

A successful strategy for
Teaching students to think more
critically and scientifically

Dr. Douglas Duncan

Including research done with Dr. Leilani Arthurs

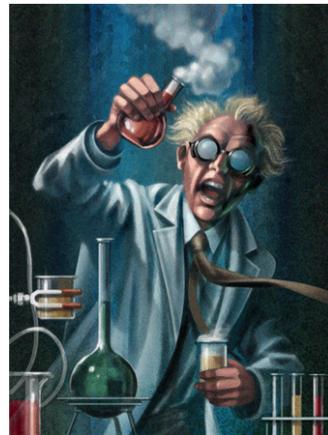
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This isn't just for science classes!

History teachers want students to distinguish between facts and opinions.

...to be able to read more than one argument and decide which to believe.

Good teaching is about more than memorizing facts!



Science teachers agree!

When we say “think scientifically” this includes:

Do students understand what science is?

Do they think they **need** to think scientifically?

Do they distinguish between facts and opinions?

Do they have the ability to think scientifically
themselves?

Can they distinguish believable scientific results
from bogus ones?

Do they know when they understand something
and when they don't? (*Metacognition*)

Some disappointing results:

Labs that are supposed to be small examples of “doing science” rarely ask students to think about and discuss the meaning of what they are doing.

They apparently assume that just by doing science activities students will implicitly “pick up” more scientific attitudes and thinking.

There is little evidence this happens, and much against it (Lederman 1998; Sandoval 2003). **SO...**

We decided to give students explicit practice in talking about science and in distinguishing good science from bad (or pseudoscience)

First, we discuss, “What is Science?”

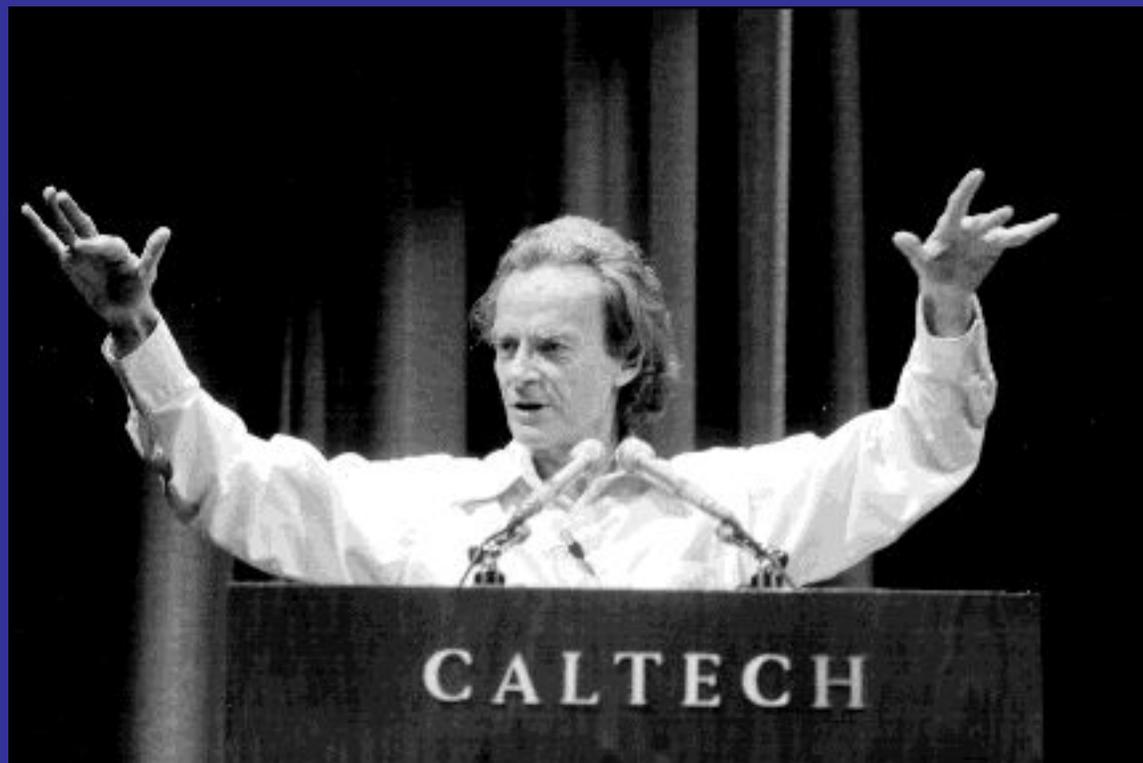
• What is Science?

