Inquiry-based Physics labs for life science students

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What happens in the Lab...

First Lab:
The Vitruvian Man

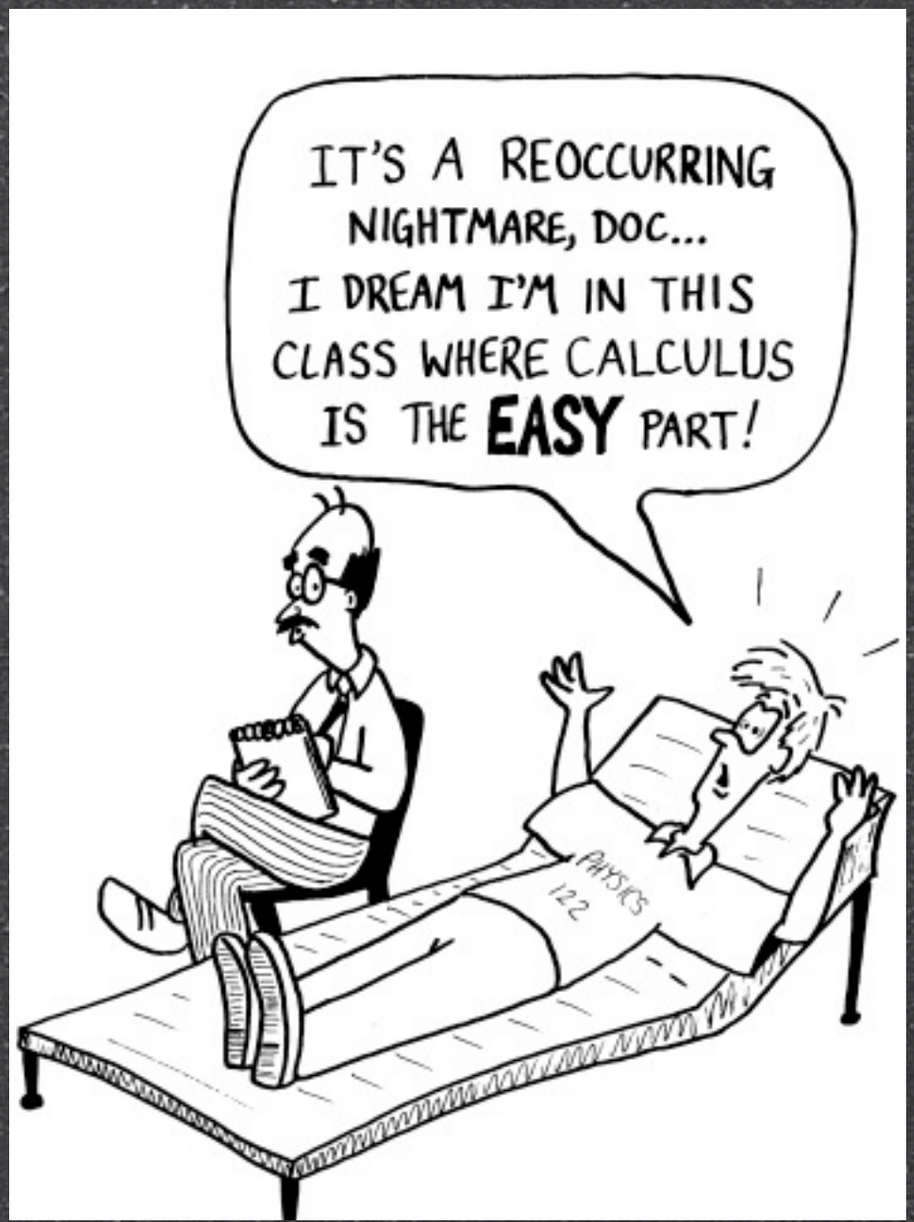
Why is Physics relevant to life sciences?

- Physics saves lives...

- "The principles of physics are central to the understanding of biological processes, and increasingly important in sophisticated measurements in biology"

  Bio2010: Transforming Undergraduate Education for Future Research Biologists, http://www.nap.edu/catalog/1047.html

Physics-Phobia



http://talklikeaphysicist.com/

- Students are afraid of Physics
- They do not see the connection between Physics and their own discipline

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As a result...

- Students experience high levels of anxiety
- Students are not engaged during class
- Students do not learn well

How should we teach physics to non-physicists?

Goals

- Method:

  1. Make our labs inquiry-based

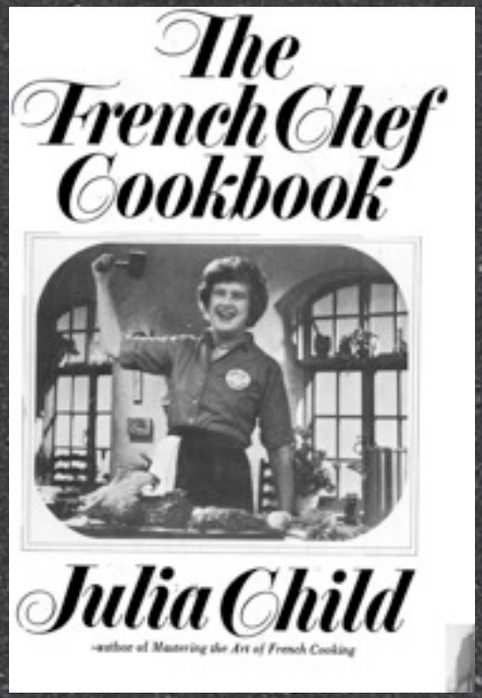
  2. Make the topic of the labs relevant for Life/Medical Science students

- Imperial Oil grant: 65k$ over two years to change labs in our course "Modern Physics for Life Scientists" (Physics 1BB3).

Why inquiry-based labs?

- "Cookbook" style labs: students just follow a recipe

  → Repeatedly shown to be counter-productive



- Inquiry: students engage in the same activities and thinking processes as scientists.

  → Shown to promote more positive attitude and better learning.

Anecdotal evidence

Richard Aldrich, President of the Biophysical Society

"I was also greatly influenced by Mr. Grant, my renegade ninth grade science teacher, who believed creative thinking and experimentation were the way to learn science," he says. Mr. Grant's labs were akin to a choose-your-own-adventure storybook. "We would often show up for labs where we were only given a topic, such as 'heat conduction and thermal expansion' and a bucket full of simple apparatus and materials," Aldrich says. "Our goal was to find something out and convince him that we had actually learned something."

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Harvey Mudd Interdisciplinary Labs

- Designed to illustrate the commonality of investigative methods in Biology, Chemistry, and Physics

- Two key aspects:

  - Students participate in the formulation of scientific questions and in experimental design

  - Lab followed by a tutorial to further interpret results obtained by each group in light of those obtained by other groups.

HARVEY MUDD COLLEGE

Common features of all the labs

- Students:
  - Form a well posed and falsifiable hypothesis
  - Design a laboratory protocol, make and record measurements
  - Propagate and combine errors
  - Perform data analysis in a computer lab
  - Write scientific lab reports

- Wrap-up session (feedback; reinforcement; puts their measurement in context; interaction with TAs/ instructor; cover more ground)

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Evaluation

- Lab weight: 15% -
>20%-> 30%

- Higher quality standards for lab reports

- Rubric to specify expectations and standardize marking

- Only 4 labs

Criteria/ Assessment	Distinguished	Satisfactory	Borderline	Unsatisfactory	Unacceptable
General	• Goes above and beyond expectations. • Interesting scientific insight is provided.	• Everything is done correctly. • Report is handed in on time.	• The report contains a significant number of errors or omissions.	• The report contains a very significant number of errors or omissions.	• Copying part or all of the report from another student or source. • Making up false data.
Presentation	• Writing is energetic and inspired. • Grammar and spelling are perfect. • Formulae are typed.	• Cover sheet present and complete. • Feedback form present. • The text of the report is typed. • Writing is clear, accurate and concise. • Sections are all present and logically sequenced. • All figures and graphs have a caption. • English generally correct.	• Cover sheet is present but some information is missing. • The text of the report is typed but the writing style is unclear, inaccurate or lengthy. • One section is missing. • Frequent errors in grammar and/or spelling.	• Cover sheet is not present. • Student's name is missing. • The report is handwritten and illegible. • The writing style is unclear, inaccurate and lengthy. • More than one section is missing. • English is very poor, e.g. incomplete sentences are used.	
Introduction	• A broad context is provided, reflecting personal research on the topic.	• Some context is provided beyond what was provided in the lab manual	• The context provided is just reflecting the content of the context in the lab manual.	• No context is provided.	• The context has been copied directly from the lab manual.

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Laboratory experiments

Four new labs:

1. The Vitruvian man

2. Moment of inertia of dinosaurs

3. The electrocardiogram

4. Magnetotactic bacteria

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Expt. 1: Vitruvian Man

- the length of a man's arm span is equal to his height
- the distance from the hairline to the bottom of the chin is one-tenth of a man's height
- the distance from the top of the head to the bottom of the chin is one-eighth of a man's height
- the distance from the bottom of the neck to the hairline is one-sixth of a man's height
- the distance from the middle of the chest to the top of the head is a quarter of a man's height
- the distance from the elbow to the tip of the hand is a quarter of a man's height
- the distance from the elbow to the armpit is one-eighth of a man's height
- the length of the hand is one-tenth of a man's height
- the distance from the bottom of the chin to the nose is one-third of the length of the head
- the distance from the hairline to the eyebrows is one-third of the length of the face
- the length of the ear is one-third of the length of the face
- the length of a man's foot is one-sixth of his height

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Experiment 1: Vitruvian Man

- Breaks the ice

- Simple setting – not “blinded” by equipment

- First time many have used a computer to analyze data (we use Microsoft Excel)

	paper ledger		
	car loan		$12,000
	interest		9.6%
	# of payments		60
	monthly payment		$252.61

	A	B	C
1		computer ledger	
2			
3		car loan	$12,000.00
4		interest	9.60%
5		# of payments	60
6			
7		Monthly Pmt.	$252.61

$$\delta q = \sqrt{\left(\left|\frac{\delta f}{\delta x}\right|\delta x_i\right)^2 + \ldots + \left(\left|\frac{\delta f}{\delta z}\right|\delta z_i\right)^2}$$

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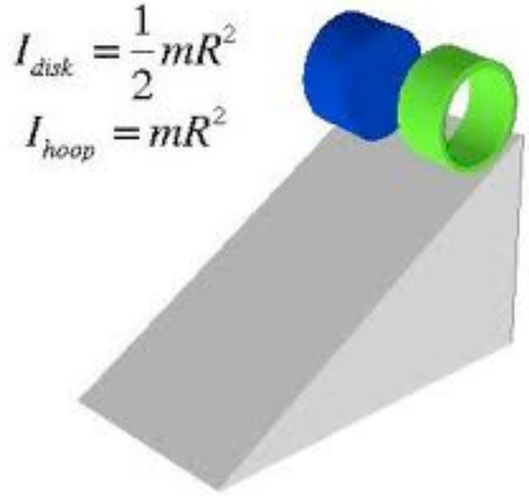
Expt. 2: Rotating Dinosaurs

