thanks: to my parents, both chemists. I grew up with science, Scientific American, things to tinker with, could talk with either parent about science.
My talented and lovely wife Mimi has put up with my haring off on various physics enterprises for many years. My children, Ricky, Alan, and Danielle, all of whom worked at various times assembling equipment for workshops, were pretty patient except when I started waffling on. Then they would tell me "Dad, you're in lecture mode."
The two schools where I spent most of my career - who allowed me to try out many different things in my teaching. I particularly thank St. Albans School for support for professional development and for allowing use of facilities at no cost for workshops over many years.
30 years ago, I was accepted in the first group of Physics Teaching Resource Agents - a program that for me and for many has made a huge difference in my professional career - my presence on this stage today is a direct outcome of that program. Among the many AAPT folk I got to know through the program is John Layman, who has been a teacher, a mentor, a thesis advisor and a friend ever since.
I have worked with Andy Elby and a number of other folk for the last 8 years on the AP Physics redesign committees. I especially thank Andy for nominating me, and Jim Nelson and my former student and successor at St. Albans Will Segal for supporting my nomination. (I think Andy was just doing an experiment to see if I could say something vaguely coherent for a whole 50 minutes.) Thanks to all the people I have worked with on the AP Physics redesign and to all of you - my AAPT friends and colleagues in this great and friendly society.

Millikan Talismans – lab manual 1906



A LABORATORY COURSE
IN PHYSICS

FOR SECONDARY SCHOOLS

BY

ROBERT ANDREWS MILLIKAN, Ph.D.
Assistant Professor in Physics at the University of Chicago

AND

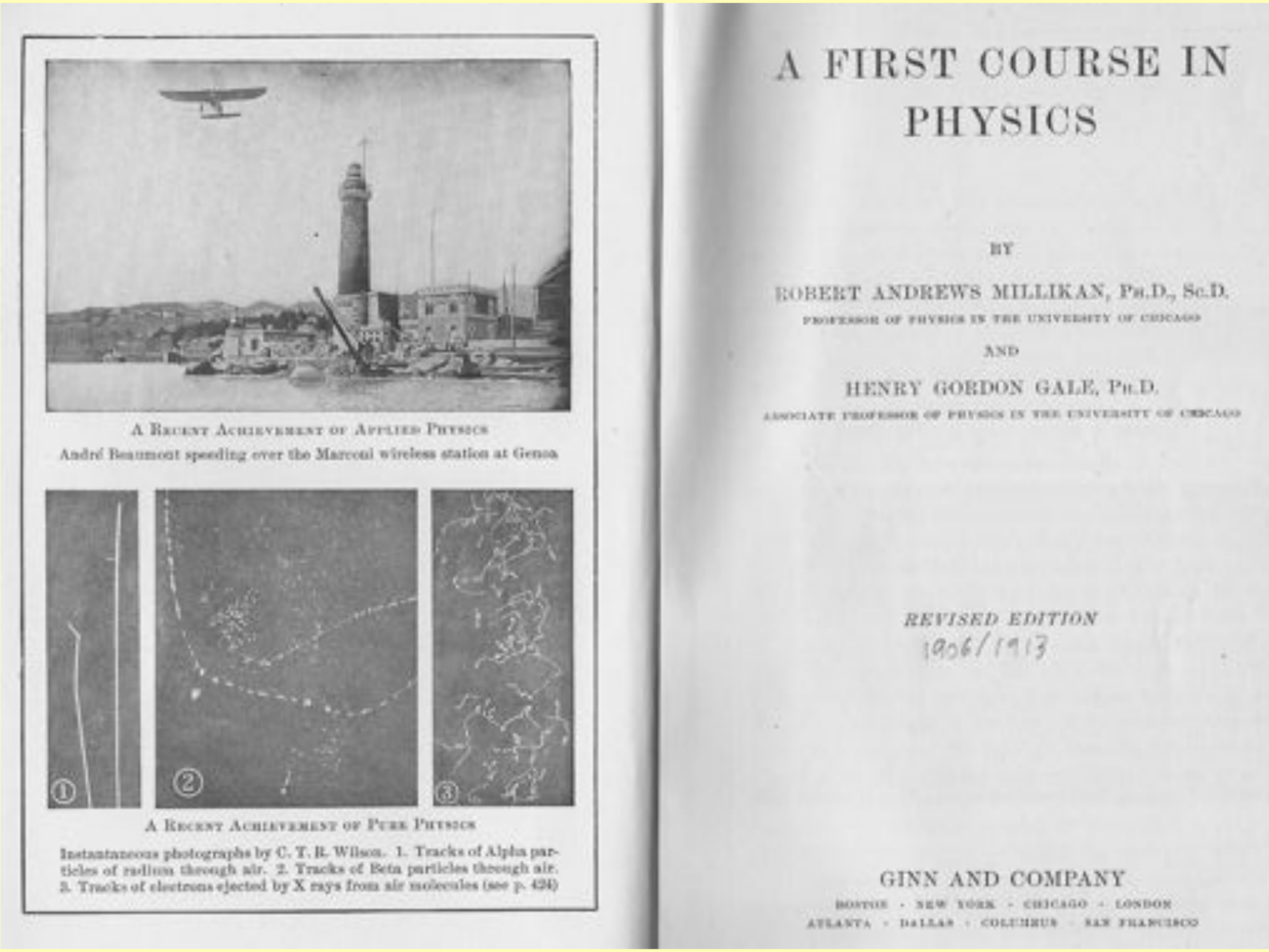
HENRY GORDON GALE, Ph.D.
Instructor in Physics at the University of Chicago

1906

GINN & COMPANY
BOSTON · NEW YORK · CHICAGO · LONDON

It is customary to talk a little about Robert A. Millikan, but that has been done well by Priscilla Laws and Joe Redish in their published Millikan talks. I did bring with me some Millikan talismans – the first is a first edition of his lab manual for high schools from 1906 written with Henry Gordon Gale. Millikan was keenly interested in the teaching of physics in high schools.

Millikan Talismans – 1906 rev 1913


A RECENT ACHIEVEMENT OF APPLIED PHYSICS
André Beaumont speeding over the Marconi wireless station at Genoa

A RECENT ACHIEVEMENT OF PURE PHYSICS
Instantaneous photographs by C. T. R. Wilson. 1. Tracks of Alpha particles of radium through air. 2. Tracks of Beta particles through air. 3. Tracks of electrons ejected by X rays from air molecules (see p. 424)

A FIRST COURSE IN PHYSICS

BY

ROBERT ANDREWS MILLIKAN, PH.D., SC.D.
PROFESSOR OF PHYSICS IN THE UNIVERSITY OF CHICAGO

AND

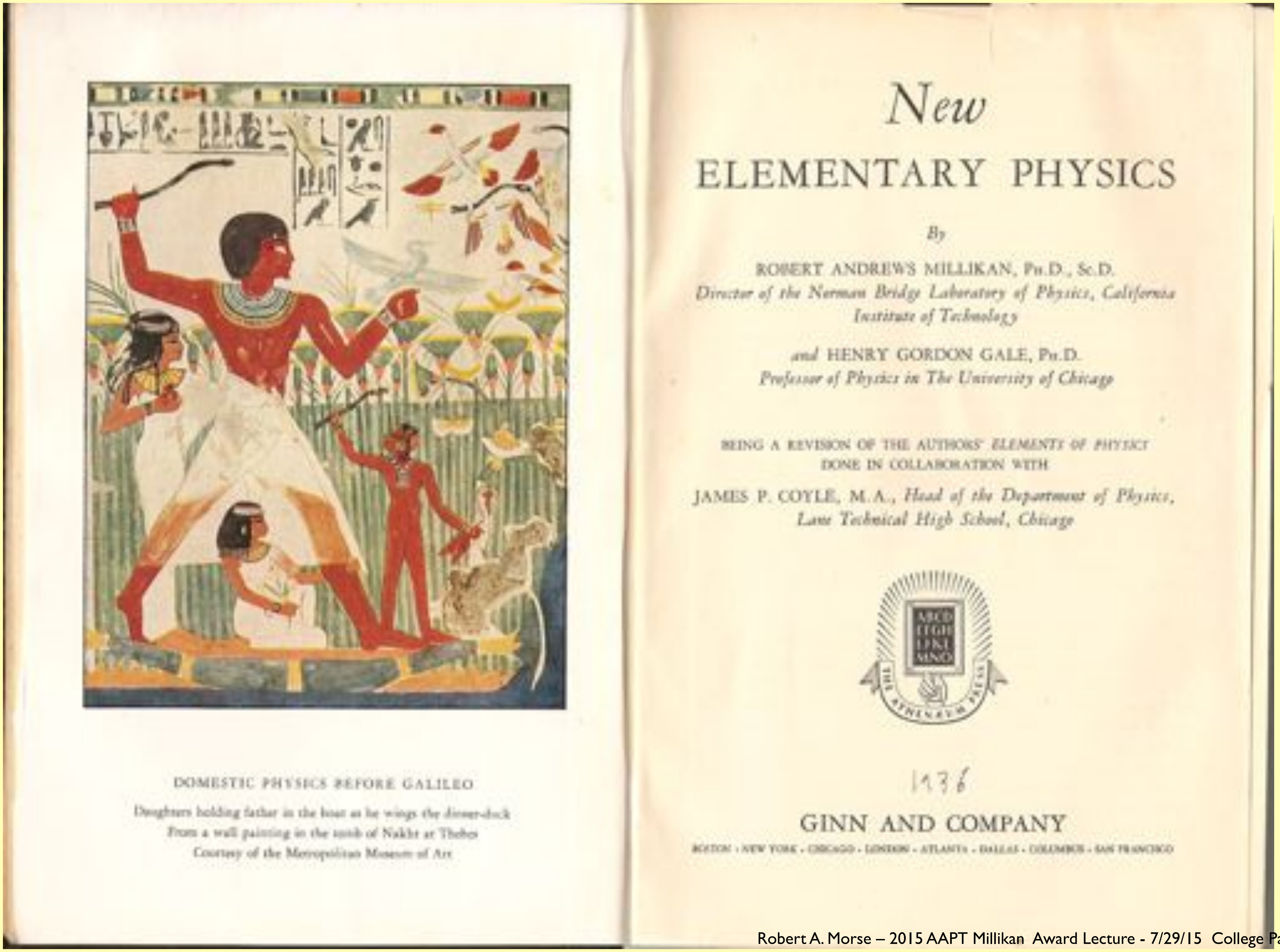
HENRY GORDON GALE, PH.D.
ASSOCIATE PROFESSOR OF PHYSICS IN THE UNIVERSITY OF CHICAGO

REVISED EDITION
1906/1913

GINN AND COMPANY
BOSTON · NEW YORK · CHICAGO · LONDON
ATLANTA · DALLAS · COLUMBUS · SAN FRANCISCO

My second talisman is a 1913 revised edition of the 1906 textbook, also written with Gale. The top photograph shows "A recent achievement of applied physics," Beaumont in a monoplane speeding over the Marconi wireless station in Genoa. The bottom photograph shows "A recent achievement of pure physics," three Wilson cloud chamber tracks showing alpha particles, beta particles and X ray ejection of electrons from air molecules.
On page 223 of this edition, it states " The charge of one electron is called the elementary electric charge. Its value has recently (1913) been accurately measured." Who better to know than Millikan!

Millikan Talismans – Textbook 1936



DOMESTIC PHYSICS BEFORE GALILEO

Daughters holding father in the boat as he wings the dinner-duck
From a wall painting in the tomb of Nakht at Thebes
Courtesy of the Metropolitan Museum of Art

New
ELEMENTARY PHYSICS

By

ROBERT ANDREWS MILLIKAN, PH.D., Sc.D.
Director of the Norman Bridge Laboratory of Physics, California Institute of Technology

and HENRY GORDON GALE, PH.D.
Professor of Physics in The University of Chicago

BEING A REVISION OF THE AUTHORS' *ELEMENTS OF PHYSICS* DONE IN COLLABORATION WITH

JAMES P. COYLE, M.A., *Head of the Department of Physics, Lane Technical High School, Chicago*

1936

GINN AND COMPANY
BOSTON · NEW YORK · CHICAGO · LONDON · ATLANTA · DALLAS · COLUMBUS · SAN FRANCISCO

My third talisman is the extensive 1936 revision, also with Gale, but also with James P. Coyle, Head of the Department of Physics, Lane Technical High School, Chicago. Here the illustration is titled "Domestic physics before Galileo. Daughters holding father in the boat as he wings the dinner-duck."