- Science is a **process** of trying to understand the world by making models (or theories) which have *predictive* power. It usually involves:
 - Observing
 - Looking for patterns (which can be clues to underlying laws)
 - This may involve
 - - Sorting
 - - Classifying
 - - Measuring
 - Suggesting an explanation (hypothesis) which explains all the observations made so far **AND** predicts new ones
 - Making an experiment or collecting more data which tests the prediction
 - (If the experiment fails) Suggesting another hypothesis, and trying another experiment....
 - Telling others what you have discovered.

• ***Science is a way of trying not to fool yourself***"

“Science is a way of trying not to fool yourself”

-Richard Feynman



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First metacognition lesson:

Just knowing facts does not mean you understand.

The Monotillation of Traxoline

It is very important that you learn about traxoline.

Traxoline is a new form of zionter. It is monotilled in Ceristanna. The Ceristannians gristerlate large amounts of fevon and then bracter it to quasel traxoline. Traxoline may well be one of our most lukized snedmas in the future because of our zionter lescelidg.

DIRECTION: Answer the following sentences. Be sure to use your best

1. What is traxoline?
2. Where is traxoline monotilled?
3. How is traxoline quaselled?
4. Why is it important to know about traxoline?

**Don't fool
yourself about
when you really
understand**

Convince students that they need
DATA to make good decisions.

Which vehicle is safer to drive?

Toyota Camry



Jeep Cherokee



Ford F-series pickup



Deaths Per Year / Per Million Vehicles

Make/Model	Type	Driver Deaths	Other Deaths	Total
Toyota Avalon	large	40	20	60
<i>Toyota Camry</i>	mid-size	41	29	70
Volkswagen Jetta	subcompact	47	23	70
Ford Windstar	minivan	37	35	72
Nissan Maxima	mid-size	53	26	79
Honda Accord	mid-size	54	27	82
Subaru Legacy/Outback	compact	74	24	98
Mazda 626	compact	70	29	99
Chevrolet Malibu	mid-size	71	34	105
Chevrolet Suburban	S.U.V.	46	59	105
<i>Jeep Grand Cherokee</i>	S.U.V.	61	44	106
Honda Civic	subcompact	84	25	109
Toyota Corolla	subcompact	81	29	110
Ford Expedition	S.U.V.	55	57	112
GMC Jimmy	S.U.V.	76	39	114
Ford Taurus	mid-size	78	39	117
Nissan Altima	compact	72	49	121
Toyota 4Runner	S.U.V.	94	43	137
Chevrolet Tahoe	S.U.V.	68	74	141
Lincoln Town Car	large	100	47	147
Ford Explorer	S.U.V.	88	60	148
Toyota Tacoma	pickup	111	59	171
Dodge Neon	subcompact	161	39	199
<i>Ford F-Series</i>	pickup	110	128	238

Convince students that anecdotal information, even if impressive, is not science!

(basketball video)

The words *theory*, *model*, and ~~believe~~ were discussed in detail since their use in science differs from everyday use of the same words.

The difference between prediction, which lies at the heart of science, and post-diction, which is the way people usually find explanations, was also emphasized.