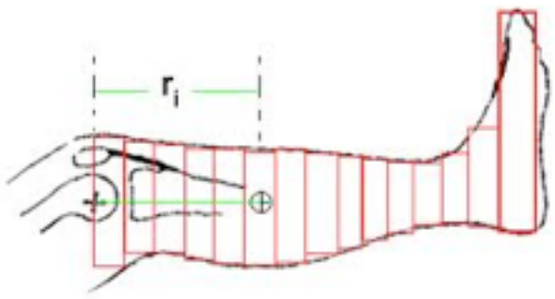
- **Moment of inertia** $I = \sum_i m_i r_i^2$



e.g. rotational kinetic energy $E = \frac{1}{2} I\omega^2$

Biological relevance:

- Biomechanics



- Extinction of dinosaurs

Carrier, D. R., Walter, R. M. and Lee, D. V., Influence of rotational inertia on turning performance of theropod dinosaurs: clues from humans with increased rotational inertia, *J. Exp. Biol.* 204, 3917-3926, 2001

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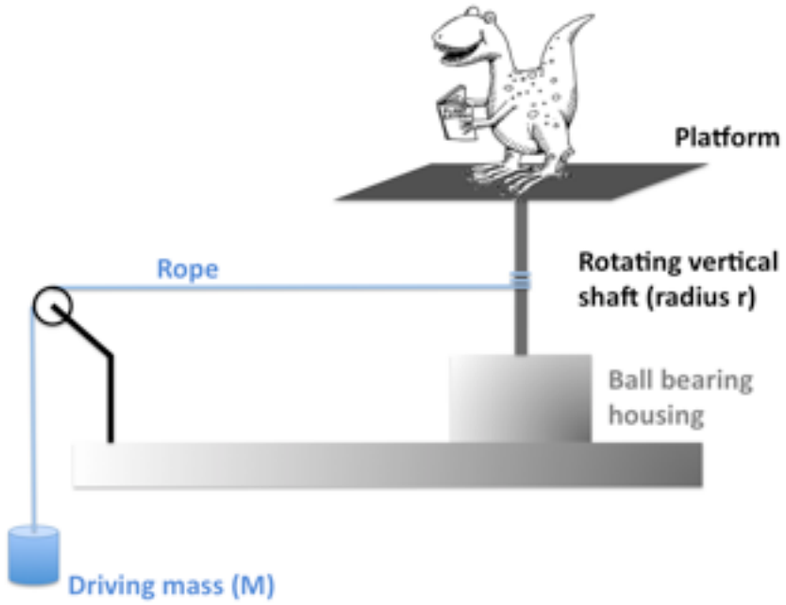
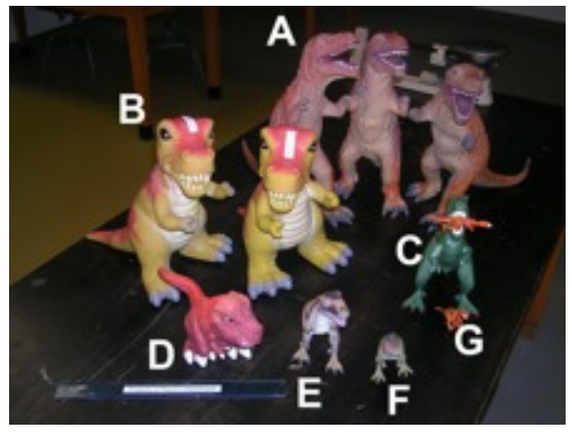
Expt 2: rotating dinosaurs

Measuring moment of inertia:

- Constant driving force F=*Mg* applies constant torque to platform+shaft+dinosaur, giving a constant acceleration
- Measure **time** driving mass takes to fall a certain **distance**
- Calculate final velocity *v* using constant acceleration formulae
- Calculate final angular velocity ω=*v/r*
- Calculate moment of inertia from $Mv^2/2 + I\omega^2/2 = Mgh$





Examples of hypotheses:

- If you change your shape (e.g. fold tail) you change your moment of inertia
- Mass distribution of dinosaur is (approximately) that of a spherical shell
- Moment of inertia is independent of where dinosaur is placed on platform (disagrees with parallel axis theorem)
- Big T-Rexs are more massive than small diplodocuses, and so have a larger moment of inertia

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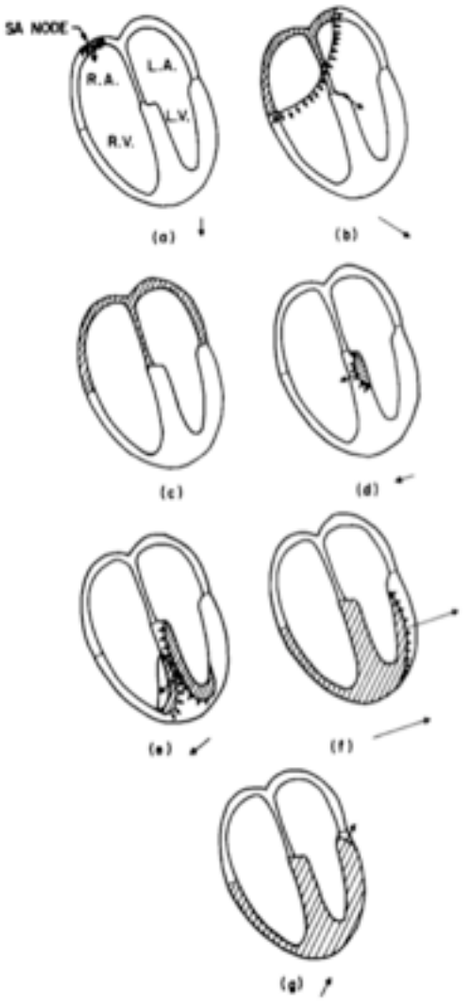
Expt 3: Electrocardiagram

- Electric potentials
- Electric dipole



Dipole moment of heart

Biological relevance

- Many cells maintain a potential difference from their surroundings to control diffusion of ions (Ca^+, Mg^+ etc.) in and out of cell
- Signal propagation along nerve cells is driven by a wave of depolarization
- Muscle cell contraction, including that of the heart, is driven by a wave of depolarization

EKG signal represents the difference in electric potential between left and right arm

Wave of cell depolarization

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Expt 3: electrocardiagram (EKG)

Pasco EKG device

- Place ground (black lead) on wrist
- Remaining two electrodes (green and red) can be affixed so as to measure potential difference between any two parts of body

Examples of Hypotheses:

- Amplitude of signal is uniformly smaller if electrodes are placed vertically (e.g. head to foot) rather than horizontally (e.g. arm to arm)
- Different orientations emphasize different parts of the signal
- Signal is compressed in time if I exercise immediately before measurement
- Amplitude of signal gets bigger if I exercise immediately before measurement
- Amplitude decreases if I measure further along arms (arms out stretched)

Expt. 4: Magnetotactic bacteria

- Magnetic dipole moment
- Magnetic fields generated by a coil of wire (Biot-Savart /Ampere's law)
- Capture trajectories using a camera
- Radius of u-turn upon reversal of magnetic field direction is

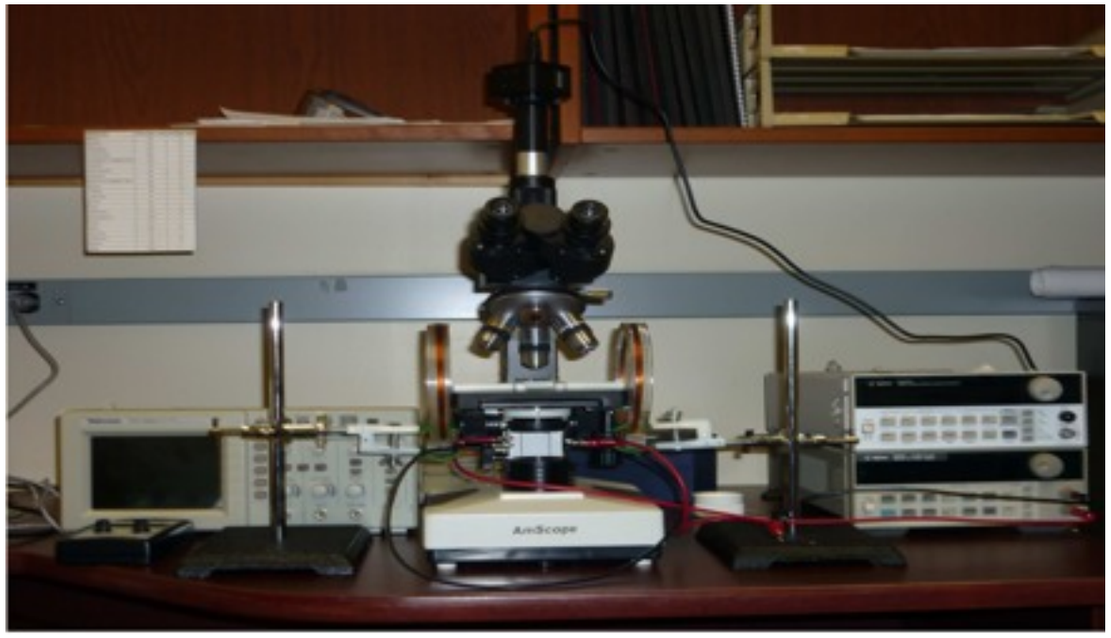
$$r = \left(\frac{8\eta\pi^2 R_b^2}{\mu_b B} \right) v_b$$

Biological relevance

- Living organisms use magnetic fields for navigation (cf. also birds)

Expt. 4: Magnetotactic bacteria

- Film motion of bacteria with/without applied magnetic field (microscopic+camera)
- Reverse magnetic field and measure radius of curvature of u-turn to obtain magnetic dipole moment of bacteria
- Can also change viscosity of medium