AAPT

Connections + Ideas + Support

Robert A. Millikan Connections

John King Lillian McDermott Joe Redish

Mario Iona

Priscilla Laws David Sokoloff

Fred Goldberg Pat Heller Jim Minstrell

Eugenia Etkina

I have relatively little direct connection with Robert Millikan, at least that I know of. I am only the second awardee to share the same first name, but I am the only one, thus far, to share all three initials with him. I am however, fortunate enough to have some connection with other Millikan awardees. In 1967-8 I was a TA at MIT in the Corridor Lab and the Project Lab under the direction of John King (1965). Unlike the traditional TA experience, these required much direct interaction with students as individuals or in groups of only 2 or 3. Lillian McDermott (1990) was kind enough to take me on as a summer TA in 1987 teaching the Physics by Inquiry module on circuits. Joe Redish (1998) served on my thesis committee, during my doctoral work. Mario Iona (1986) made a whole host of red editorial comments on my first draft of Teaching About Electrostatics, the most valuable editorial lesson I ever had. Priscilla Laws (1996) and David Sokoloff (2007) along with Ron Thornton and Maxine Willis were collaborators on a PTRA workshop in 1993 using fan carts (of which more later). I worked with Fred Goldberg (2003), Pat Heller (2010) and Jim Minstrell (1993) on the CPU project at San Diego State, along with Valerie Otero, Laura McCullough, Andy Johnson, and Paul Hickman. Most recently, Eugenia Etkina (2014) was one of the great group of people on the Curriculum Development and Advisory Committee during the AP Physics redesign work.

The Art of High School Physics Teaching

- ART: fluent combination & application of many aspects of knowledge at scales from long term course design to on-the-fly interaction
    - SCIENCE of PHYSICS: conceptual & procedural understanding of physics & history of ideas in physics
    - SCIENCE of LEARNING: research on cognition and learning, especially from Physics Education Research
- CRAFT: familiarity with lab & demo equipment, computers, tool use & skills associated with finding & using resources and maintaining a classroom laboratory
- SKILLS: presentation and people skills to organize and run an effective and efficient class

The Art of High School Physics Teaching

- CURRICULUM DESIGN: overall course design to meet external constraints and personal goals for student learning
- FACETS OF STUDENT KNOWLEDGE: familiarity with perspectives on student learning, e.g., Minstrell's Facet view of student conceptions, DiSessa's Knowledge in Pieces perspective, & Redish, Elby, Hammer et. al. work on cognitive resources among others
- PEDAGOGICAL CONTENT KNOWLEDGE: How particular content knowledge can be arranged to enhance learnability (Shulman).
- FACETS of PHYSICS TEACHING – teaching actions, of various grain size, based on experience, pedagogical content knowledge, and physics education research – a teacher's "bag of tricks"

The Art of High School Physics Teaching – Pedagogical Engineering

- Over time I was introducing new equipment and/or activities to solve learning problems in small portions of larger curriculum design often leading to finding new issues, motivating new modifications and new observations.
- Process – iterative refinements and redesign – is analogous to engineering, but applied to learning activities and tools for thinking as well as apparatus design.
- I have adopted the term pedagogical engineering – a continuing process of improving connected areas of practice, informed by knowledge of science as well as practical experience - to describe this process. (Collins, A., 1992 Toward a design science of education. In *New directions in educational technology.* Springer)

Pedagogical engineering is not a new term – but I don't recall seeing it before in the context of PER. In the rest of the talk I will go through two examples of my long term process of pedagogical engineering, relating that work to a few "facets of physics teaching."
Much of the work I will discuss has been based on or inspired by physics education research, but only a few pieces have been validated by any formal research. I have some idea of effectiveness from informal research in the form of action or classroom research.

Examples : Facets of Teaching and Pedagogical Engineering

- FACETS of Physics Teaching – a teacher's "bag of tricks"
- Teachers can use the notion of facets of teaching to codify their gleanings from various sources including research and personal observations in order to apply this knowledge to help students make meaning
  - short term design of student experiences for efficient learning
  - choosing pedagogical techniques to address identified difficulties in learning physics

In talking about facets of physics teaching, I have used them as motivation for actions in modifying both apparatus and student activities – I do not propose them as new notions – but discussing them gives some examples of my thinking

FACETS of Physics Teaching: Example 1

Mathematics and Physics

- Observation - math has different meaning for students and physicists (Redish & Gupta, 2009 GIREP conf. – UMD PERG website)

$$\vec{a} = \frac{\sum \vec{F}}{m}$$

a - observable F and m - causal

- For high school student : recipe for calculation
- For physicist : compact form of Newtonian concept – The time rate of change and direction of change in the velocity of an object is caused by the directional combination of interactions of the object with other objects and fields, relative to its inherent sluggishness (inertial mass).

See also the talk by Joe Redish, talk BK03, in the session titled “Art and Science of Teaching”

FACETS of Physics Teaching: Example 1 cont.

Mathematics and Physics

- Facet based on knowledge cited and also experience
- Action to reinforce semantic meaning –
  set expectation that students read equation as words, not symbol string – interpreting equation each time they read it.
  - Not "a equals sigma F over m"
  - But "acceleration is caused by the combination of forces exerted on an object relative to the inertial mass of the object"

Although this short statement does not capture the full richness of the physicist's understanding of the concept, I think it does help to remind students of the semantic use of equations to codify concepts in our toy universes.

FACETS of Physics Teaching: Example 2

Mathematics and Physics

- Observation: students have trouble articulating meaning of ratios and what "per" means. (Arons, TPT, 1983)
- Related observation: Students have trouble translating verbal expression of a ratio into a symbolic expression – well known example of setting up equation relating number of students, number of teachers and student teacher ratio.

T = RS? S = RT?

If R = student – teacher ratio, S is students, T is teachers, then is T=RS or is S = RT? This is a well known example, but I could not recall the reference at the time.

Facet – familiar ratios – analogs for meaning of physics ratios

- Students have experience with money.
  - Eggs cost $2 for10 eggs. What is price for one egg?
  - Write & test equation to find price, P, for each egg from cost C for N eggs. (Units $/egg - read as dollars for each egg)
- Object moving on surface has normal force of 10 N exerted on it, causing 2 N frictional drag.
  - What is frictional force for one newton of normal force?
  - Write & test equation to find this *friction fraction* (coefficient of kinetic friction) from frictional force and normal force.
- Units give meaning to ratios.
  - Coefficent of friction units of N/N - not customary – <u>useful</u> for novices

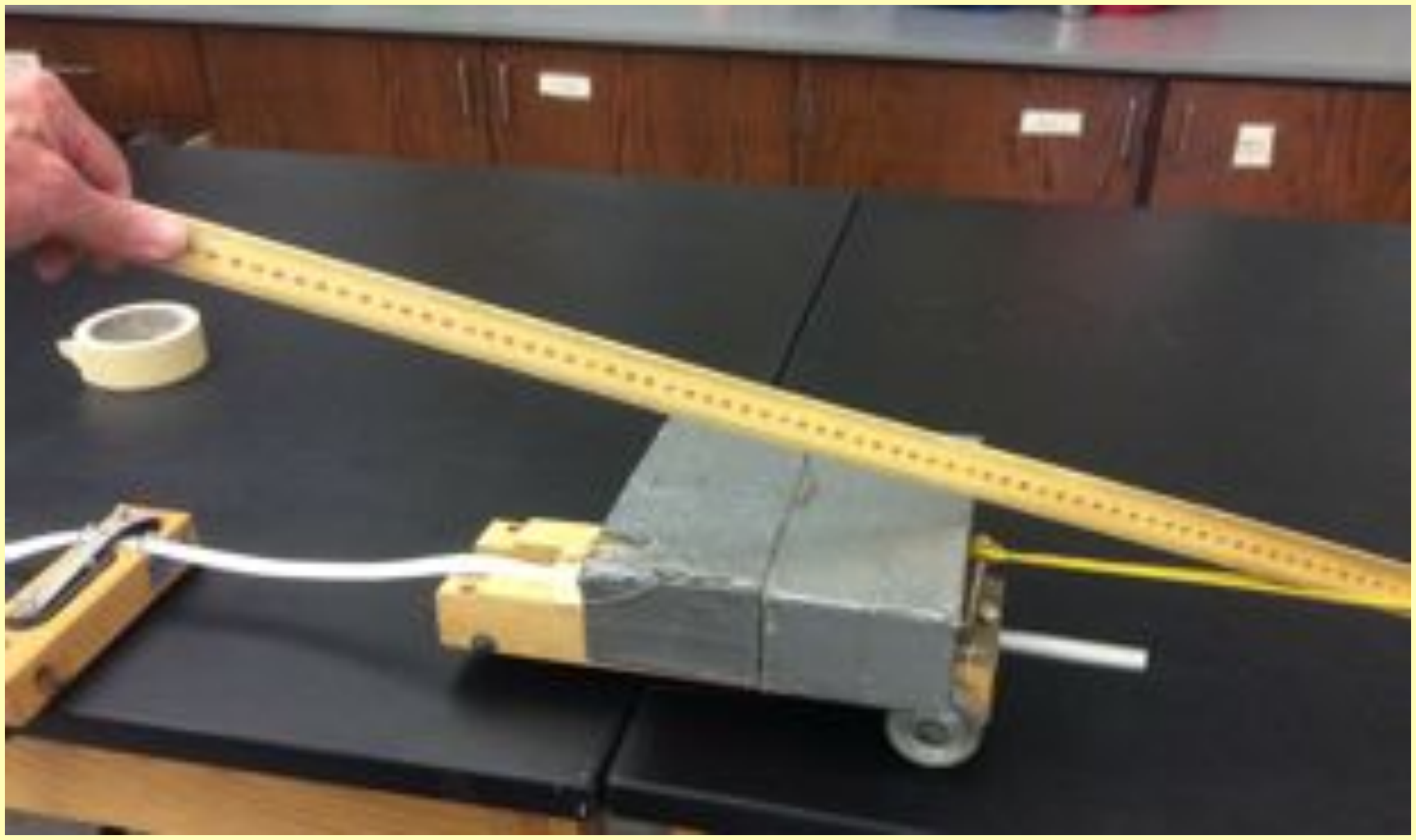
Formally the units cancel, but having students read 0.2 newtons of frictional force for each unit of normal force helps understand the physical meaning of the coefficient of friction, just as 0.2 dollars for each egg makes clear the unit price for the eggs.

Pedagogical Engineering
A Mechanics Example

In the rest of the talk I will give two detailed examples of what I mean by the process of pedagogical engineering. Note that these did not take place rapidly. Each of the examples discussed took about 20 years or so of development to reach their current stages.

Pedagogical Engineering & Newton's 2nd Law

- Starting point: PSSC lab – Newton's Second Law
- Cart, bricks, rubber bands, ticker tape
- Investigate a vs F & a vs m and combine
- Emphasis on inertial property of mass



I didn't really KNOW physics in any depth before I started teaching PSSC in my first year of high school teaching and later learning and teaching Harvard Project Physics. I was pretty good at means – ends analysis in my college courses, but, as I discovered in working with students, I needed to develop a much better conceptual understanding of physics.