Typical Assignments:

Go to the www or to YouTube, or both. Find two science sites or videos on scientific subjects, one you think is really good, and one you think is bogus. If you can find sites related to the science of astronomy, great, but other sciences are fine.

For the "bogus" site, I'll be most impressed if you find something that looks credible, but is actually not true.

Write the web addresses or identifying information from YouTube here:

Good site: _____

Bogus site: _____

Now comes the most important part of the exercise. Explain how you decide whether something you read or see on the web is true or false. How did you decide that your bogus site was not telling the truth? Do you apply the same criteria to something you see on TV or read in the paper? Please be thoughtful about your answer, and write it here. Turn this paper in to your learning assistant in recitation.

Each recitation will, as a group, make up a list of common characteristics of good, believable sources, and another one of sources that are trying to fool you. Your LA will email this to me and I will choose the best. - D²

How to recognize Good Science

compiled by Dr. Douglas Duncan and his students at
the University of Colorado

web or other sites:

Should be logical, based on facts and data, not just opinions.

Clear references are given so that you can look up data and check that statements are accurate.

Information has been published in *peer reviewed* (checked by other scientists before publication) journals.

Contrary information is given when it exists, not just information supporting an idea or theory.

What is not known is identified.

If a claim is extraordinary, it demands extraordinarily strong evidence. - Carl Sagan

Two special good sites for reliable information about important topics:

The *National Academies* (independent organization of several hundred of the country's best scientists). Publishes understandable articles about topics of high public interest. <http://www.nationalacademies.org/>

The *American Association for the Advancement of Science* (AAAS: The world's largest general scientific society, with many thousands of members). Also publishes the scientific consensus about topics important to the public. <http://www.aaas.org/>

3. FactCheck.org (Annenberg/ Univ. Penn.)

4. Snopes.com

How to tell if something is Pseudoscience.

Beware if it...

Is based on **Post**-diction, not **Pre**-diction (explanation is made up after the fact)

Explains things people care about that may not have other explanations (avoids the scientific response, “We don’t know,” which people often find unsatisfactory)

Uses scientific-sounding language and jargon (often incorrectly; e.g. “energy flows”)

Does **NOT** use the scientific method of clearly stating the hypothesis and *then* making a test

Has an explanation even when the idea fails (e.g. “astrology is only a tendency,” “the faith-healing treatment must have been started too late,” etc.)

If it contradicts known scientific principles or is not generally accepted, the originator of the theory claims to be “persecuted by the scientific (or other) establishment,” is not recognized because “the jealous establishment,” etc.

Convince students this can be FUN

*** is there time for video clips?

John Edwards (famous Psychic) vs.

James (“The Amazing”) Randi vs.