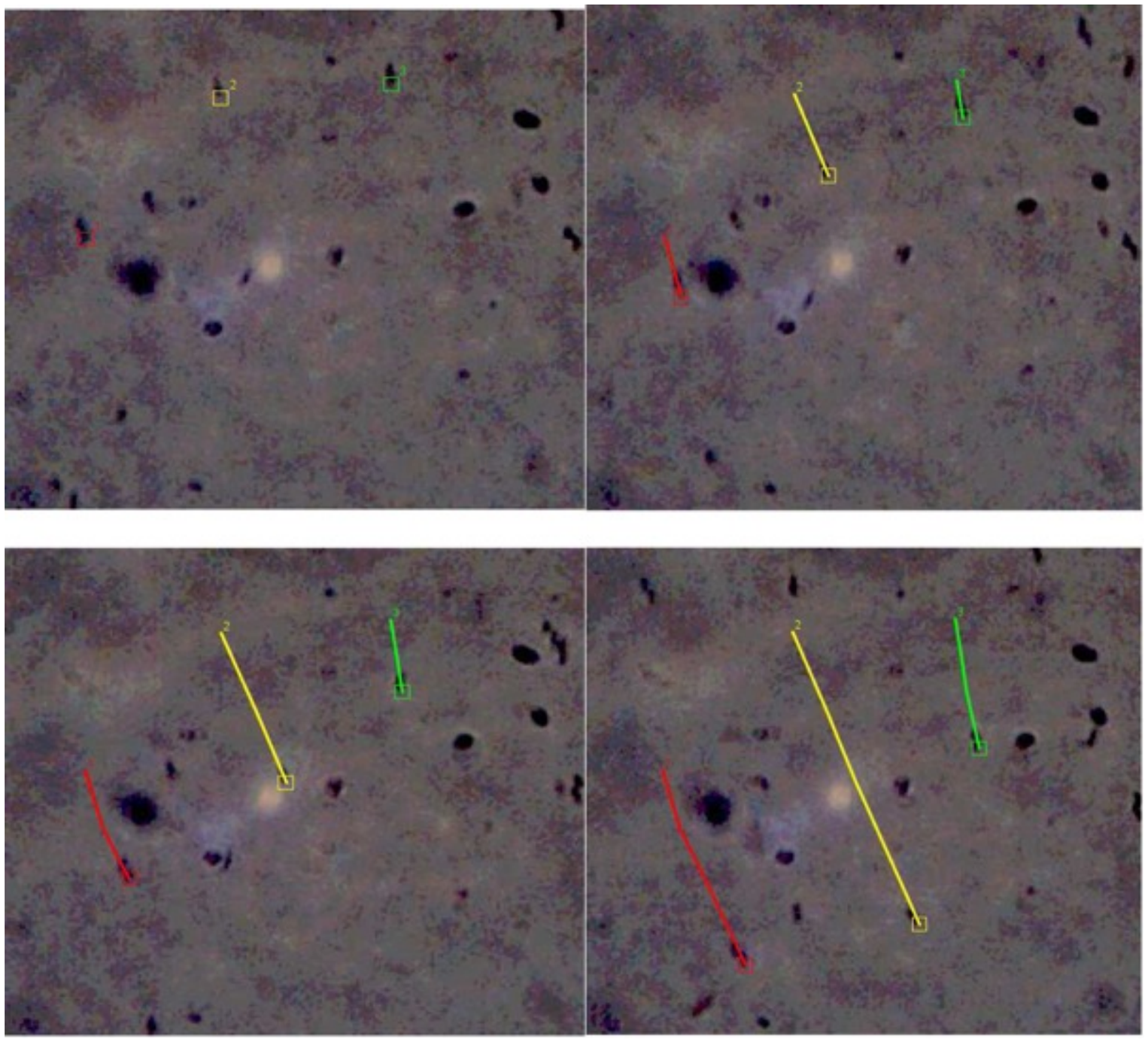


Examples of hypotheses:

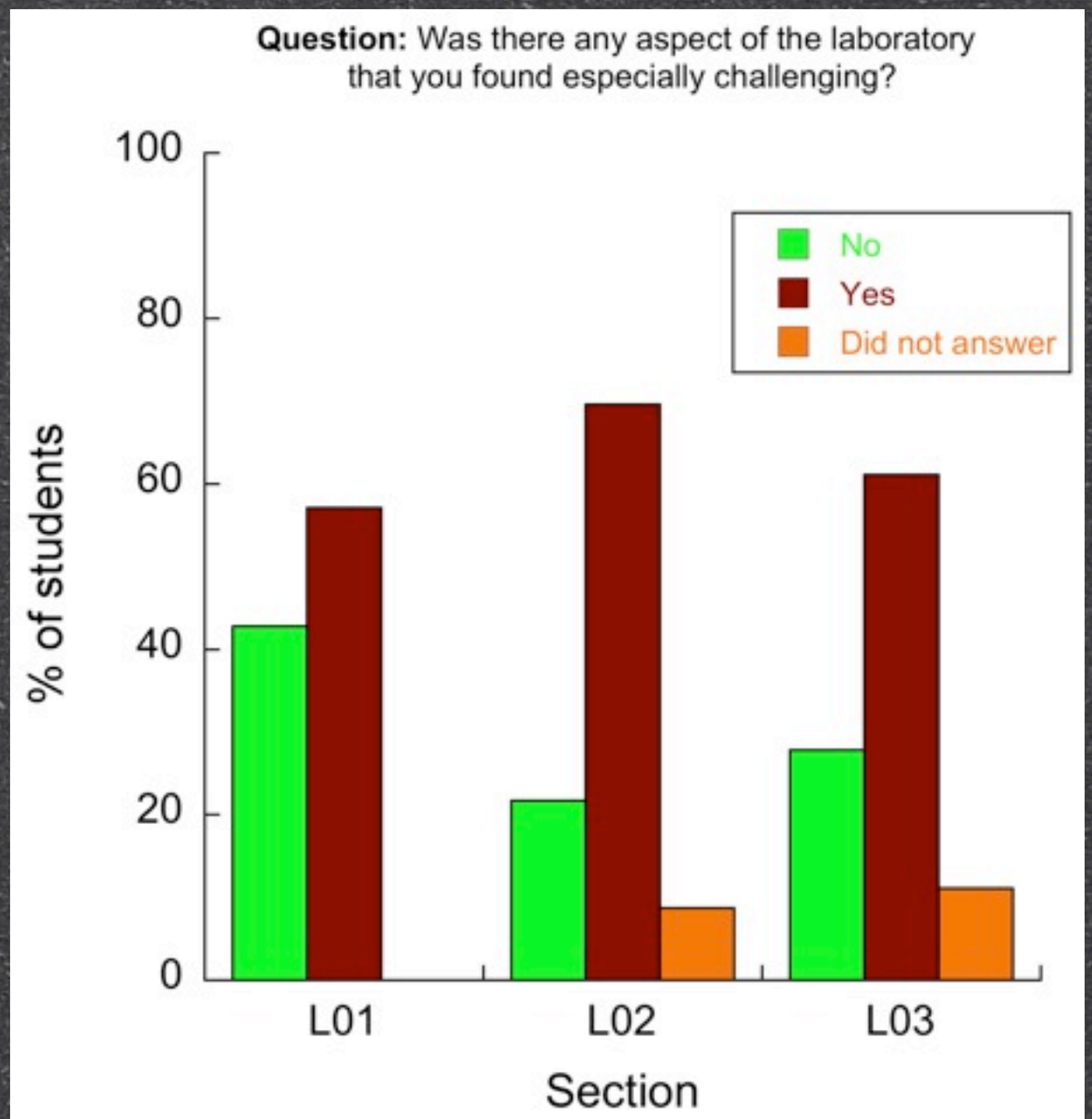
- Bacteria swim in random direction without applied magnetic field
- Bacteria go in opposite direction to magnetic field
- Dipole moment is proportional to length of bacterium

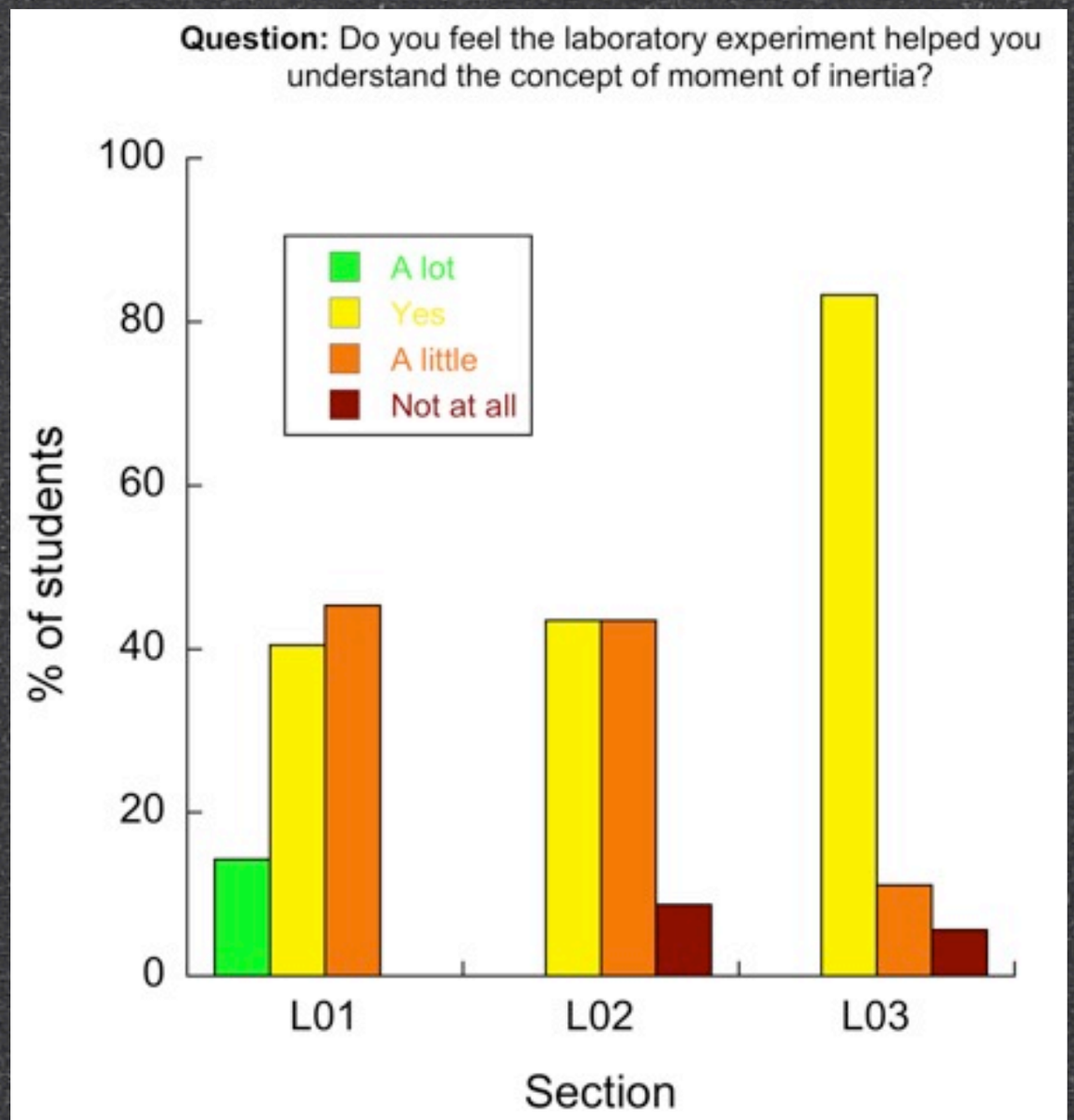
Expt. 4: Magnetotactic bacteria

Expt. 4: Magnetotactic bacteria



What the students think - Dino lab





What the students think

- Did you learn any useful skills during the labs? No: 9% Yes: 74% Yes!: 13%
  - Scientific skills (testing hypothesis, being creative, identifying sources of errors...) 45%
  - Calculating uncertainties 23%
  - Writing a lab report 23%
  - Technical skills 6%
- Things the students struggled with (found challenging, thought should be changed...)
  - Formulating an hypothesis and designing an experiment
  - Not having specific guidelines
  - Writing a lab report (too long, not enough guidelines, not worth enough marks, marked by different TAs...)