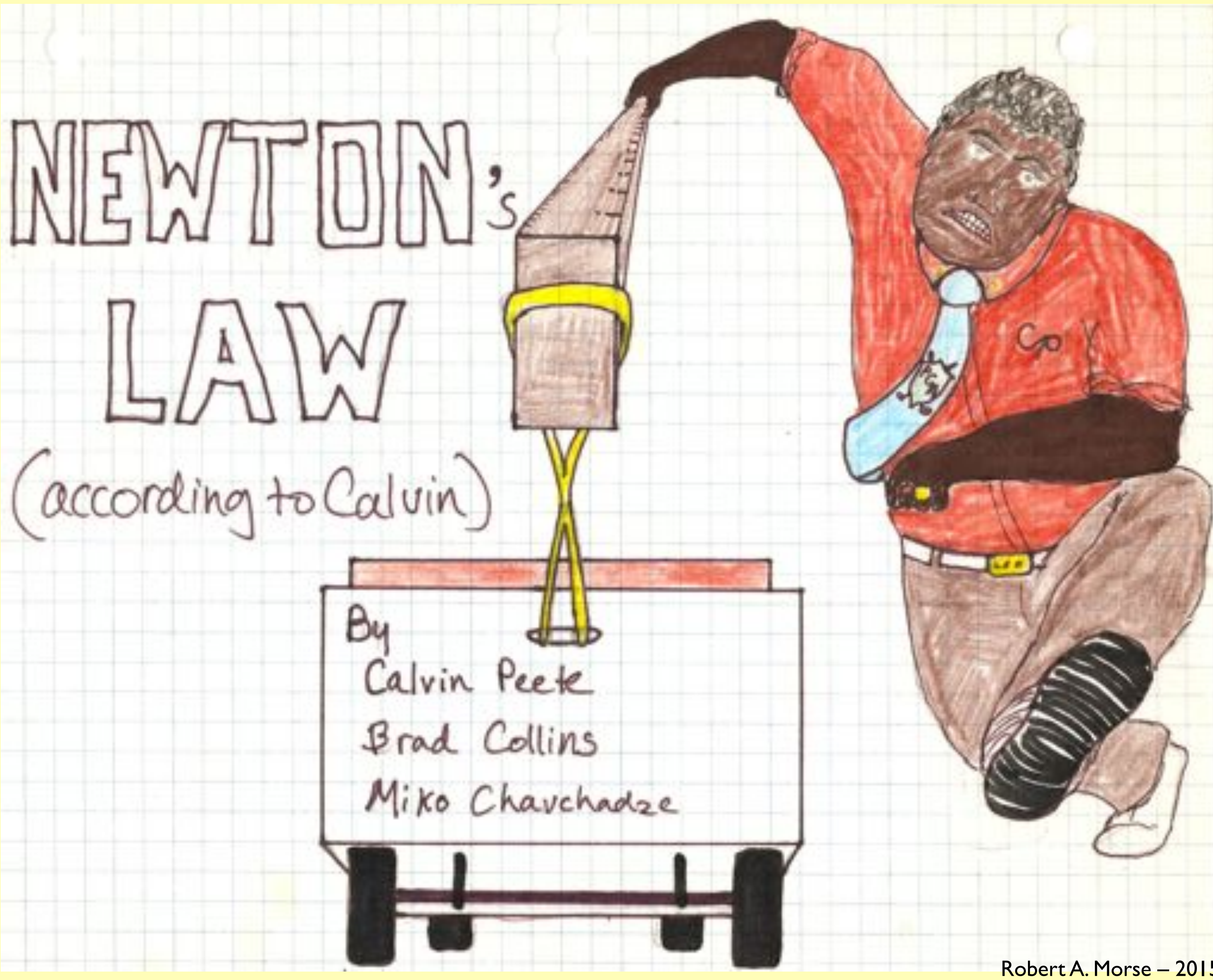
PSSC rationale

- Deliberate design to distinguish the inertial and gravitational functions of mass by <u>not</u> using version of Atwood's machine
- Historically a concern of Newton & Eötvös
- Inexpensive equipment for HS budgets – could be built by teachers or assembled from kits
- "Homely physics" in Cliff Swartz's term using common materials

Both Newton and Eötvös carried out experiments to test for any difference between the gravitational and inertial properties of matter.

Issues & Observations

- Done on floor, took up lab space, six lab groups could be quite "exciting!"



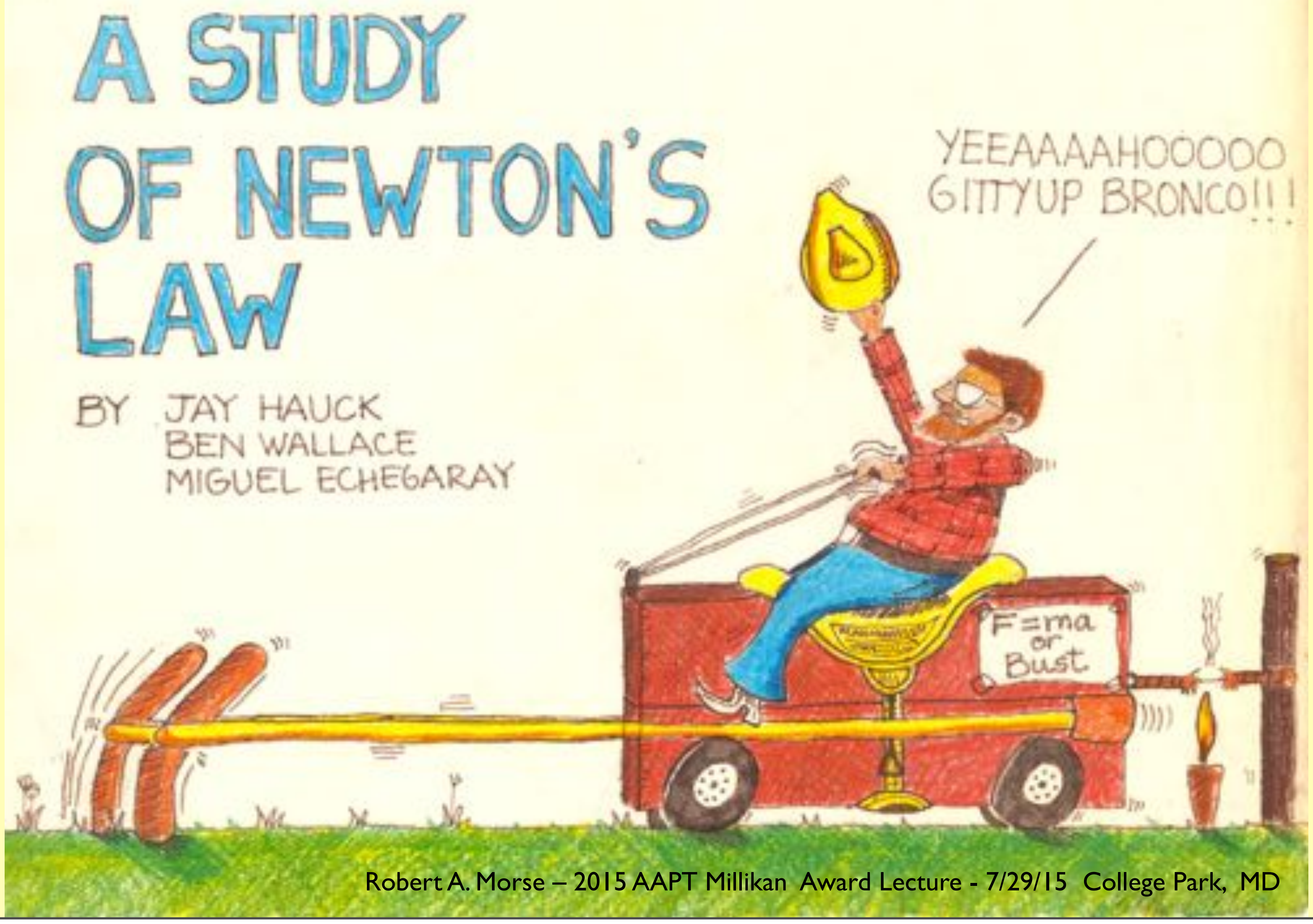
Physics Lab Cover Art

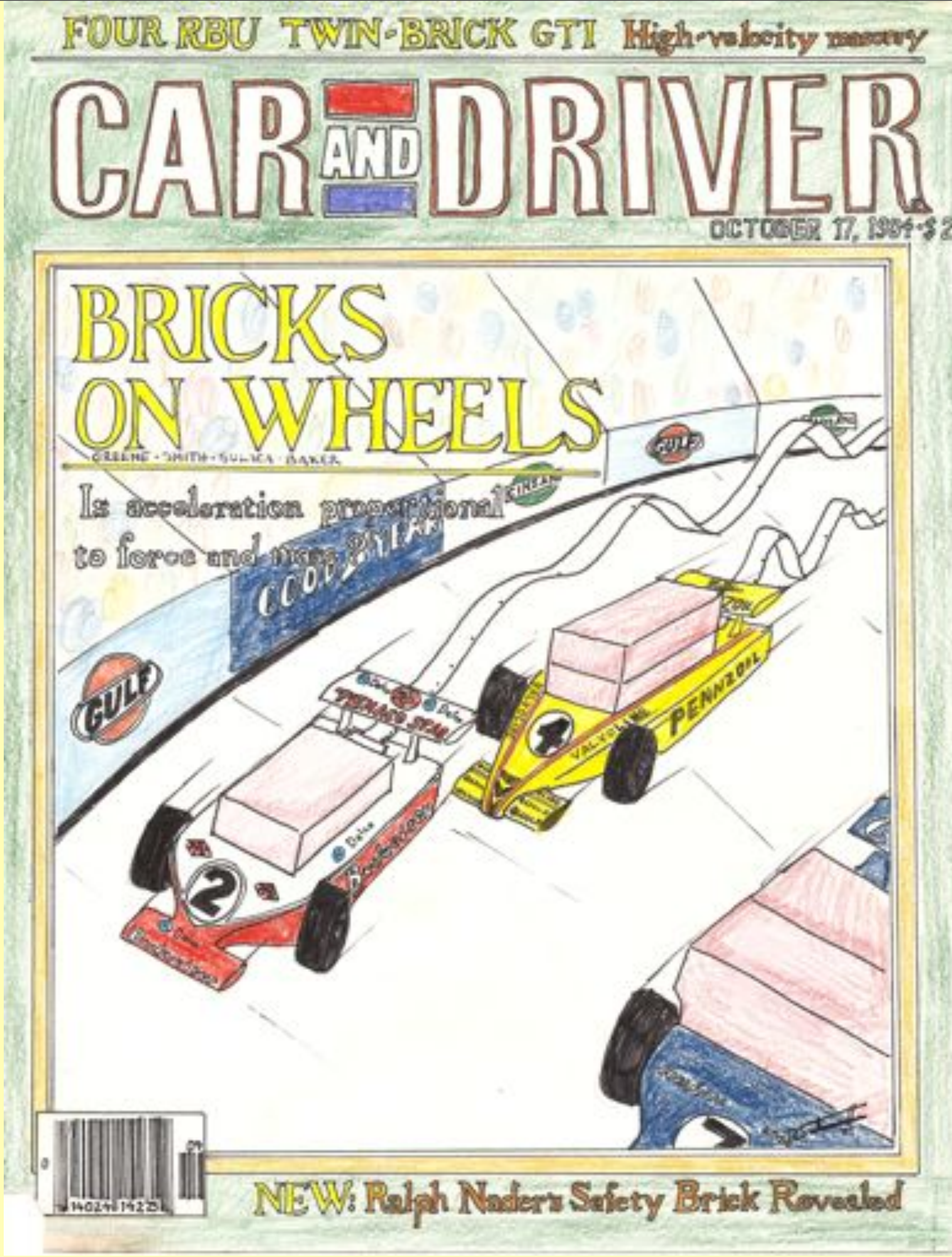
Imagine jamming all the furniture in the lab off to one side to get the floor space for six groups of students to go charging across the floor trying to keep a constant force on the rubber bands.

Issues & Observations

- Data collection, analysis of ticker tapes, sorting out effect of number of rubber bands and number of bricks – many steps before reaching a conclusion
- Focus on sub-goals interferes with understanding goal of experiment. (Simon, 1976 in Simon, *Models of My Life,* 1991, p 88)

- No easy "Ah Ha" moment of discovery
- Students not always clear on function of rubber bands





But it was exciting!

FACET - Physics can and should be challenging and fun – a mix of shallow fun in the moment and deep fun in long term satisfaction with accomplishment.