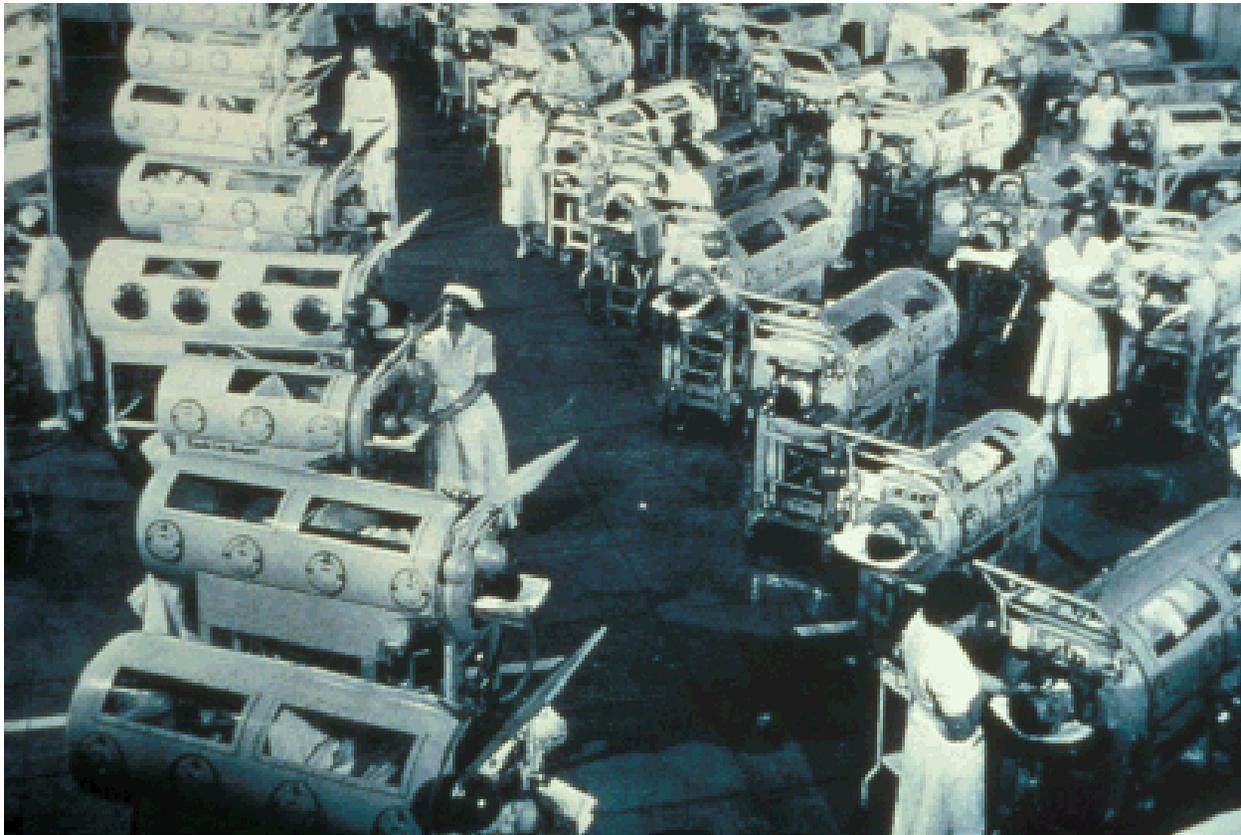
South Park

Eggs on the equinox



Convince students science *MATTERS*

Read a letter to the Daily Camera advocating from a person who thinks vaccines cause autism and should be abolished.



**Show a
Polio
ward**

Is a drug like this tested by the government before it is sold to you?



Yes, tested that it won't kill you.

Yes, tested for effectiveness.

Tested with a control group that takes a "placebo."

All of the above

No, it is not tested

Is a drug like this tested by the government before it is sold to you?



Yes, tested that it won't kill you.

Yes, tested for effectiveness.

Tested with a control group that takes a "placebo."

All of the above

No, it is not tested

Is a health supplement like this tested by the government before it is sold to you?



Yes, tested that it won't kill you.

Yes, tested for effectiveness.

Tested with a control group that takes a "placebo."

All of the above

No, it is not tested

Ephedra Is Back and Legal

and it's the best weight loss aid the world has ever known. 100% organic, all-natural herb that grows in China.

It's been used by humans for many centuries, and is currently being used safely by millions of people.

We have it in stock. Right now. We're the only company with this product in stock. You'll lose those pounds you've been fighting with, and you'll do it without being hungry, spending hours in the gym, or having any adverse side effects.

Our proprietary combination of ephedra, caffeine and aspirin is optimally designed to maximize your weight loss with zero side effects.

The pounds will literally fall off your body. At least 5-8 pounds per week.

We Swear By It.

Is a health supplement like this tested by the government before it is sold to you?



Yes, tested that it won't kill you.

Yes, tested for effectiveness.

Tested with a control group that takes a "placebo."

All of the above

No, it is not tested

**Tell how it killed a 23 year old
Baltimore Orioles pitcher...**

Ephedra Is Back and Legal

and it's the best weight loss aid the world has ever known. 100% organic, all-natural herb that grows in China.