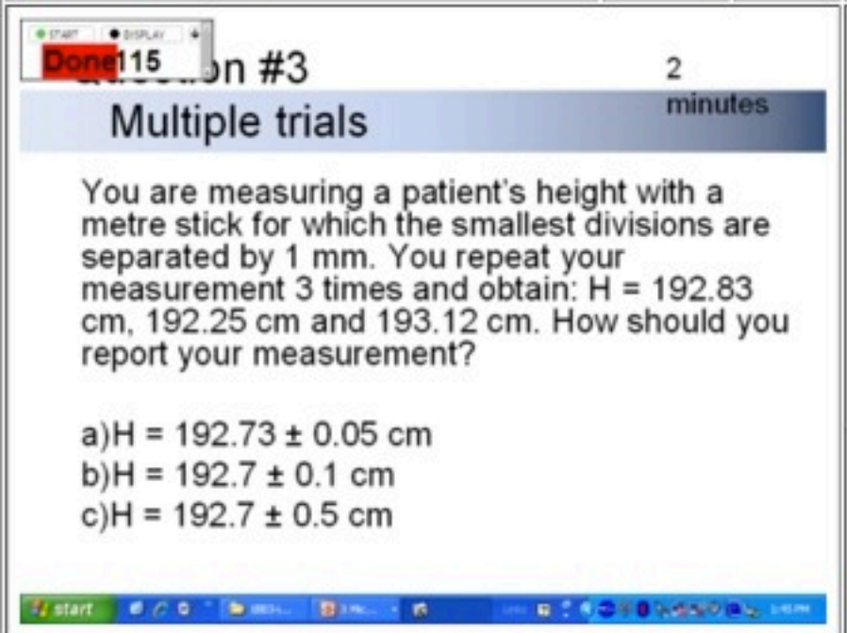
What the TAs think

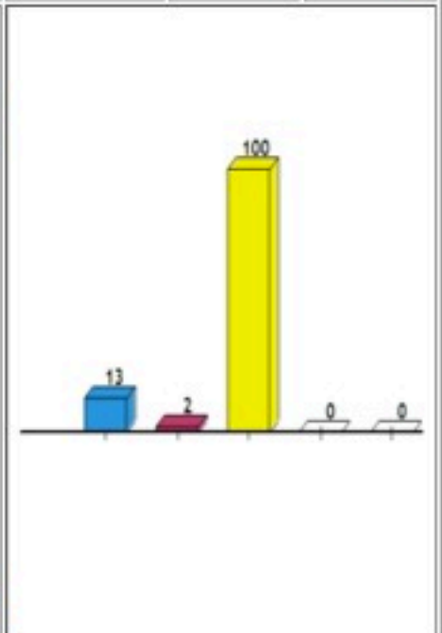
- Labs are more fun and more satisfying to teach (teaching how to think instead of giving instructions).
- Students are more enthusiastic (because they got to come up with their own ideas and test them).
- Being in the computer lab is helpful, with students learning directly from the TAs (and often grateful).
- Marking lab reports is harder and takes more time (but overall, TA load is comparable to previous 1BB3 sessions).

Do the students really learn more?

QUESTION 3

Time Started: 1:42:54 PM Number of Responses: 115 Number Missing: 0	Correct Answer: Maximum Score: 1 Class Average: 0.87				
Choice	**A**	**B**	**C**	**D**	**E**
Number	13	2	100	0	0
Percentage	11 %	2 %	87 %	0 %	0 %
Performance Points	0	0	1	0	0





iClicker questions in class shortly after the lab

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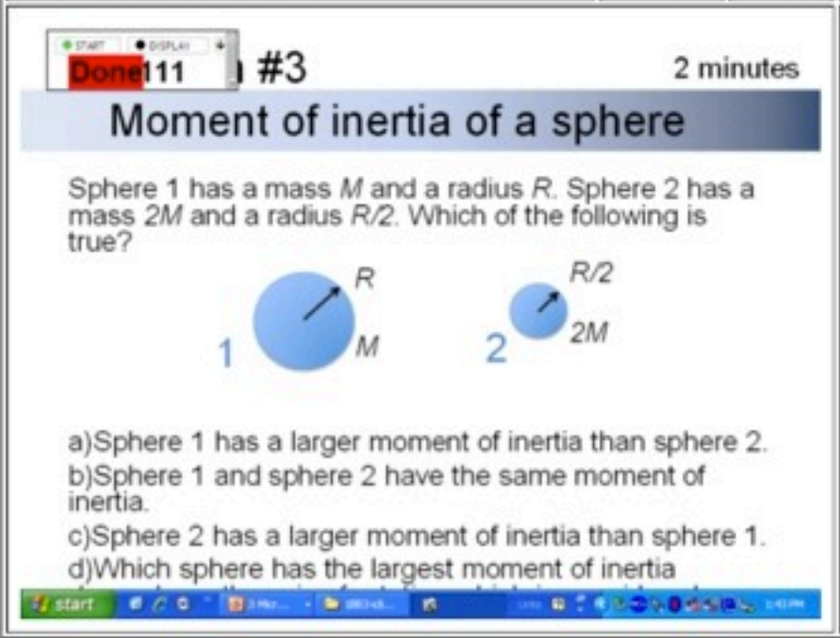
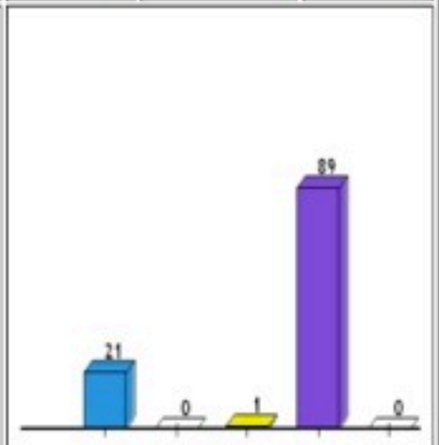
Do the students really learn more?

QUESTION 4

Time Started: 1:41:44 PM Number of Responses: 111 Number Missing: 0	Correct Answer: Maximum Score: 1 Class Average: 0.80				
Choice	**A**	**B**	**C**	**D**	**E**
Number	21	0	1	89	0
Percentage	19 %	0 %	1 %	80 %	0 %
Performance Points	0	0	0	1	0





iClicker questions in class shortly after the lab

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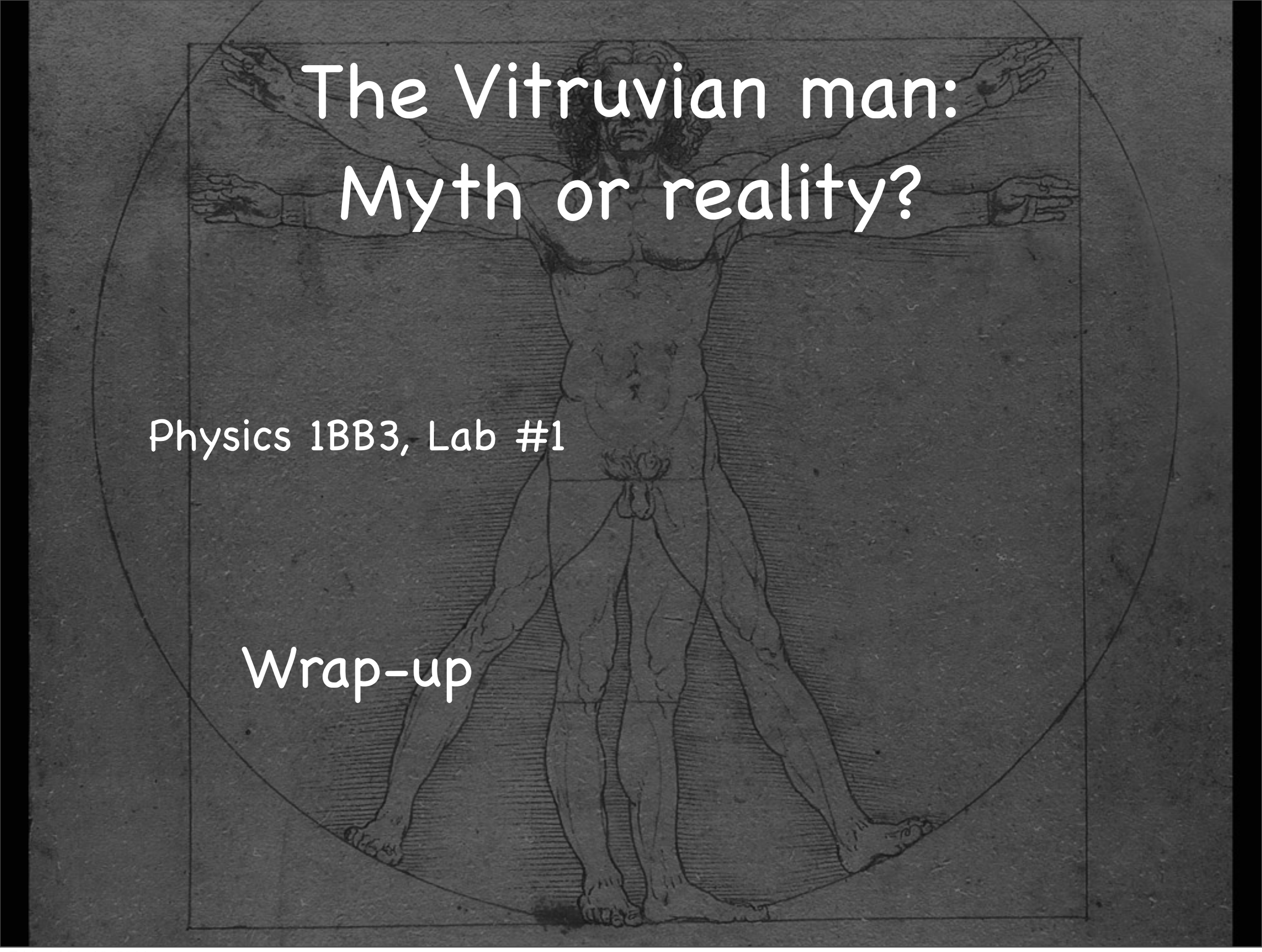
Conclusions

- Overall, students are definitely more engaged.
- Testing whether desired skills are acquired remains to be done
- Sustainability
- Need to permanently train and motivate instructors & TAs (resistance, inertia...)