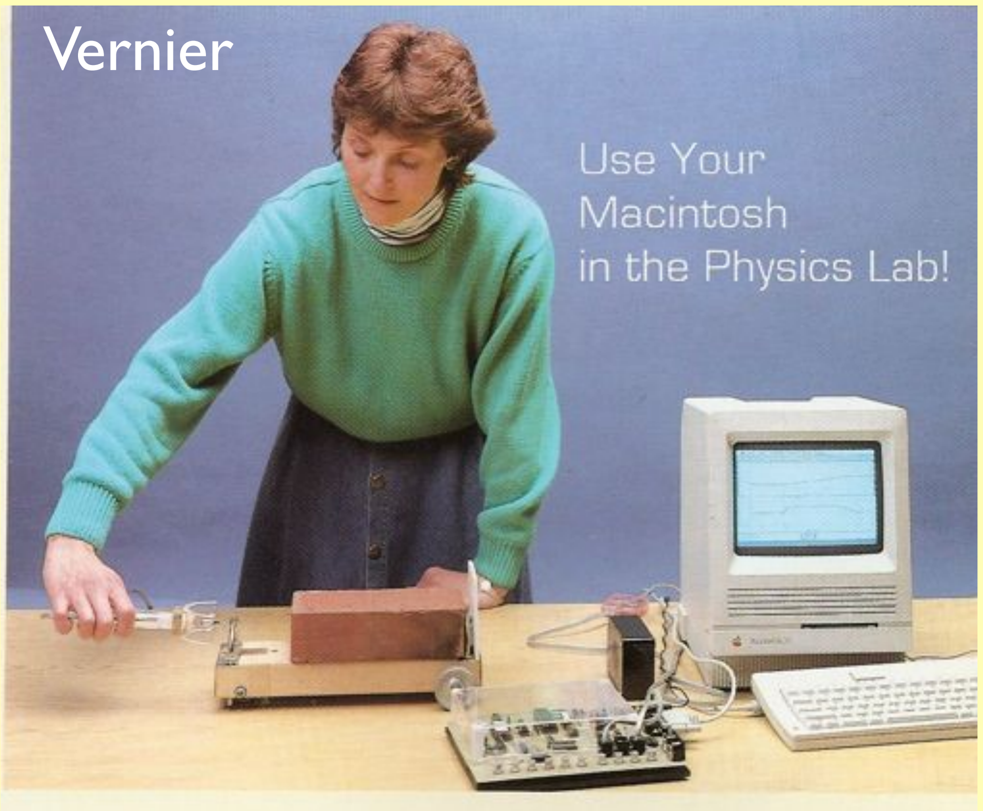
IF there is too much fun
THEN fun becomes the focus
AND physics gets lost

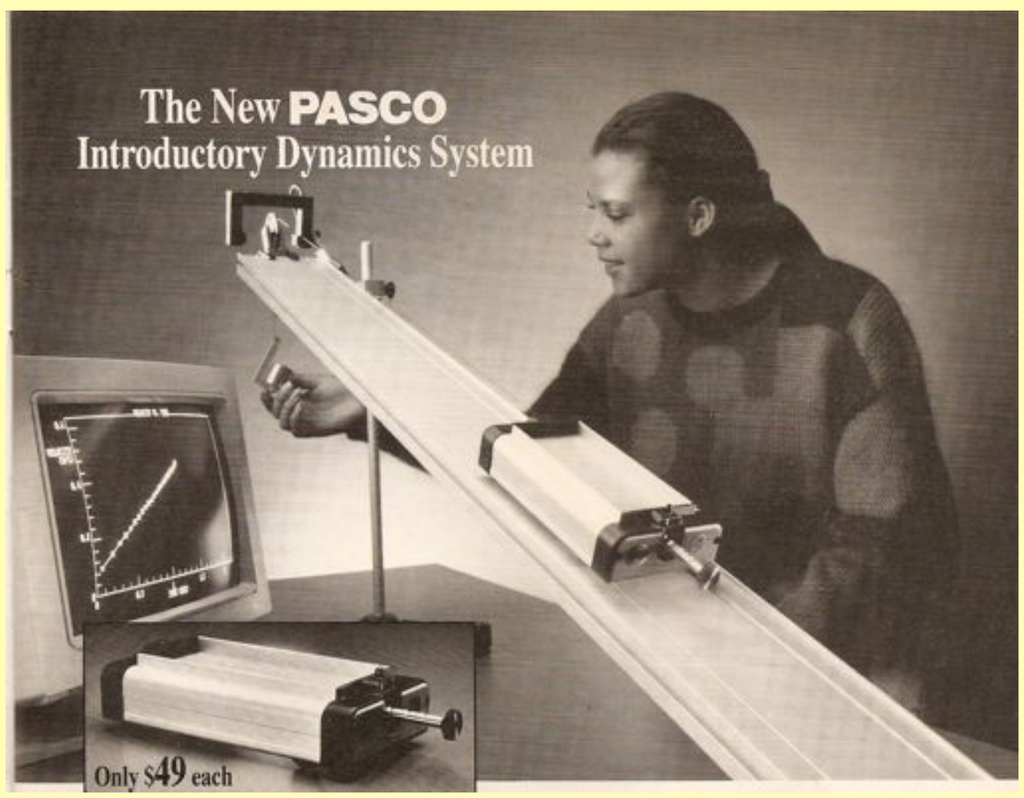
Why not use Atwood's Machine?

- Gravitational force:
  - Weights differ but free fall acceleration doesn't – confusing when masses are shifted to get different forces in Atwood's machine analysis – more confusing when mass just added to change force
  - Semantic/conceptual confusion between weight as property of object and as interaction
- Boring – can't vary it – can't turn it off – too weak to perceive effect of anything but Earth
- PER: conceptual issues for students with modified Atwood's machine

New Technology => New Possibilities c. 1991

(Thornton, Laws, Sokoloff – Vernier & PASCO)

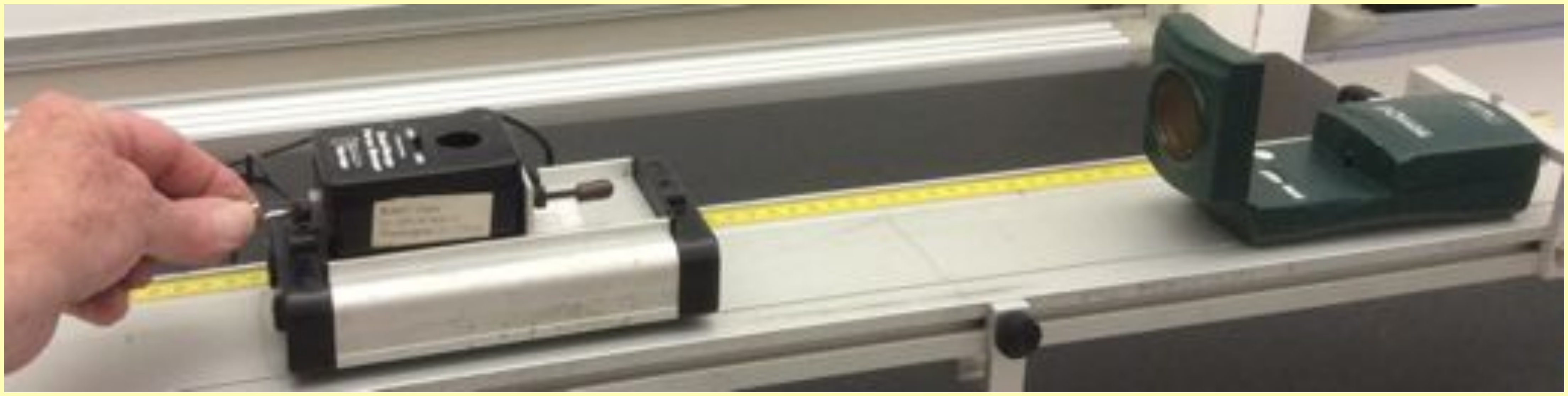




- Ultrasonic motion sensor
- Force probe
- Low friction cart
- Computer interfaces and software to allow simultaneous plots of different variables

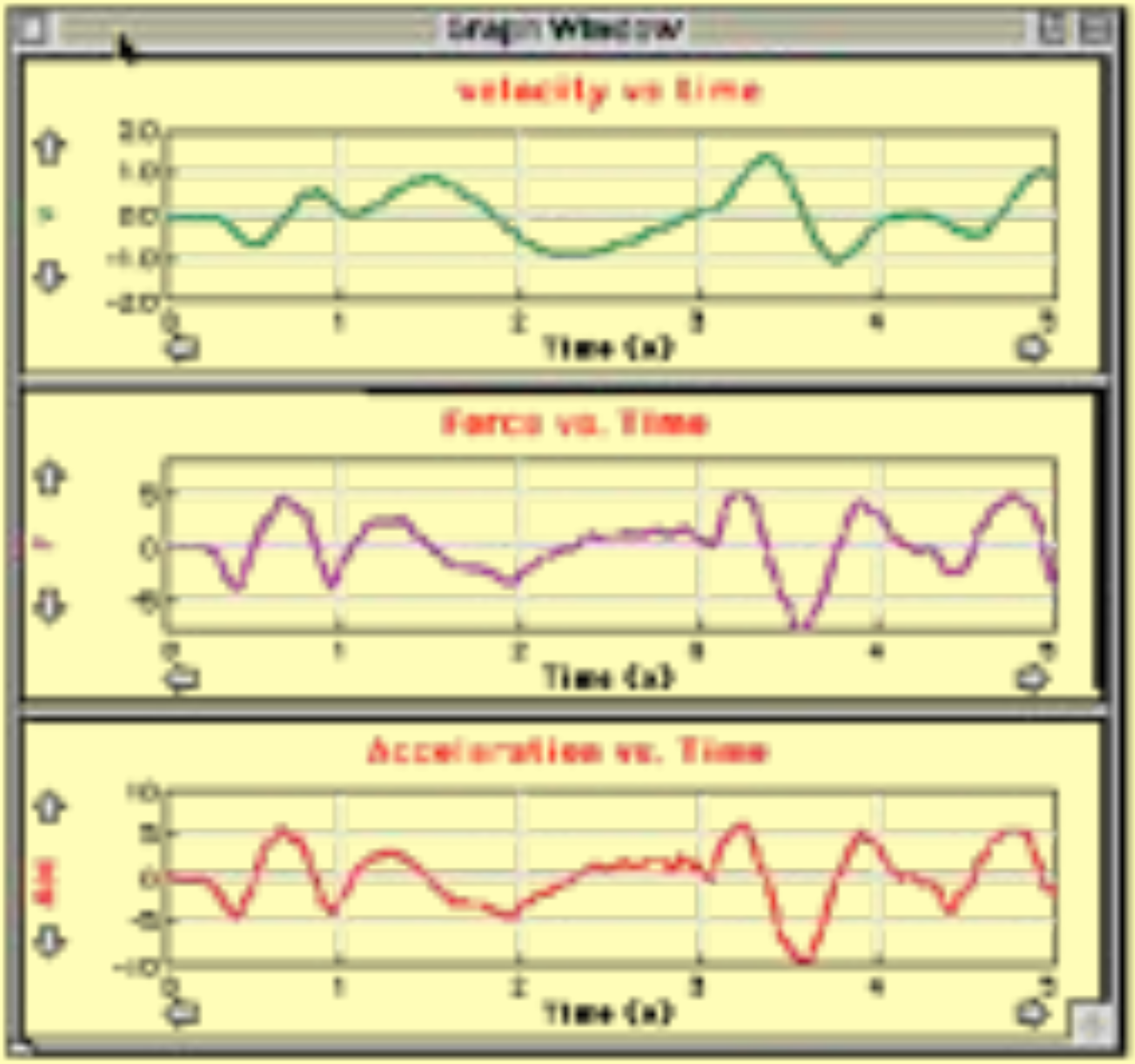
Alternative to PSSC lab

- How does force affect motion? Students unclear on whether more force causes more velocity or more acceleration
    - With force sensor on cart and motion detector on track student wiggles cart back and forth on track applying force only to sensor.
    - Three real-time graphs plotted simultaneously : velocity, force and acceleration as function of time



Real time graphing of data can be a powerful tool to associate events with their graphical representation.

“Wiggle” experiment result - Eureka!



FACET

Discovery = Recognition
Ah-Ha moment
Visual pattern match is efficient for initial learning
(Simon)

Less cognitive load => easier recognition of relationships.