It's been used by humans for many centuries, and is currently being used safely by millions of people.

We have it in stock. Right now. We're the only company with this product in stock. You'll lose those pounds you've been fighting with, and you'll do it without being hungry, spending hours in the gym, or having any adverse side effects.

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Concerning the article on Alien Abductions...

1. I agree with Mr. Coleman and the scientists: It is likely that people who believe they were abducted by aliens are mistaken.
2. I agree with Mr. Eck, who essentially says that every person is entitled to their own opinions and scientists have no business challenging them.
3. I'm not sure who I agree with
4. I didn't read the article

Concerning the article on Repressed Memory Syndrome:

Suppose you were on a jury, and a person testified in court that during therapy they remembered being molested as a child, and that they previously had repressed their memory. Suppose that their testimony included many vivid details, but there was no other corroborating evidence. Would you vote to convict the accused?

1. No. It is possible people who remember something vividly are mistaken.
2. Yes. Lawyers and scientists have no business challenging personal memories, especially if the person believes them strongly. Besides, better safe than sorry when dealing with a molester.
3. I'm not sure how I would vote
4. I didn't read the article
- 5.

1. Did the class discussions of science as a way of “trying not to fool yourself,” how science must be based on evidence, or of “Alien Abductions,” affect how you just voted?
2. Yes
3. No

At the time germs were discovered by Pasteur and evolution by Darwin (in the mid-1800s), life expectancy was 40 years.

Modern medicine is based on these two ideas, and life expectancy has nearly doubled.

If everyone rejected science your parents would probably be dead. (So would your teacher.)
Have you ever thought of science in this way?

Is this somewhat “In your face?”

YES

So what are the results?!

[note - ALL these activities are on line, linked
on Doug Duncan’s home page]

Assessment strategy

Interviewed 58 students – **TEST CLASS** (22), **CONTROL CLASS** (27), no astronomy at all class (9)

Each student asked 9 questions concerning the nature of science and how it is applied.

All interviews recorded, transcribed, and placed in categories. Both authors did this separately, as did a student assistant

241 students given the Epistemological Beliefs Assessment for Physical Science (EBAPS)

EBAPS covers a number of different topics, including:

How should one study science?

What does it mean to know a scientific topic?

Which is more important when learning science, natural ability or hard work?

Should science make sense?

Does it relate to life outside of class?

What is the role of equations and formulas?

Does science consist of many small concepts or a few large ones?

Uses a 5-division Likert scale from “strongly agree” to “strongly disagree.”

Students in the **TEST** class were much more likely to say that anybody can do science.

Students in the **CONTROL** class were more likely to say that “science people” do science.