"I expect you all to be independent, innovative, critical thinkers who will do exactly as I say!"



The Vitruvian man: Myth or reality?

Physics 1BB3, Lab #1

Wrap-up

Vitruvian vs. Reality

Length 1	Length 2	Number of teams	Number of subjects	Average ratio	Error	Ratio (Vitrus Pollo)	True or false??
Height	Armspan	13	69	1.01		1	

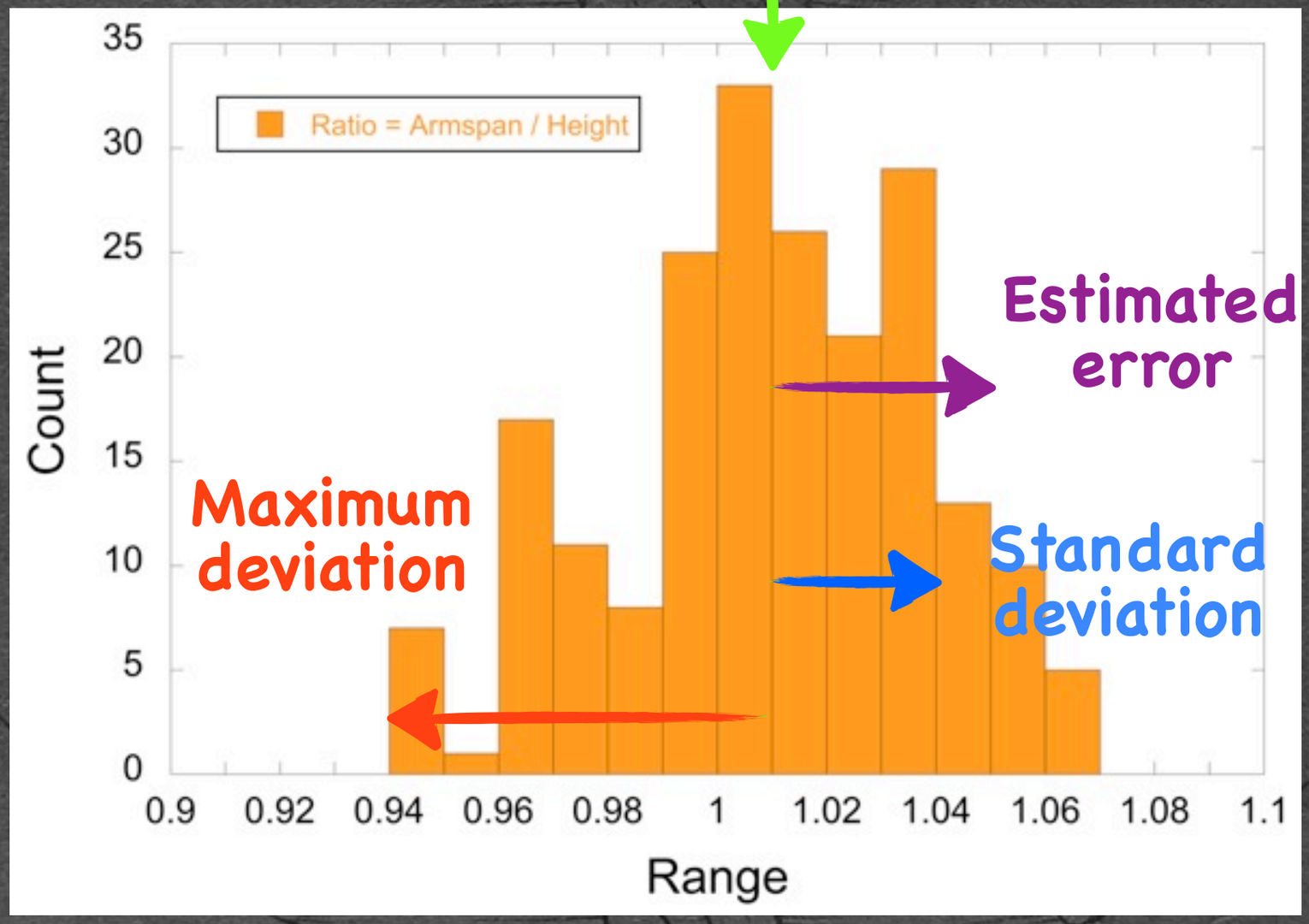
Vitruvian vs. Reality

Length 1	Length 2	Number of teams	Number of subjects	Average ratio	Absolute Error	Ratio (Vitrus Pollo)	True or false??
Height	Armspan	13	69	1.01	0.04	1	✔

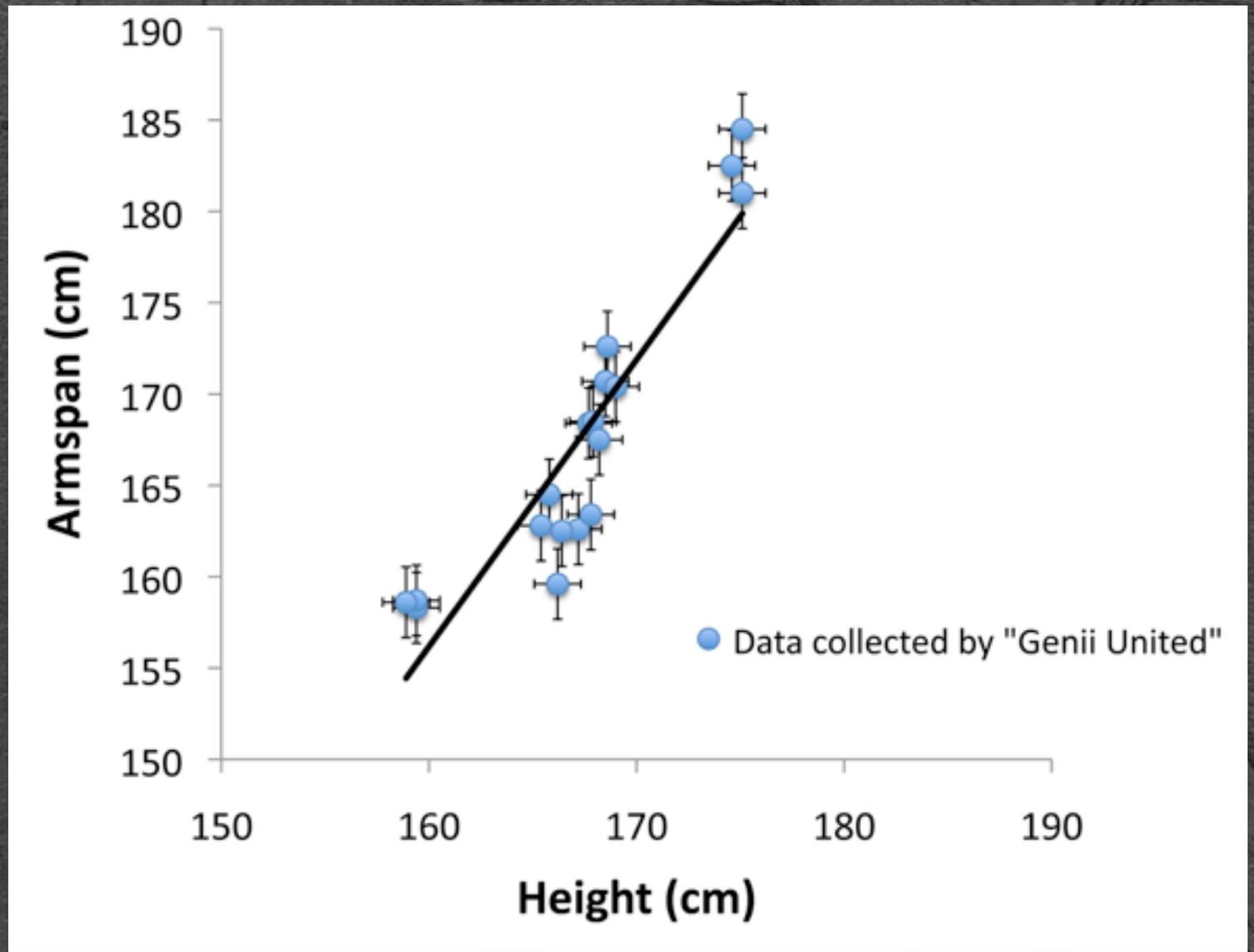
Length 1	Length 2	Number of teams	Number of subjects	Average ratio	Absolute Error	Ratio (Vitrus Pollo)	True or false??
Height	Armspan	13	69	1.01	0.04	1	✔
Height	Hand	5	29	0.107	0.005	0.1	✖
Height	Forearm	5	26	0.266	0.005	0.25	✖
Height	Shoulder width	1	6	0.256	0.002	0.25	✖
Height	Face	1	5	0.113	0.002	0.1	✖
Height	Foot	1	4	0.145	0.002	0.166	✖
Shoulder width	Elbow - armpit	2	11	0.56	0.04	0.5	✖
Forearm	Face	1	4	0.45	0.03	0.4	✖
Hand	Face	1	6	1.01	0.03	1	✔
Armspan	Hand	1	5	0.105	0.003	0.1	✖

31 groups, 165 students

Distribution of values for the ratio between armspan and height

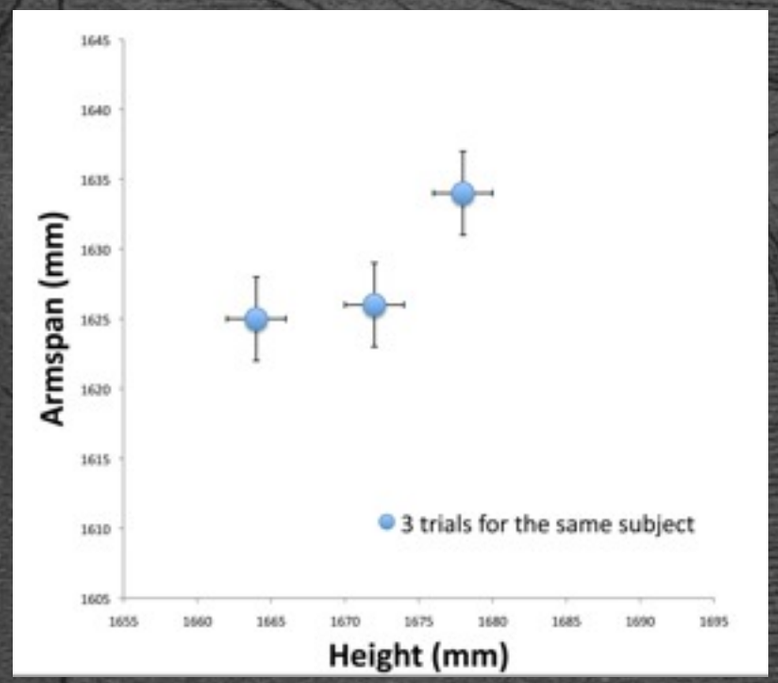


What makes a good graph?