Replay reinforces – acceleration shape matches force shape

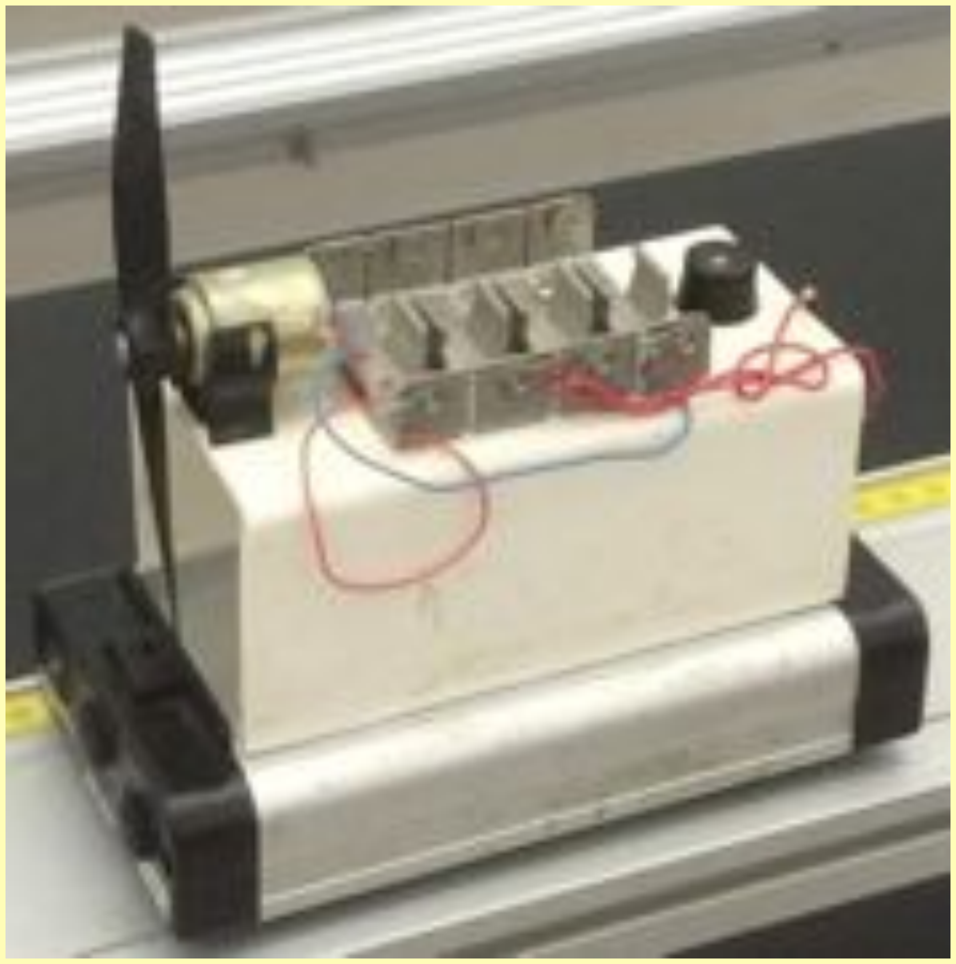
Eureka? It ain't that easy.

- Logic:
  IF force and acceleration patterns match,
  THEN 2F => 2a, etc.
  (Facet - use capital IF …THEN to emphasize reasoned argument being made – Eric Rogers)
- Observation: not all students fully translate that into a = (const) F. Need to reinforce acceleration and force relation.
- Need to bring inertial mass into picture
- Solution - find new constant force for modified PSSC lab.

When laying out a reasoned argument, I often use Eric Rogers technique of capitalizing IF and THEN as in his PSSC videos and his textbook “Physics for the Inquiring Mind,” to emphasize to students that there is a formal reasoning sequence being laid out, much as you might do with a proof in Geometry.

Fan units for non-gravity constant force

- Project Physics fan carts in storage room, with slot for "sail" for fan to push on. Can tow ticker tape for acceleration graph – but bearing friction gave non-constant acceleration.
- Motor, battery case and switch from fan cart used to make fan unit accessory to fit on PASCO™ cart.



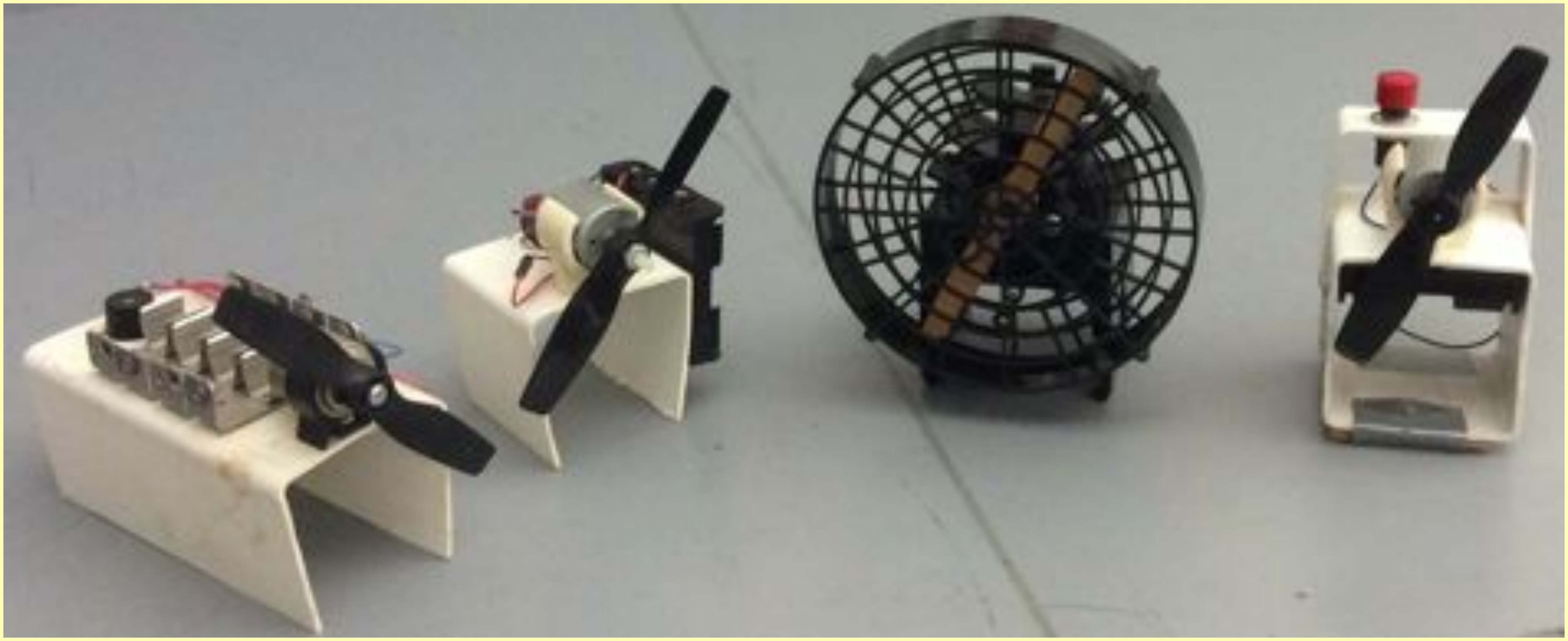
Constant acceleration over 2 meter distance.

Change force by replacing cells with "dummy cells" cut from Al rod.
Open space below fan for adding mass.

Modifying the PSSC lab

- Began working with Laws, Thornton, Sokoloff and Willis – thinking on similar lines.
- Developed modification of Real Time Physics using redesigned fan unit for investigating acceleration and Newton's second law. Real-time graphing used to find accelerations for different forces with dummy cell arrangement and different mass by loading mass bars on PASCO™ cart.
- Used in a PTRA workshop in 1993 at Boise

Fan unit development - phase 1



From left

Original – first "public" unit – PASCO™ – improved DIY version

Model airplane propellors, DIY bodies cut from PVC downspout, dummy cells (Al rod) to change fan speed

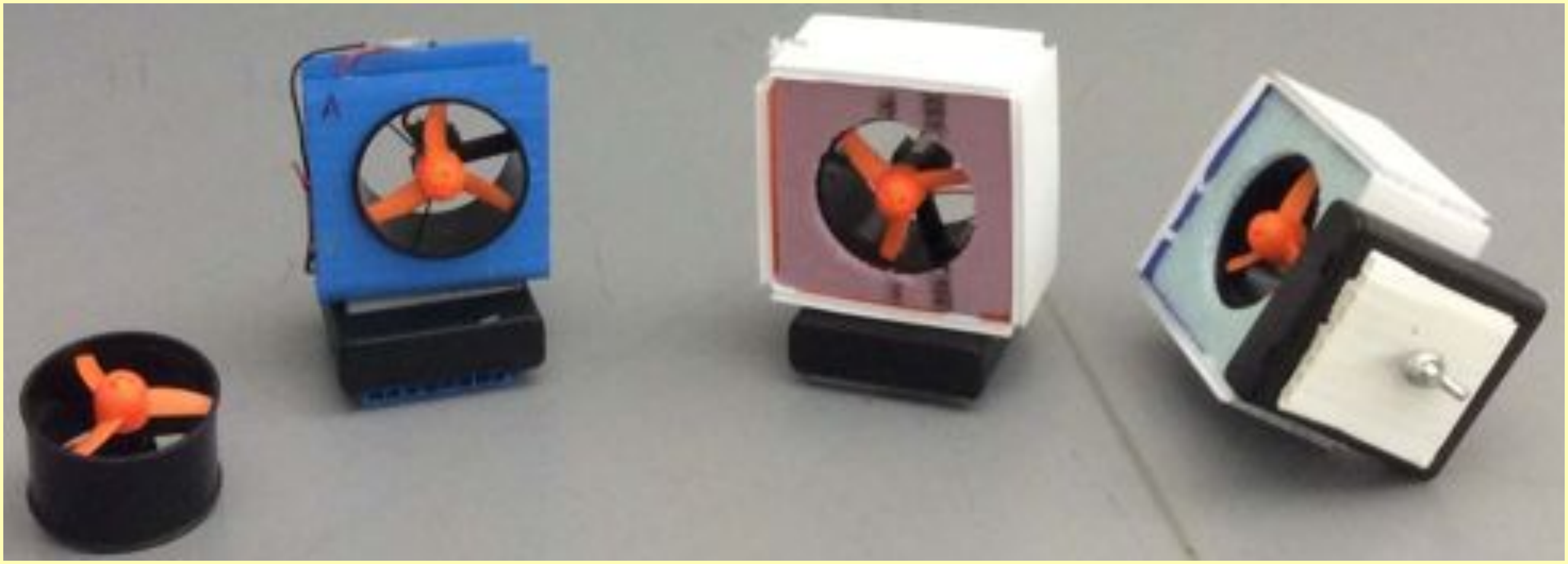
The unit on the left was the first I made from parts cannibalized from an older fan cart used in Project Physics. The second was the more compact version made for the 1993 PTRA workshop. PASCO made a fan unit adapted from that - originally without the propellor guards, but their wooden prop was a bit more of a hazard than the nylon ones I had used so they added the guards. The last version I made using model airplane propellors is shown at the right.

2nd published DIY design

Slightly easier to build, could be fastened together in groups

That version was slightly easier to build and had the virtue that several of them could be fastened together as you see in the picture.

Technology marches on!
Further fan unit development - phase II



Improved magnets led to lightweight ducted fan units for electric model airplanes

Redesigned fan units mount ducted fan on battery case with built-in switch

Can add removable bolt for mounting to surface for rotational motion

Since the original design, development of small powerful magnets has made lighter weight more efficient motors possible, leading the model airplane industry to develop ducted fan thrust units as seen at the left. Once I discovered these, I redesigned the fan unit to make construction easier and make the units smaller. All three of the units shown use corrugated plastic, such as you see in political election signs (a good thing to salvage the day after the polls close.) The two versions at right use thick foam insulation board with a hole cut with a hole saw to press fit the ducted fan into.

Rethinking the PSSC experiment as ILD a la Thornton & Sokoloff

FACET - easy as 1, 2, 3. Numerical patterns with small whole integers and ratios with small whole numbers are easy to spot and think with. (Some research indicates various primates & human infants have number sense for 1, 2, 3 - S.Carey, Science, 10/23/98)

This one is obviously linear

2	1		1.37	4.66
4	2		3.79	12.9
6	3		5.02	17.1

Is this one linear?