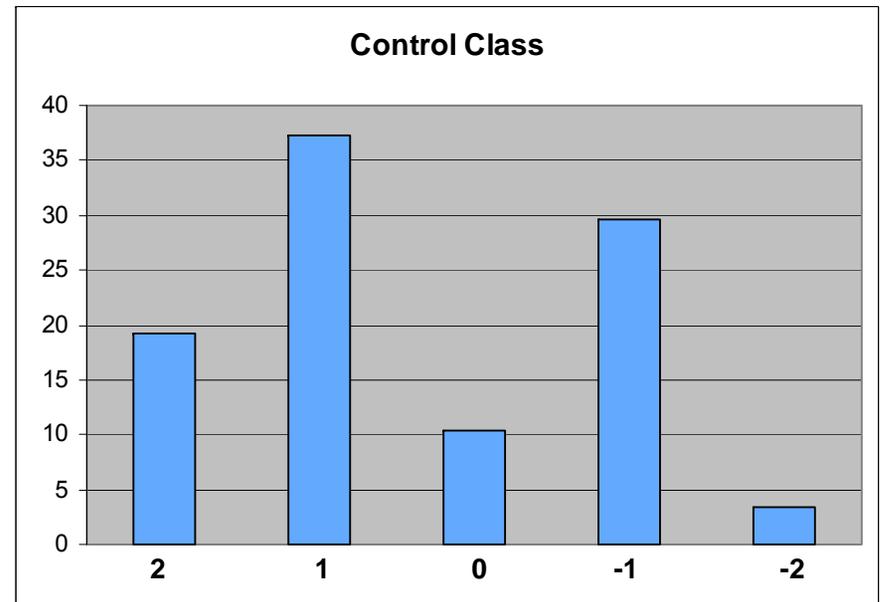
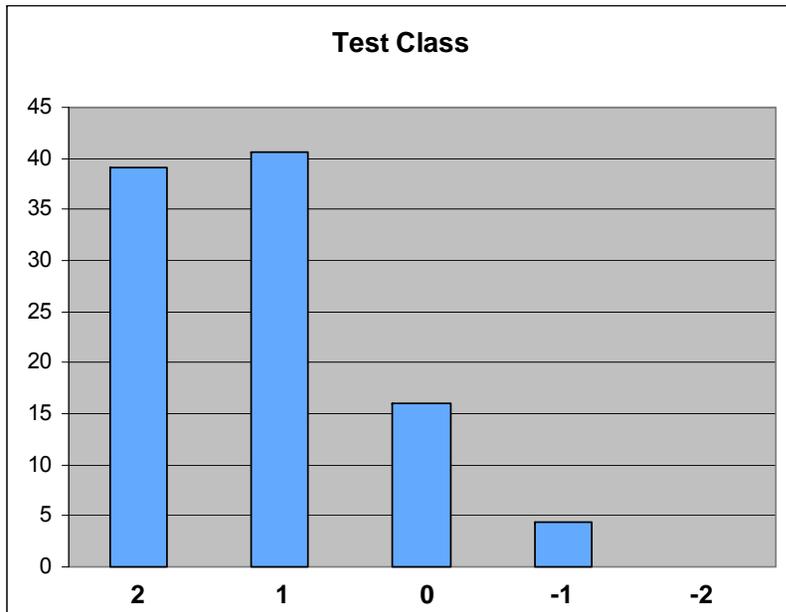
Of the 30 EBAPS questions, 6 showed distinctly different ($> 3 \sigma$) answers between the **TEST** and **CONTROL** classes.

5 of the 6 were on the same subject:
“Who can do science?”

Every question related to “Who can do science?” or “What is necessary to do science” was different between **TEST** and **CONTROL** classes

Example: When it comes to science, students either learn quickly, or not at all.”

2 means “strongly disagree,” 1 “disagree,” 0 is neutral, -1 “agree,” and -2 “strongly agree.”



Test Class in GREEN, Control Class in Red

EBAPS Question

4. When it comes to science, most students either learn things quickly, or not at all.

9. Someone who doesn't have high natural ability can still learn the material well even in a hard chemistry or physics class

16. Given enough time, almost everybody could learn to think more scientifically, if they really wanted to.

22. To be successful at science:

(2) Hard work is much more important than inborn natural ability.

(1) Hard work is a little more important than natural ability.

(0) Natural ability and hard work are equally important.

(-1) Natural ability is a little more important than hard work.

(-2) Natural ability is much more important than hard work.

25. Anna: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant. Emily: Maybe she is. But when it comes to being good at science, hard work is more important than "natural ability." I bet Dr. Kinoshita does well because she has worked really hard. Anna: Well, maybe she did. But let's face it, some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science!

(2) I agree almost entirely with Anna.

(1) Although I agree more with Anna, I think Emily makes some good points.

(0) I agree (or disagree) equally with Anna and Emily.

(-1) Although I agree more with Emily, I think Anna makes some good points.

(-2) I agree almost entirely with Emily.