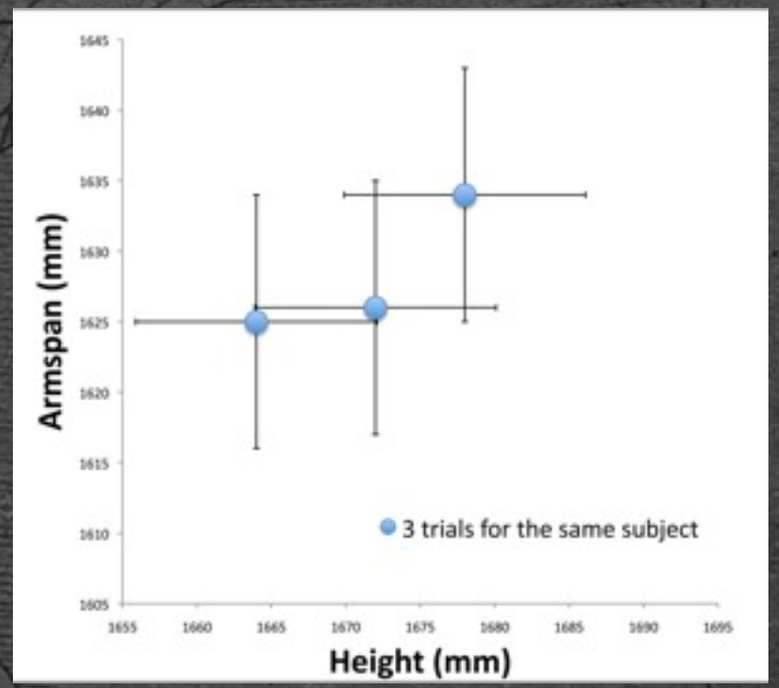


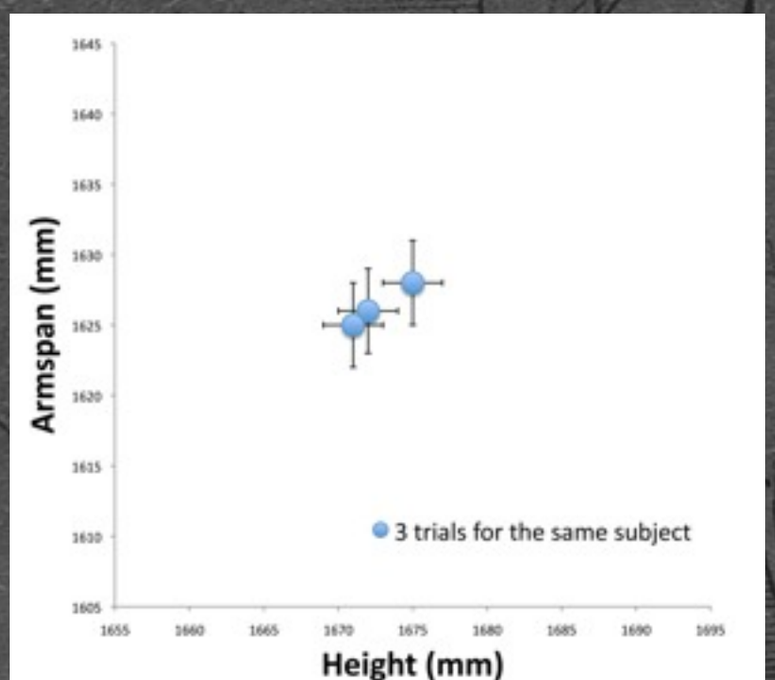
- Error bars
- Axis labels (with units!)
- Legend
- Good scale
- Large font

Problem!