Dummy cell force changes were not linear with number of cells.

Need to make force and mass values simple and obvious

When you are trying to guide students to make a discovery, keeping things simple reduces the cognitive load – later you can have them go back and deal with more complex data, which they also need to do.

Solution: multiple forces, multiple masses

Turn on 1,2,3 fans keep mass same

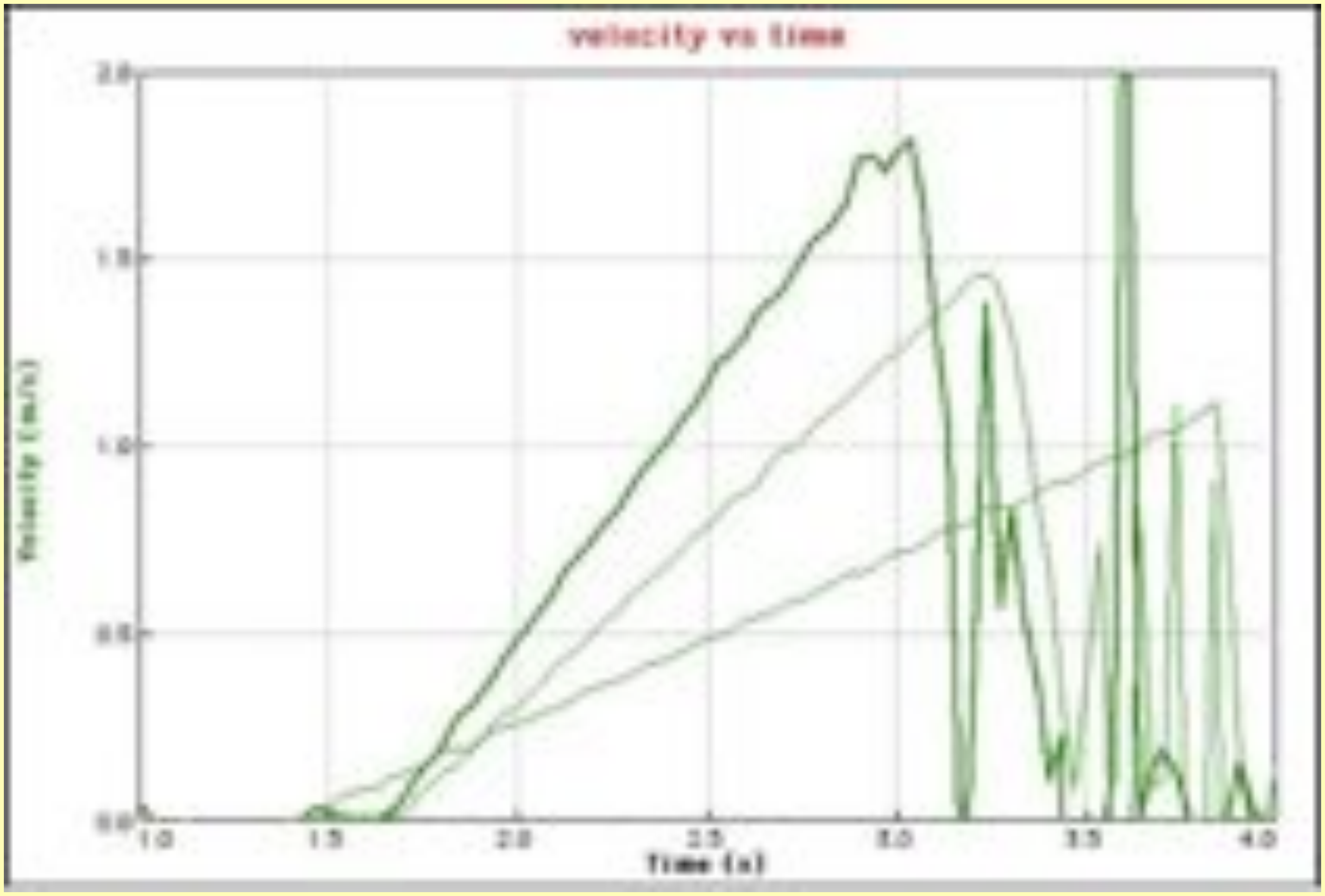
(Fastened by skewers running through corrugated plastic)

Run only 1 fan add fans & carts

In the first photo you see three fans mounted on one cart. That whole contraption counts as one unit of mass. Turn on 1 fan, 2 and then 3 and overlay the velocity-time graphs (next slide) to look at relationship of acceleration and force.

In the second photo I start with 1 fan on one cart, then pile a second fan on top and load onto a second cart, giving twice the mass, but only running the original fan. For three times the mass, pile 3 carts up and use the skewers to attach all 3 fans- but only run one. (At the end, I acquiesce to the students demands to run all 3 fans at once - they are hoping for some disaster.)

Velocity - time graphs for acceleration comparisons



V-t slope a more dramatic display difference than a - t levels would be - software allows rapid slope determination

Analysis by ratios – Pattern Matching

Data (acc scaled relative to smallest)

force	acc	mass
1	1	1
2	2	1
3	3	1
1	1	1
1	1/2	2
1	1/3	3

Various ratios
Match to data columns

F/a	F/m	a/F
1	1	1
1	2	1
1	3	1
1	1	1
2	1/2	1/2
3	1/3	1/3

Matches mass
m=F/a

Matches acc
a=F/m

No match!
Meaning?

Discussion focus: interpretation of ratios

From the acceleration data we fill in the table scaling the acceleration relative to the first value to get rough integer values in the table at left, then use those values to populate the table of ratios at the right. For full discussion see my PTRA manual "Teaching About Newton's Second Law"

The F/a column matches the mass. So mass can be interpreted as describing how much force must be exerted on that object to cause one unit of acceleration.

The F/m column matches acceleration – acceleration of an object of a given mass increases as the force exerted on it increases

The a/F column does not match any of the data, but can be interpreted as telling the amount of acceleration of an object caused by a unit of force. A large ratio means that object will have a large acceleration for a given force – it has the property of "liveliness" or "alacrity" – not used in mechanics, but it is a property of an object. Reciprocals do have utility in other areas of physics – series and parallel combinations of resistors can be understood by resistance and conductance respectively. Capacitance has a reciprocal, not much used now, called elastance. Inductance and reluctance (at least in one meaning) are reciprocals. (For discussion see R. A. Morse, TPT, vol 43, 2005.)

Other Uses

Fan cart on ramp – balanced forces. Multiple fans can be used

Platform on rotary motion sensor

Students design experiments on effects of forces at different angles, different radii and different numbers of fans

Also different masses at different radii

Rotational analog of second law fan cart experiment

See 2013 AAPT Apparatus Competition

Fan units on cart on ramp can be used to get balance with fan on, measure acceleration with fan off, turn around and turn fan on and get additional acceleration down the ramp. With a three fan set up students can explore the vector sums of the forces.

The rotary motion setup allows students, typically later in mechanics, to design their own experiments to investigate rotational motion. I used this during my last year in the classroom, and my successor, Will Segal has used it in his classes to good effect.

Pedagogical Engineering
An Electrostatics Example

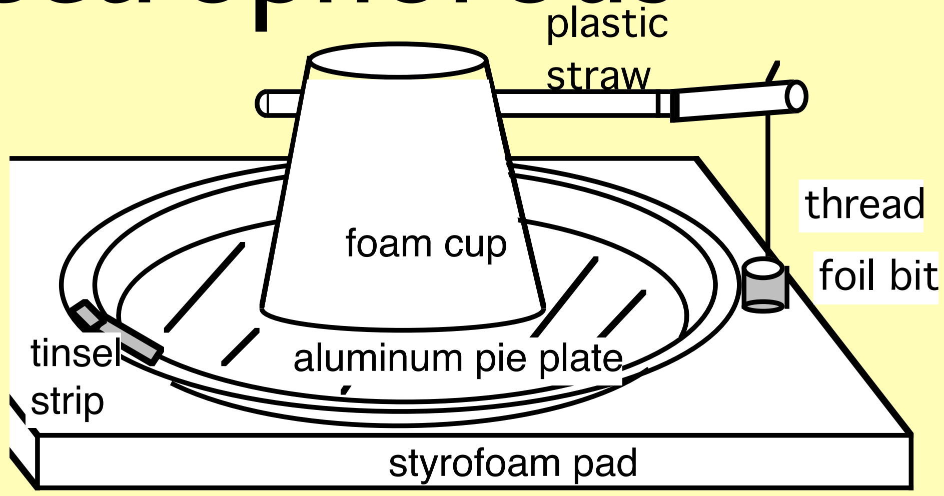
Pedagogical Engineering in Electrostatics

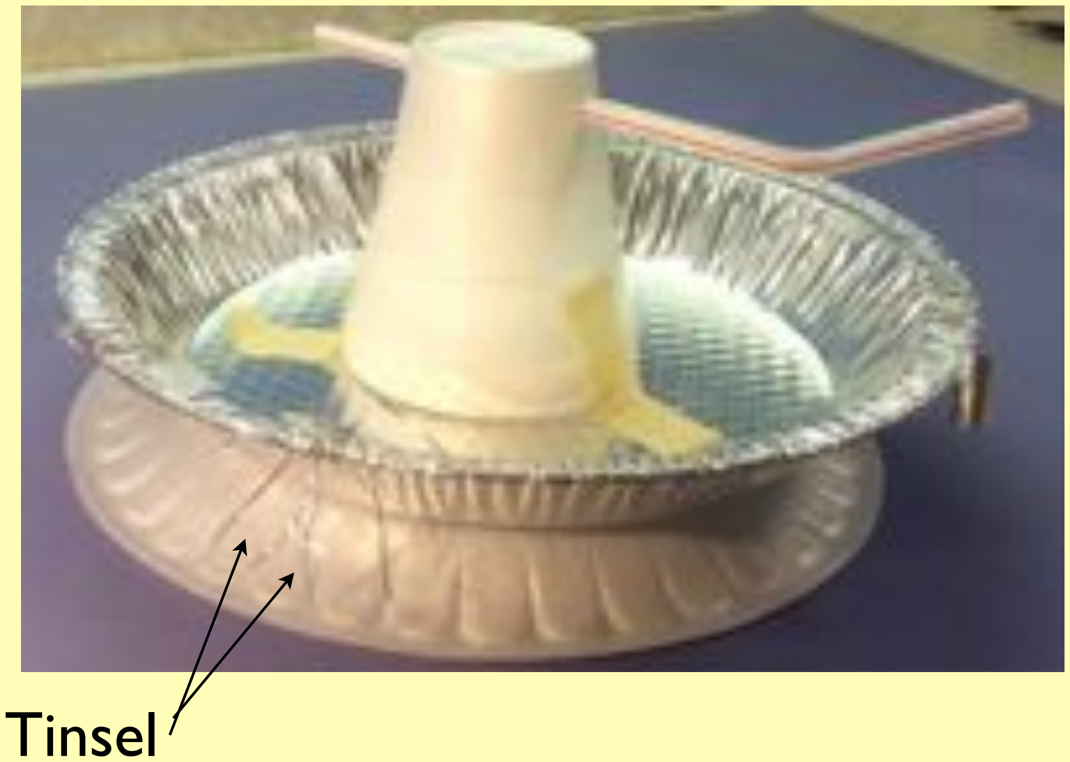
Volta's electrophorus – deepened understanding of induction & effects of distant action by electric charge

- Catalog version is expensive
- Electrophorus for student use : Al pie tin, foam picnic plate & foam cup handle – one per pair of students

- Student experience: draw sparks on charge and discharge. Test sign of charge by repulsion with pair of oppositely charged objects. Explain.
- Explanations confused – naive ideas of charging