30. Jessica and Mia are working on a homework assignment together...

Jessica: O.K., we just got problem #1. I think we should go on to problem #2. Mia: No, wait. I think we should try to figure out why the thing takes so long to reach the ground.

Jessica: Mia, we know it's the right answer from the back of the book, so what are you worried about? If we didn't understand it, we wouldn't have gotten the right answer. Mia:

No, I think it's possible to get the right answer without really understanding what it means.

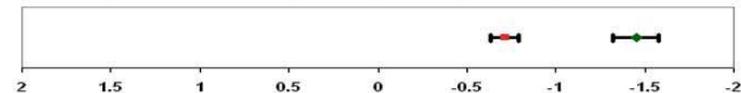
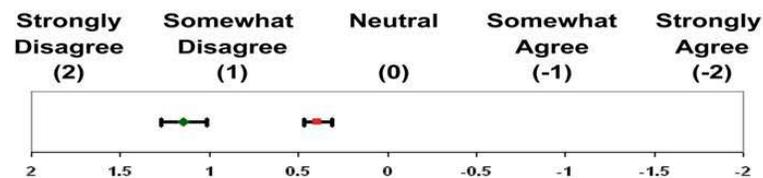
(2) I agree almost entirely with Jessica.

(1) I agree more with Jessica, but I think Mia makes some good points.

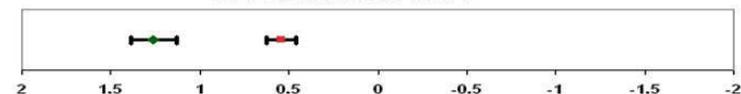
(0) I agree (or disagree) equally with Mia and Jessica

(-1) I agree more with Mia but I think Jessica makes some good points.

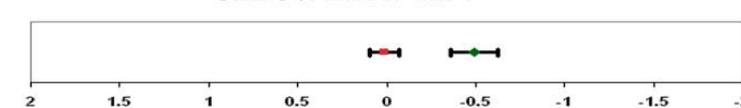
(-2) I agree almost entirely with Mia



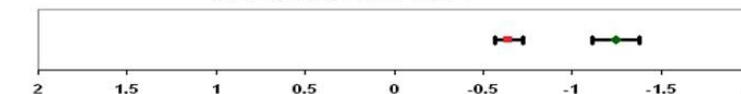
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SEE SCALE AT LEFT