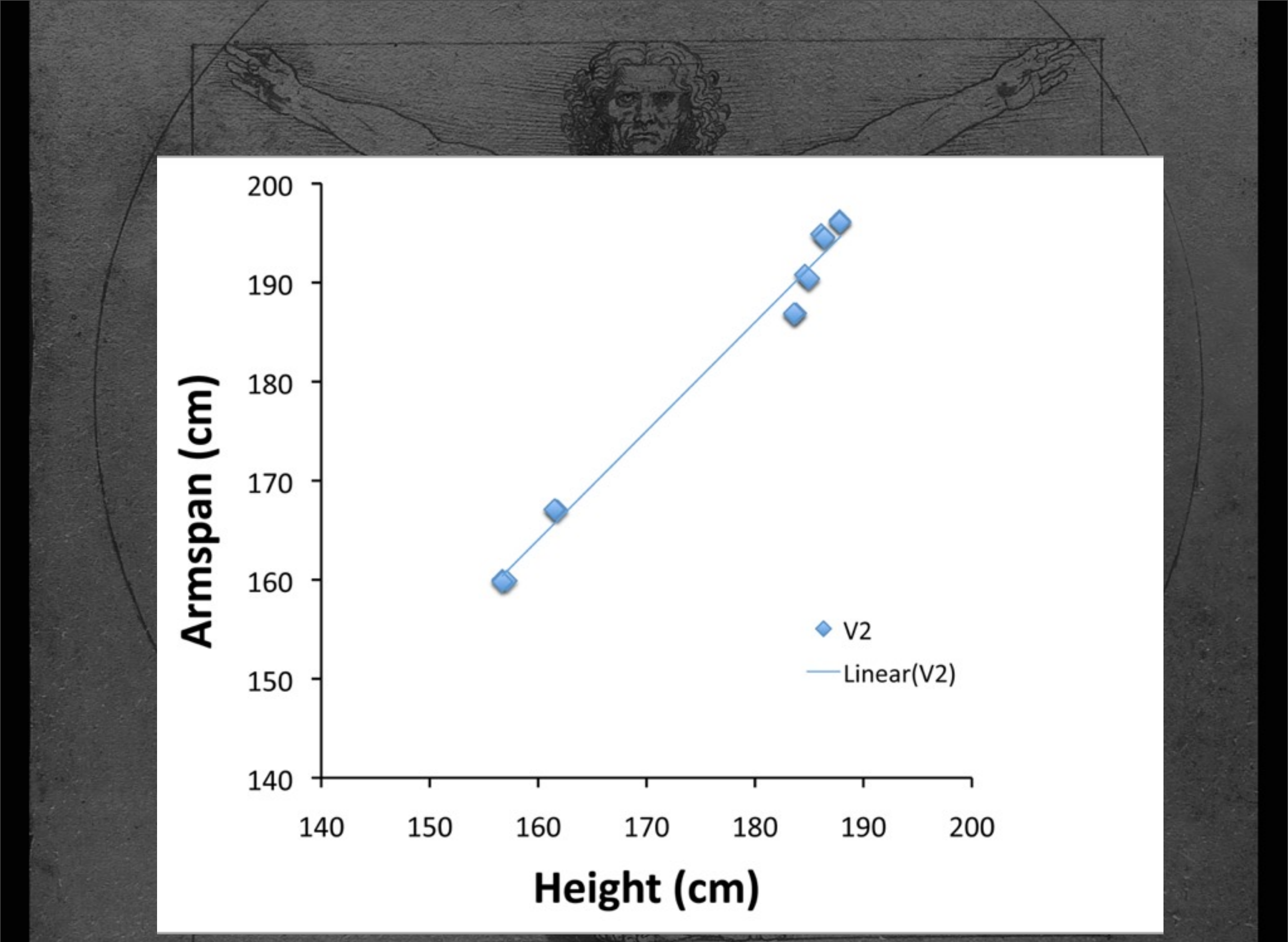


Better





Best!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Armspan (cm)
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Height (cm)
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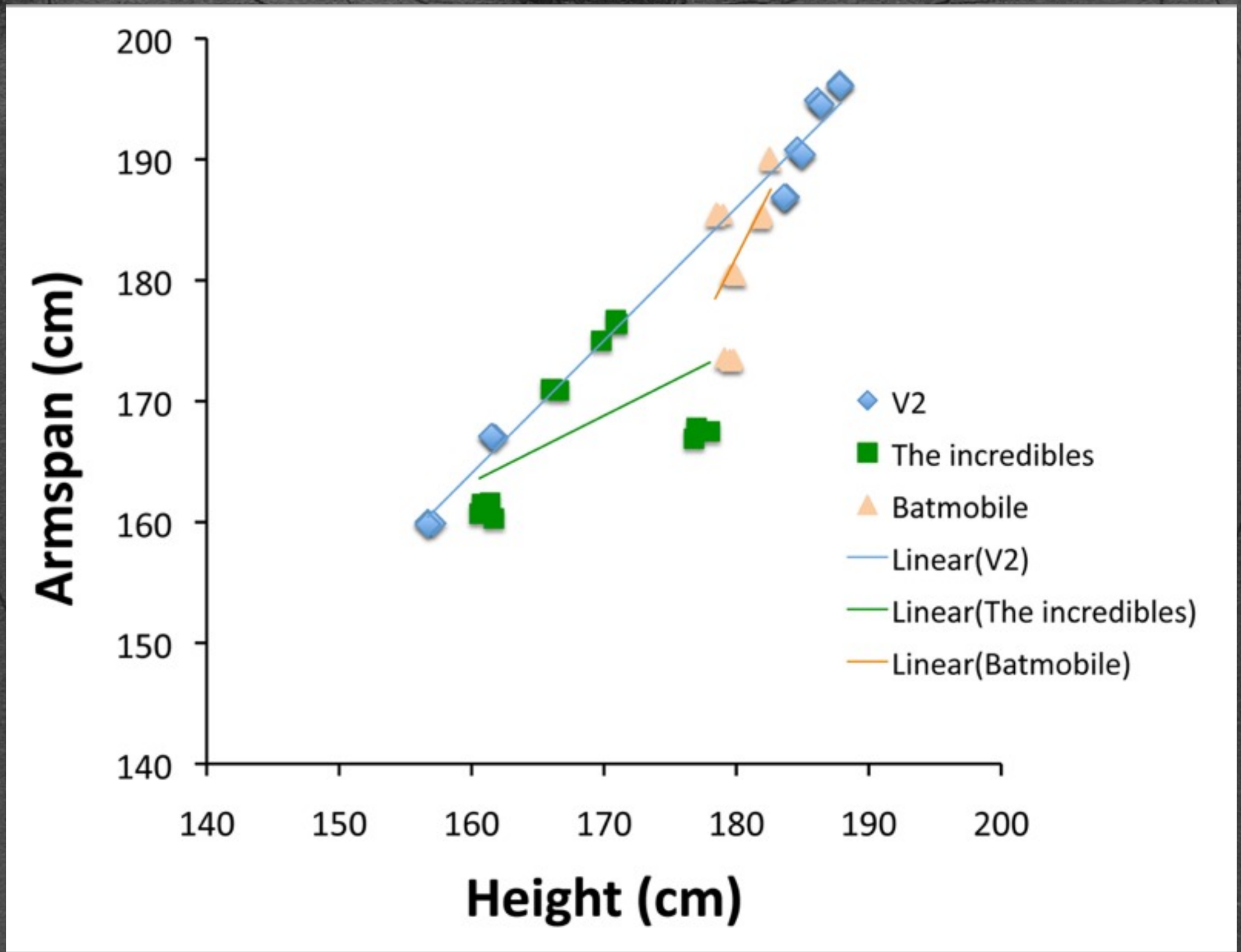
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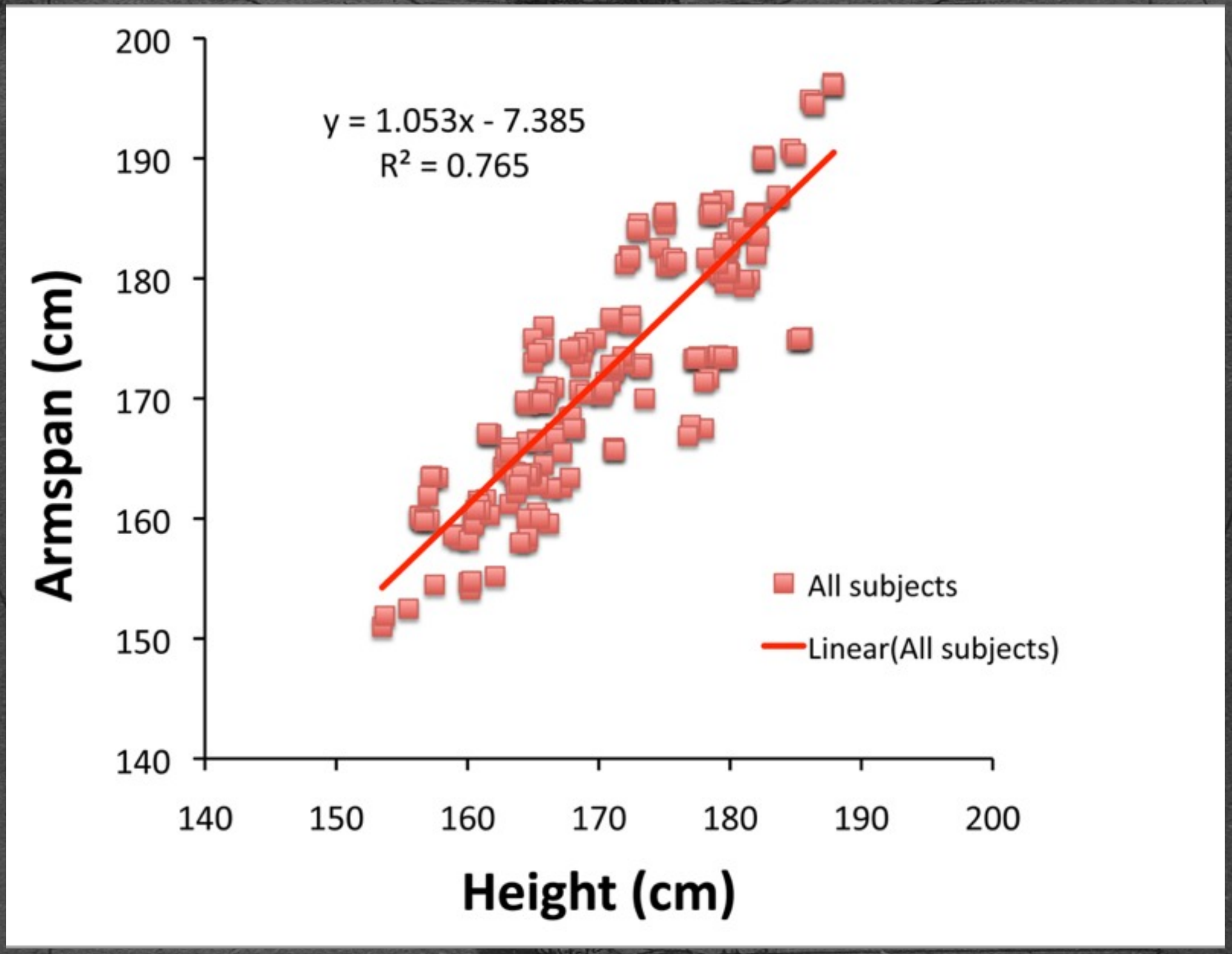
y = 1.053x - 7.385
R² = 0.765
All subjects
Linear(All subjects)
Armspan (cm)
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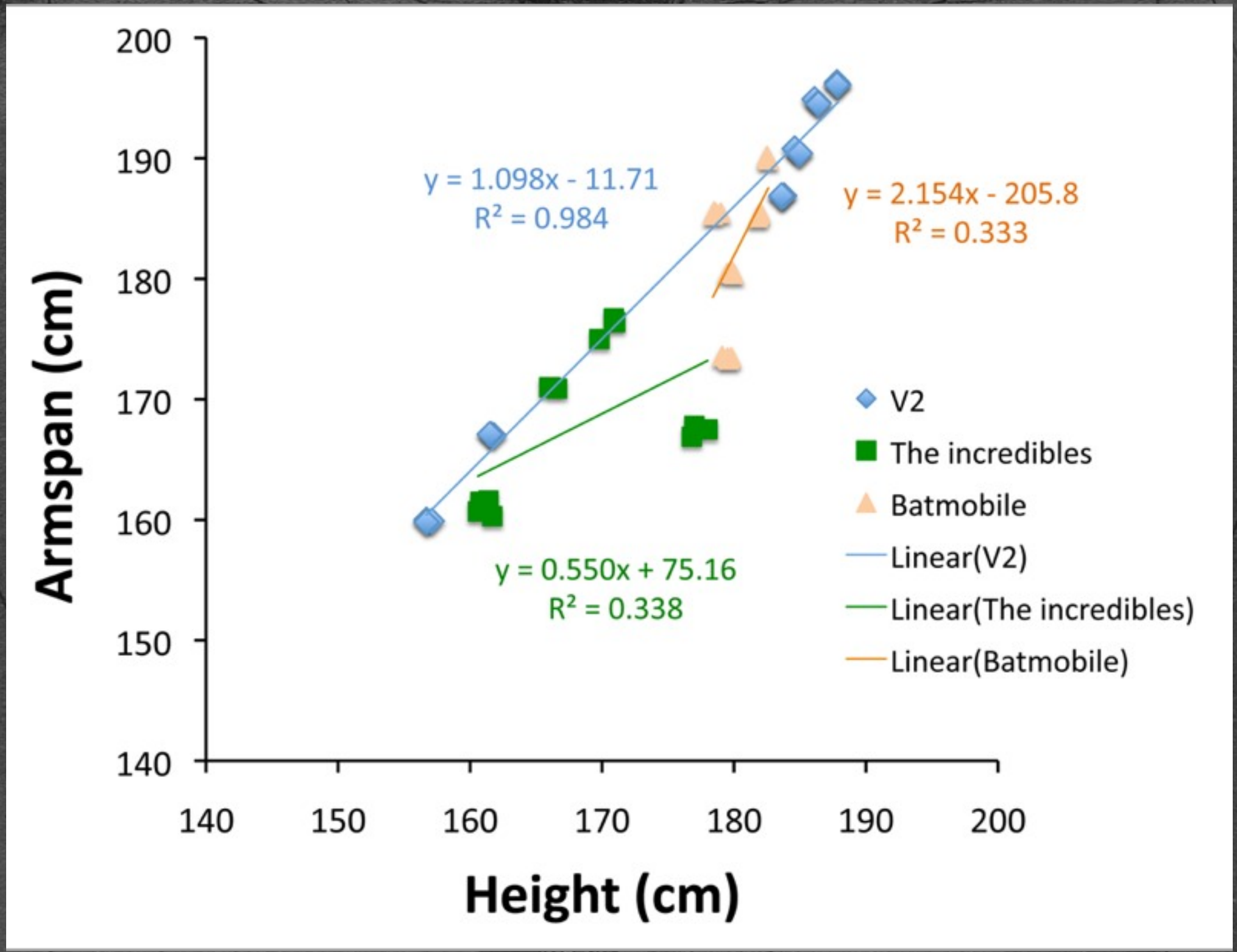
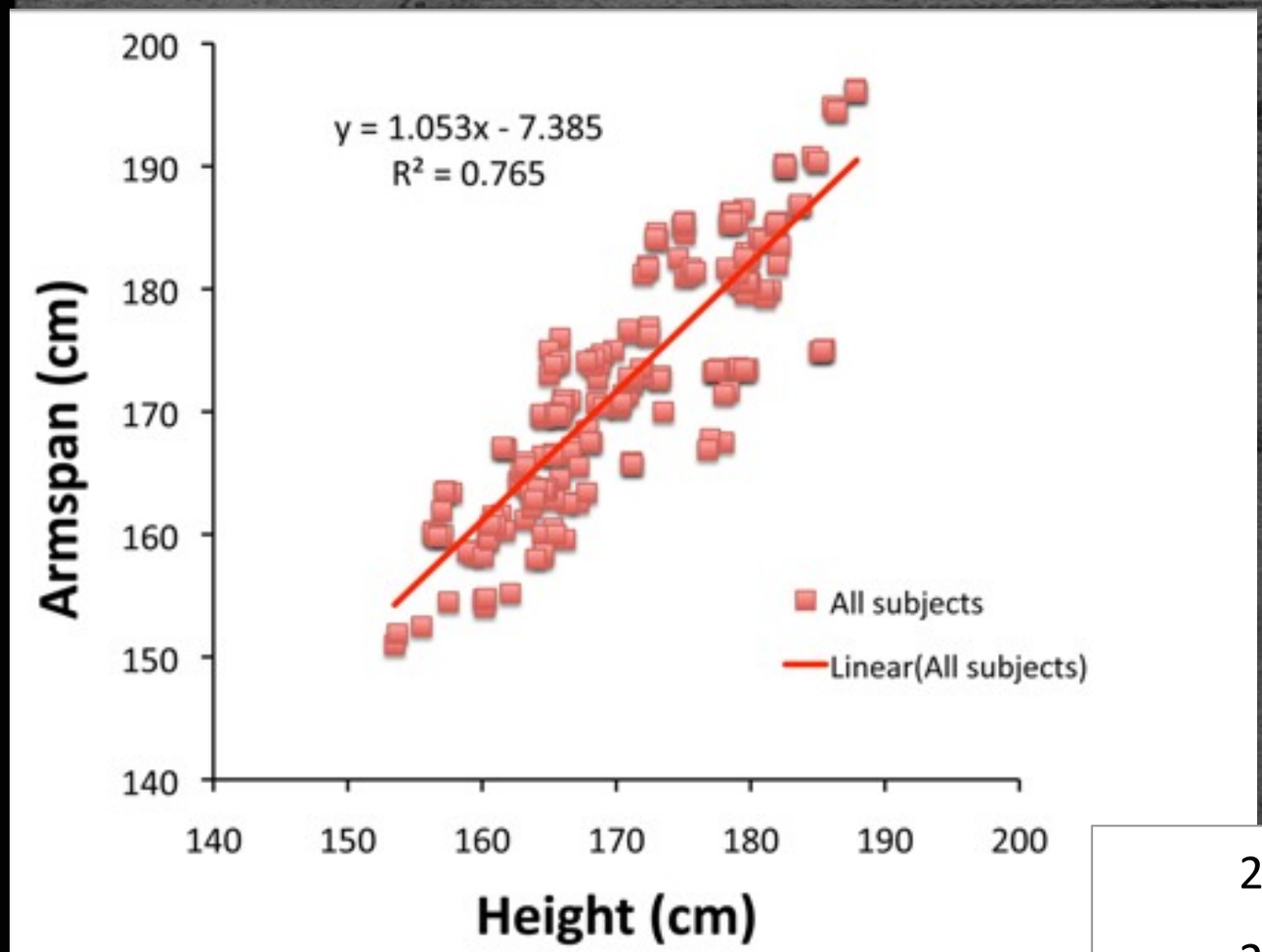
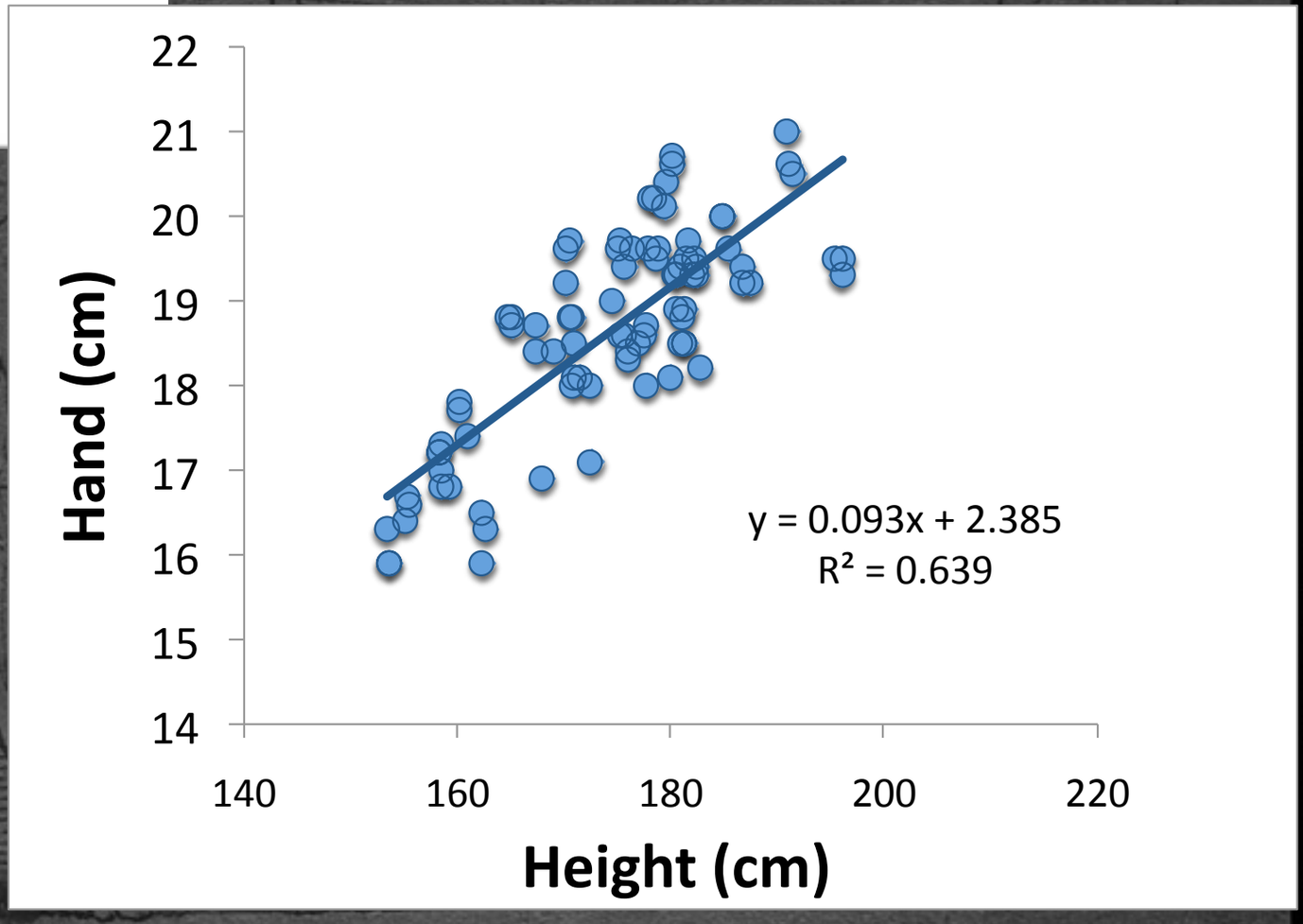
190
200