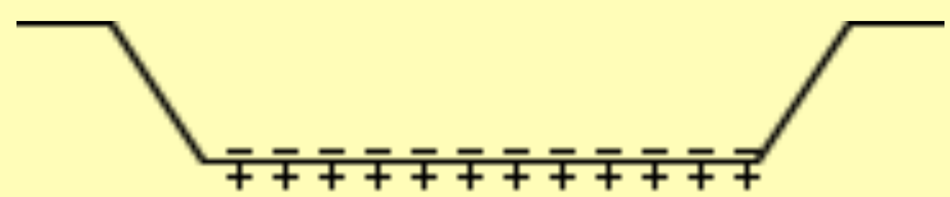
Instrumenting the Electrophorous





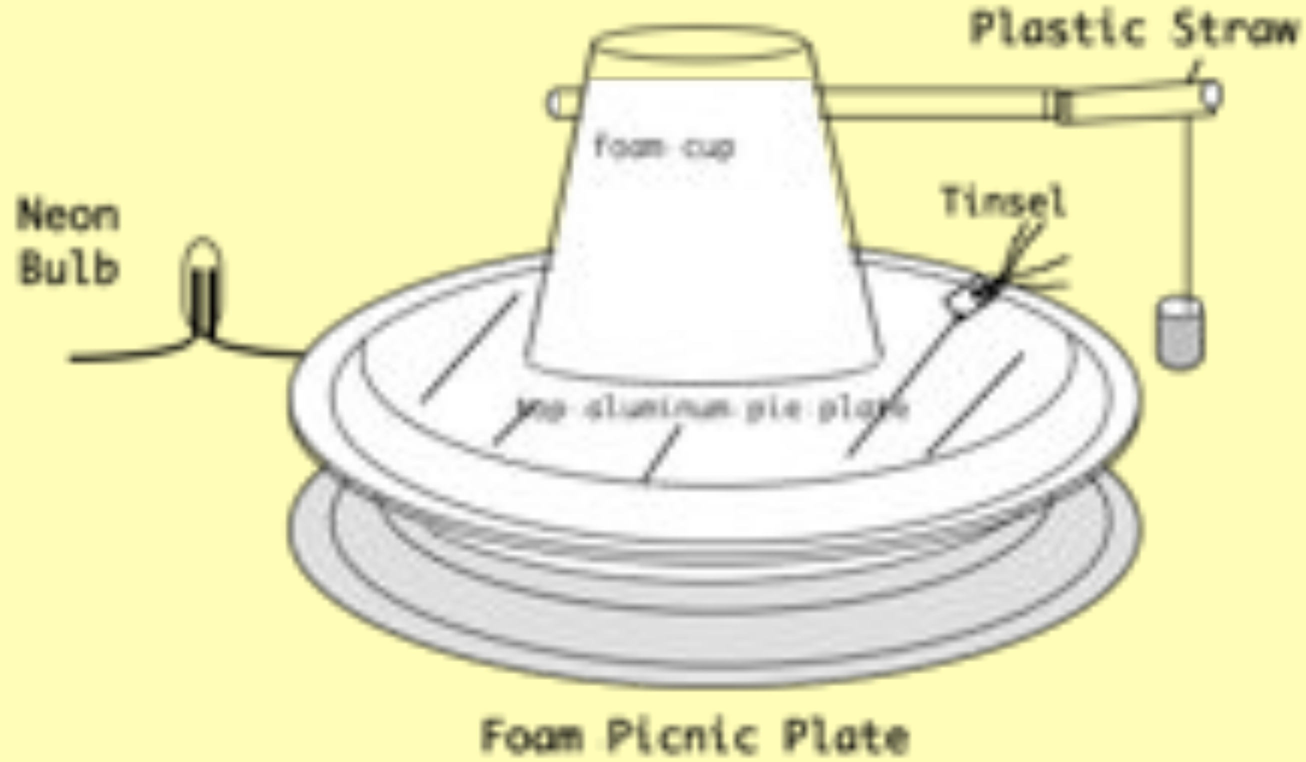
- Franklin – pith ball on thread to monitor charge transfer – add soda straw and thread with foil bit
- Shows charge transfer – sort of ammeter
- Spray of tinsel – shows surface charge state and potential
- Neon bulb – shows charge transfer & sign of charge

Student issues – thin metal – hard to visualize & realistically represent charge location

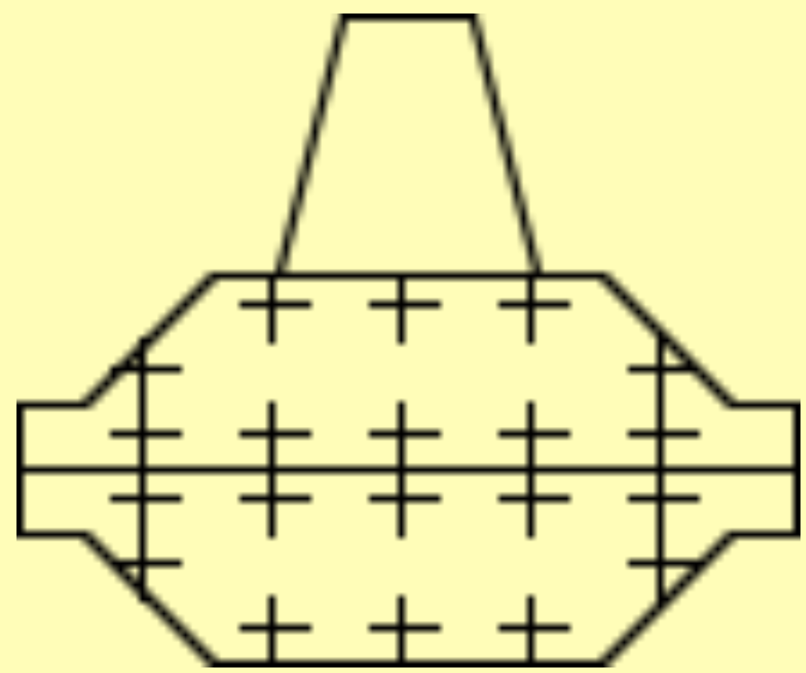


It is hard for students to think that an electron on the top of the aluminum pan is very far from one on the bottom, and our usual diagrams can’t fit the charged particles in where they actually belong.

Symmetrical Instrumented Electrophorus

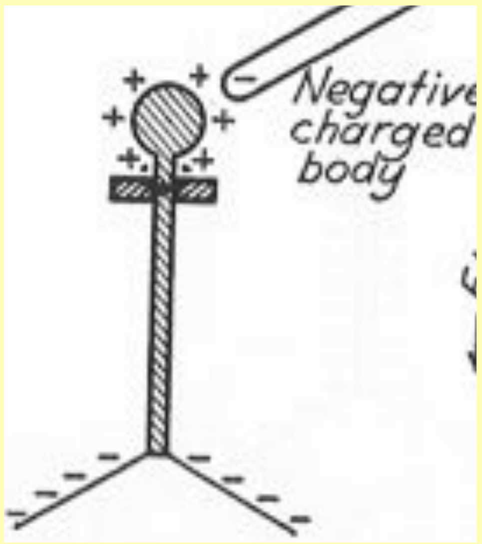


- Two pie tins clipped together
  - New diagram - symmetrical
  - pre-populated with atomic cores



Representing charge distributions

"Floating" charges
Charge not conserved on neutral electroscope
(+6 and -8 ≠ 0)



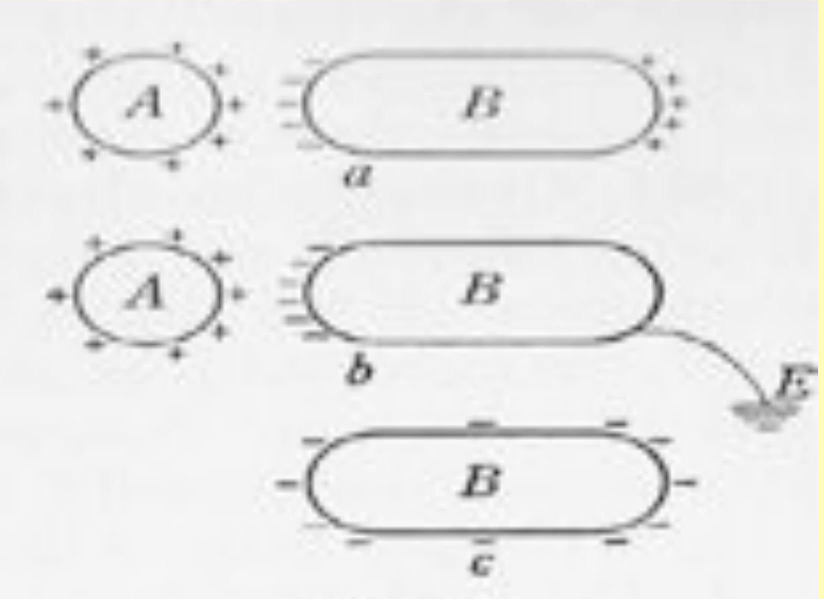


FIG. 237

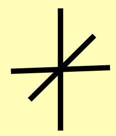
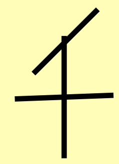
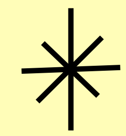
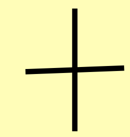
Which charged objects moved?
Not conserved
b -6 c -11

- Students may recite atomic model, but need to visualize charged states in terms of atomic scale changes.
- Standard representations don't emphasize this. Only show net charge. Mechanical Universe video – charge & charge displacement shown by colors – not practical for sketching
- Need sketchable representation – emphasize conservation of charge – distinguish polarization from transfer
- Facet – good representations facilitate visual thinking

Although students in the introductory course know about atoms and electrons from chemistry and earlier courses, they tend to casually think of electricity as a substance, not a subject. We want the atomic model to be as real as possible for students
Charge is not just a state – it represents a set of objects that have properties and positions in space. In showing charged states of macroscopic objects we need to treat positive and negative charge as associated with microscopic objects, namely atoms and electrons, and our representations should help visualize this.

Representing Charged States

New convention for atoms – lose or gain only one electron – only participating atoms shown