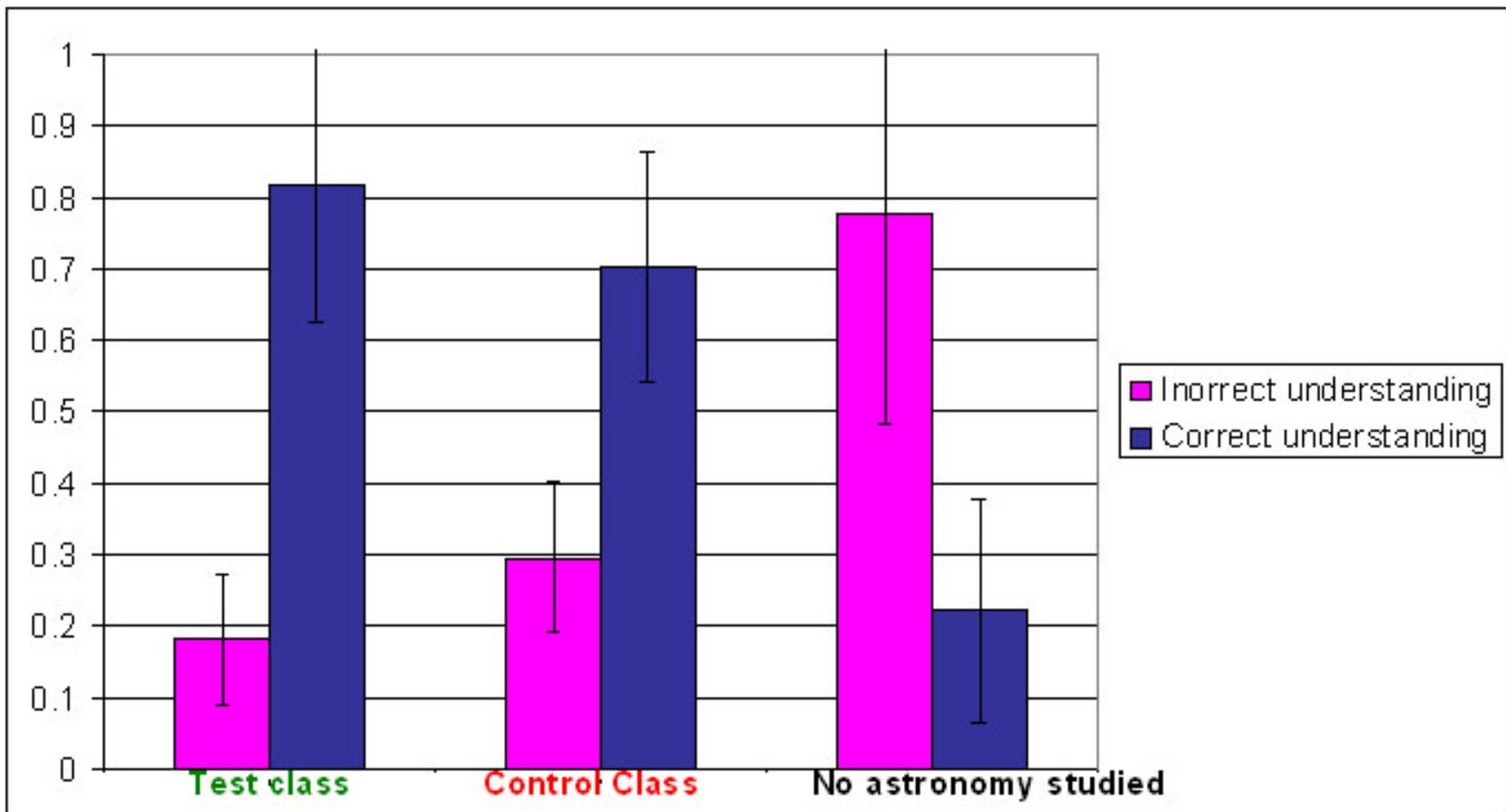


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theory?” (the word scientific was emphasized)

correct if they said: based on data, evidence, experiment, observations, a proven or tested idea. **Incorrect** if they said: (just) an idea, a guess, an opinion or hypothesis” without mentioning any testing



Test Class students were asked on their final:

Has this class changed the way you think about astronomy, science or pseudoscience? If so, how?	Number	Percentage
I'm less likely to be fooled by bad science or pseudoscience.	41	32%
I'm a more critical or scientific thinker; critical thinking is more important to me; my thinking should be based on data or be testable or repeatable.	37	28%
I'm more likely to apply science to everyday life.	21	16%
Science is more accessible, enjoyable, or important to me.	14	11%
No, my thinking has not changed.	12	9%
Particular astronomy topics mentioned.	7	5%
I am more skeptical about the www or other media.	5	4%
Science is broader than I thought. My perspective on our universe has changed.	6	5%
Other answers	7	5%
Left blank	19	15%

Conclusions

Most students in the test class believe that anyone can do science if they work at it.

Students in the control class are much more likely to believe that you must have natural ability to do science.

Giving students practice distinguishing good and bad science in outside of the classroom leads them to self-report more confidence in their ability to distinguish good science from bad, and that they are more likely to think scientifically and apply science in their own lives.

The National Science Standards suggest

“...in order to participate effectively in a democracy, citizens must understand the nature of scientific claims that increasingly influence or even become matters of public debate.” They must also be willing and able to participate.

The present investigation shows that practice enhances this important outcome.