What makes a good measurement?



How do we interpret our data?





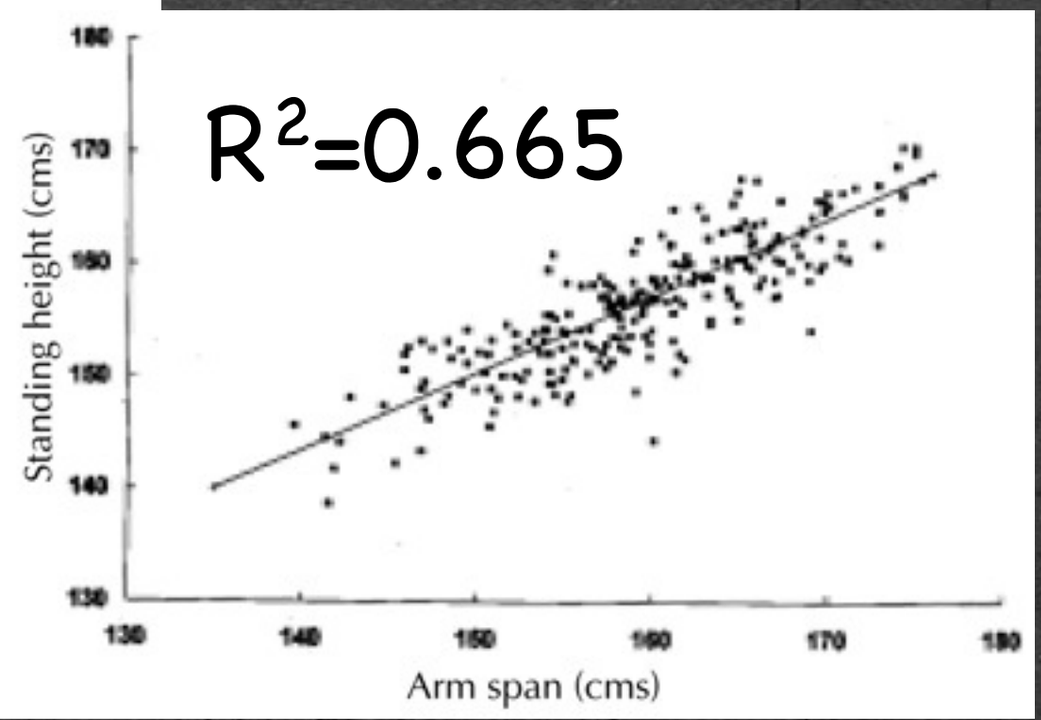
What is there to discuss about our results?

- Compare your results to other studies.

Journal of Orthopaedic Surgery 2001, 9(1): 19–23

The use of arm span as a predictor of height: A study of South Indian women

SP Mohanty, S Suresh Babu and N Sreekumaran Nair
Kasturba Medical College and Hospital, Manipal, Karnataka, India



- ✓ Arm span and leg length correlate reasonably well with standing height

What is there to discuss about our results?

South African Archaeological Bulletin **53**: 98-108, 1998

THE ROLE OF HAND PRINTS IN THE ROCK ART OF THE SOUTH-WESTERN CAPE

ANTHONY MANHIRE

Independent variable	r	Reduced major axis
Hand length (L)	0,94	H = 8,86L + 52,73 (± 4,08)
Hand length (L)	0,85	A = 0,19L - 16,12 (± 0,14)

Your result: Hand length (L) 0.81 H = 6.86L + 46.47

- ✓ Your results differ from those used in this article. Why?

How do I conclude?
What makes a good hypothesis?

- Answer your hypothesis. Be logical.

  - *<u>On average in our group of students</u>, the armspan of a subject was equal to his/her height:* $r = 1.01 \pm 0.04$ $\Rightarrow$ ***Yes!***

  - *<u>On average in our group of students</u>, the length of a subject's hand was one tenth of his/her height:* $r = 0.107 \pm 0.003$
    $\Rightarrow$ ***No!***

  - *The armspan of a man is equal to his height:* $\Rightarrow$ ***No, not always in this group, and might be different for other groups***

  - *There is a correlation between the armspan and height of a human being:* $\Rightarrow$ ***Yes, although it is not a perfect correlation.***