neutral  polarized  negative ion  positive ion 

0. Initial blank diagram

top +

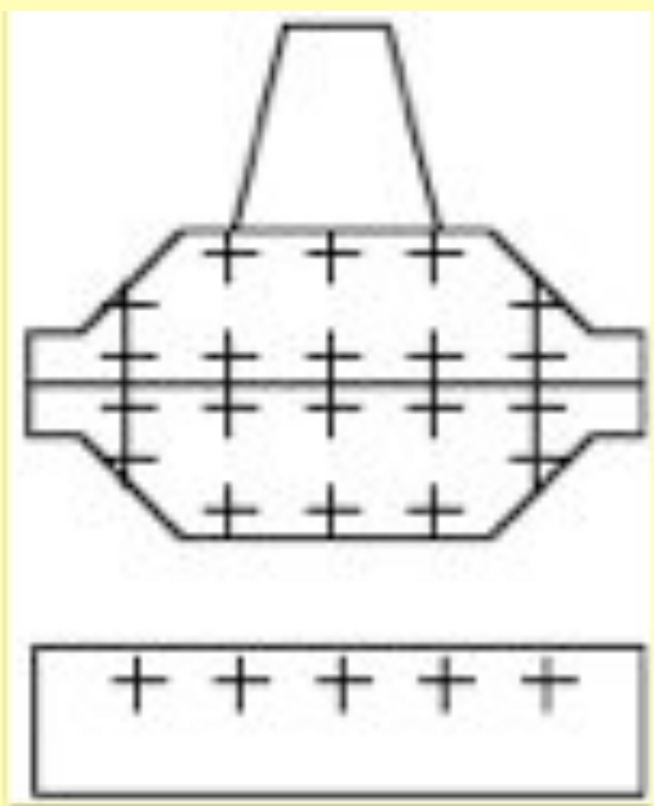
top -

bottom +

bottom -

foam +

foam -



1. Neutral electrophorus

top + 10

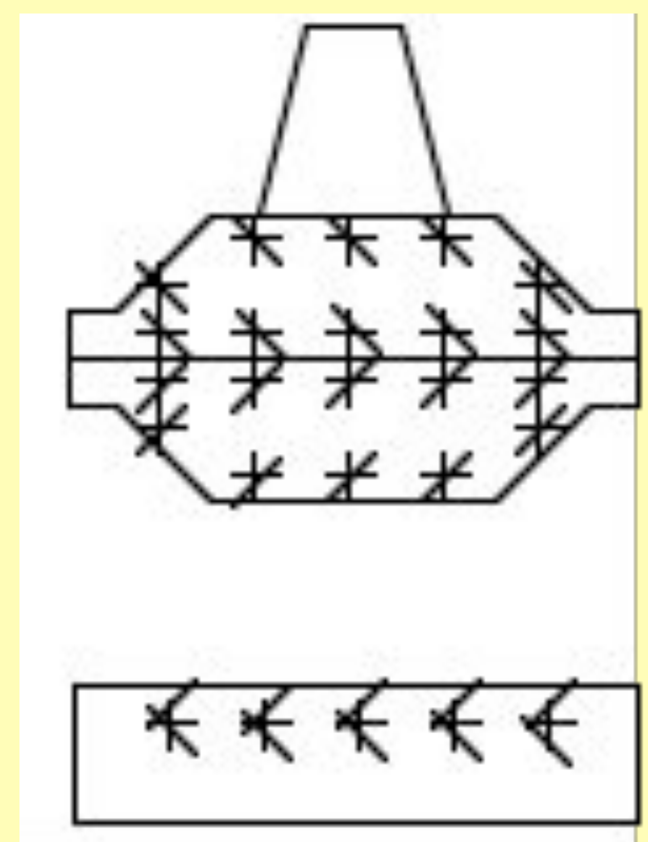
top - 10

bottom + 10

bottom - 10

foam + 5

foam - 10

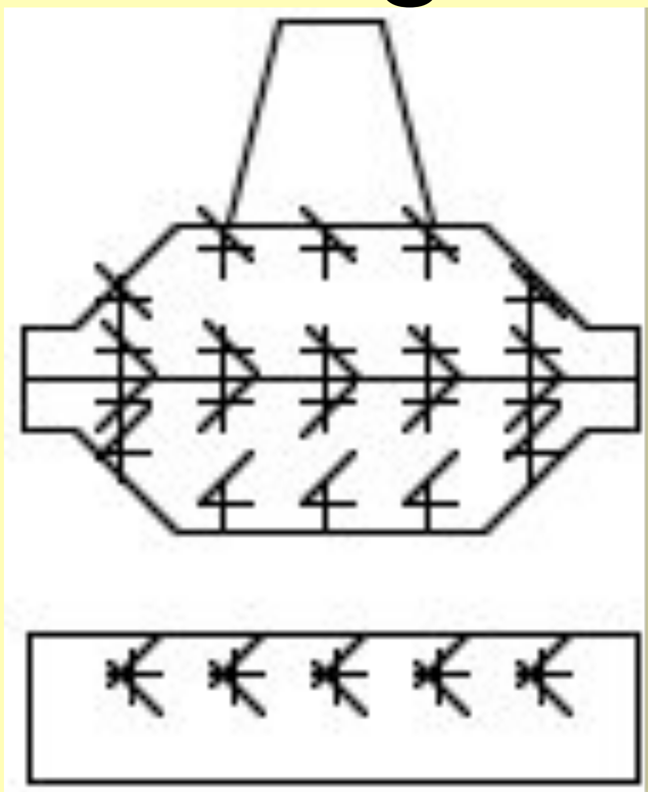


To promote understanding the atomic nature of the charging and discharging process in solids and solid conductors, I use a representation that emphasizes the nature of those processes. Most of the atoms in a conductor or insulator do not actually participate much in the process. If you calculate the surface charge density of a solid at the breakdown field strength in air, (3 million newtons/coulomb) you find that only 1 in a million atoms has gained or lost an electron. (You could fit all the atoms that have an excess electron on a fully charged square meter sheet of plastic in 1 square millimeter of surface.)

So we show only atoms in these sketches that participate in the process. A neutral atom is drawn with the positive ionic core as a positive sign and the electron to make it neutral as a slash, so it does not get lost in the crossbar of the + sign. The electron slash can be shifted up, down, right or left to show a polarized atom. A negative ion would have two slashes, and a positive ion none. In the electrophorus charging sequence we first draw the neutral electrophorus and the negatively charged foam note electrons of surface charge) and total up the number of + and – charges in each plate of the electrophorus and the foam.

Stages of induced charge separation

2. Closer – neutral – beginning to polarize



3. Neutral – charge separated

top + 10

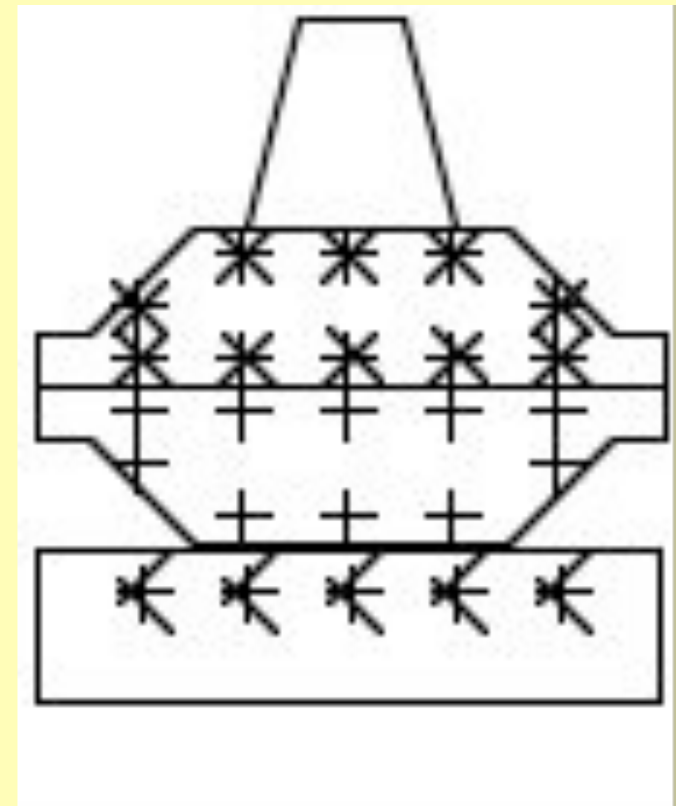
top - 20

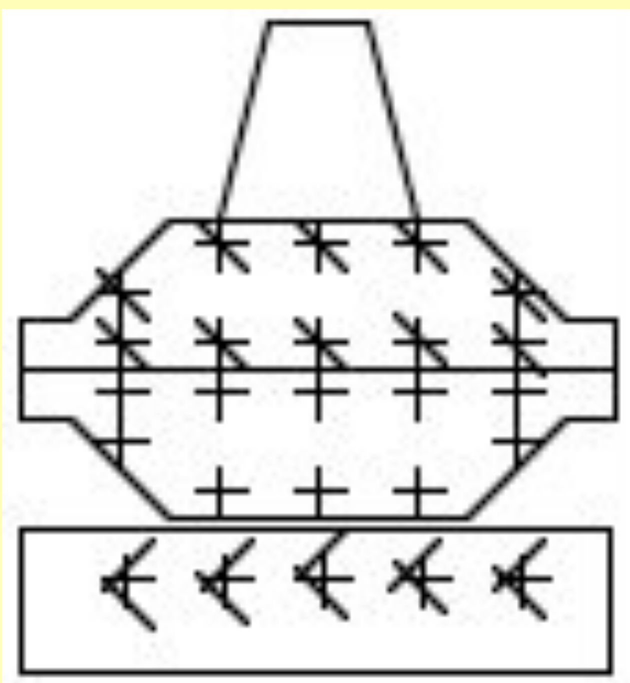
bottom + 10

bottom - 0

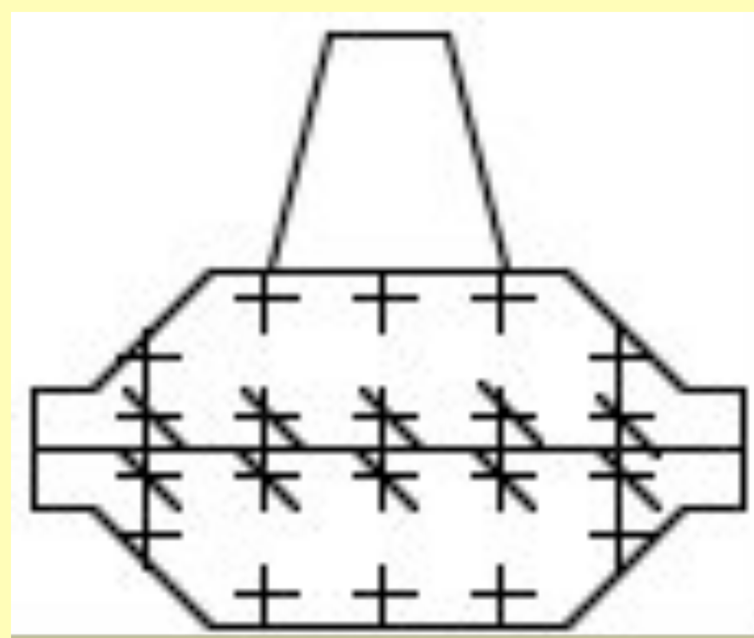
foam + 5

foam - 10





4. Charged near & far from foam



As the electrophorus approaches the foam plate we see polarization taking place – leaving a negative surface charge developing at the top and positive at the bottom.This would be shown by the tinsel on the top plate starting to spread apart. In the third step, we consider that all charge transfer will have taken place – there are no participating electrons in the bottom pie tin, but all have moved to the top pie tin. When the top pie tin is touched with the finger, the excess negatives leave, and the top pie tin is neutral, which is indicated by the tinsel (not shown in these diagrams) which would be lying flat on the top plate. Finally when the electrophorus is move far from the charged foam. the electrons would be distributed evenly between the two pie tins, leaving top and bottom surfaces with net positive charge.

Value of Articulation

Facets of teaching and pedagogical engineering are something that many teachers do.

Articulating them sharpened my description of processes I engaged in to improve student learning, helping me think explicitly about my observations and information about learning that I used to choose the changes that I made in equipment and in learning activities.

Final Reflections

Learning is a student's responsibility, but as teachers (expert learners), we need to examine whether our curriculum, at every scale, is readily learnable.

As experts in our field a hard thing to remember is what is was like not to understand. Research in physics education helps us know what students have trouble understanding.

As teachers, we should continually examine our techniques and how effective they are with students, then continue to tweak our teaching strategies and tactics, based on all the knowledge we can acquire.

Final Reflections

Formal research in the high school classroom is not well supported by our education system, but informal action research – observing and reflecting on student learning and keeping reasonably abreast of formal research can inform our work.

We do see in the PER community a number of research collaborations between HS teachers and PER folk - we probably need more.

For the youngsters in the crowd – teaching high school can be an intellectually and personally rewarding profession for a physicist.

Final Reflections

A concern is that the US, locally and nationally, seems engaged on a shifting search for a magic method that will immediately improve teaching. Well done, strategic testing can help – poorly done, it can only hurt.

Learning to teach and teaching to learn is a career-long process that takes hard work. The requisite continuing professional development needs better support, particularly for teachers and schools which have the greatest challenges.

I am proud to be an AAPT member. We continue to work in support of teaching at all levels and to build knowledge of learning to improve teaching. Through the PTRA program, a major factor in my professional life, and other programs, we have had and are continuing to have an impact on teachers eager to learn and on new folk entering our profession.

Final Reflections

P. W. Bridgman once said "The scientific method, as far as it is a method, is nothing more than doing one's damndest with one's mind, no holds barred."

I say that the scientific method of teaching, as far as it is a method, should be nothing less than doing ones damndest with ones mind, no holds barred.

Finale

THANK YOU ALL

I have been rather serious through this talk, spouting off about facets of teaching, PER, pedagogical engineering, etc. I really do not take myself all that seriously, so to show you, I will close with a musical finale. If you want a good rousing piece of music, especially one to poke some fun, Gilbert and Sullivan are a good bet. So with apologies to them and to my PER friends out there, here is my version of Bunthorne's song from Patience.

If you're anxious for to shine   in the Phys. Ed. Research line   as a prof. of knowledge rare,
You must get up all the germs   of the Piagetian terms   and plant them everywhere.
As you talk of concrete stages   and discourse in novel phrases   of constructivist theories of mind
The meaning doesn't matter   if its only idle chatter   of the cognitive resource kind.
And everyone will say as you follow the modeling way
If that's not deep enough for this old prof, which is rather deep for me
Why, what a very singularly deep old prof, this deep old prof must be.