The Global Epidemic of Confusing Hypotheses with Predictions

Fixing an International Problem

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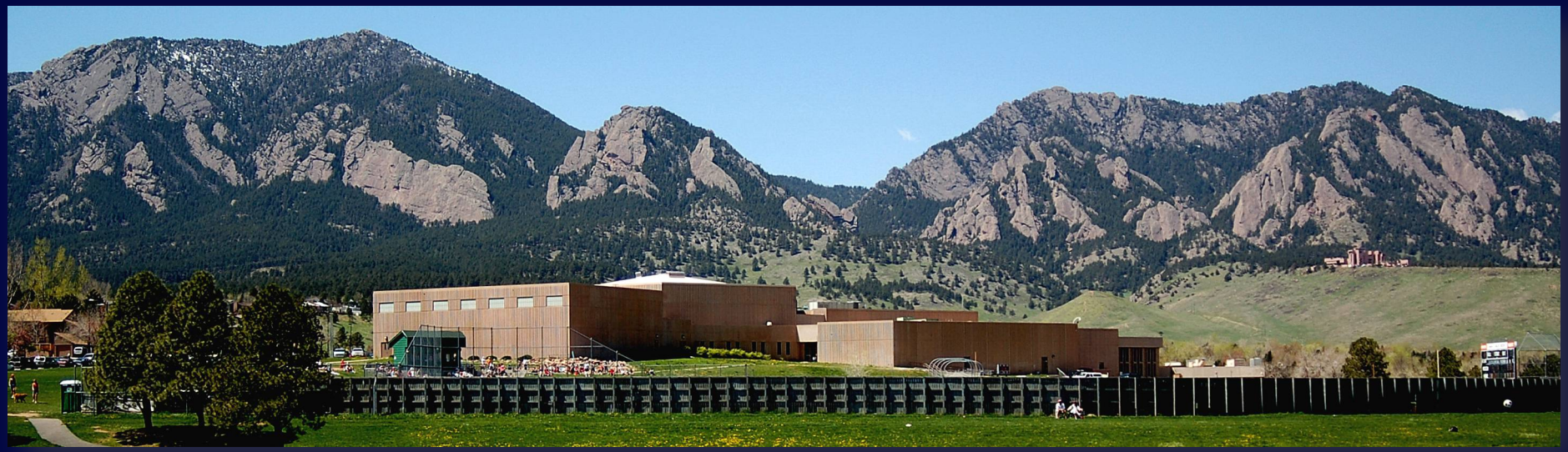


The Scientific Hypothesis

Survey:

- Write the definition of a hypothesis in science.

- A farmer observes that one edge of his onion field produces taller plants and larger onions. This same edge borders a prairie that the farmer has been slowly restoring over the last 10 years. Every two years the farmer initiates a controlled burn in the prairie to clear out invasive species. Each year he burns the prairie, it grows back greener than in the years he doesn't burn it.

- Write a hypothesis about this observation that the farmer could test with an experiment:

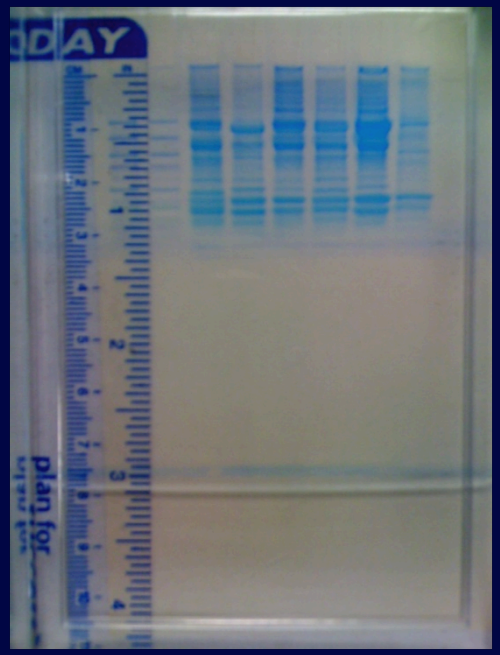
Hypothesis vs. Prediction

"We routinely use the term 'hypothesis' when we mean 'prediction.' This unacceptable substitution dilutes the power of the scientific method to the extent that invoking the 'scientific method' has become largely meaningless" Guy McPherson, *American Biology Teacher*, April 2001

Oxford English Dictionary:

Hypothesis - In the sciences, a provisional supposition from which to draw conclusions that shall be in accordance with known facts, and which serves as a starting-point for further investigation.

Prediction - The action of predicting future events; an instance of this, a prophecy, a forecast.



Hypothesis vs. Prediction

How textbooks define the hypothesis:

Wilbraham A.C. *et al*. (Pearson Prentice Hall 2008) *Chemistry: the Molecular Nature of Matter and Change*

Hypothesis - "A proposed explanation for an observation." (p. 22)

Serway and Faughn (Holt, Reinhalt, and Winston 2009) *Physics*

"A reasonable explanation for observations--one that can be tested with additional experiments." (p. 8)
"He hypothesized instead that all objects fall at the same rate in the absence of air resistance." (p. 8)

Campbell and Reece (2008) *Biology*, 8th Ed.:

Hypothesis - "A tentative answer to a well-framed question--an explanation on trial." (p. 19)

Hypothesis vs. Prediction

Hypothesis in science:

A tentative, testable, and falsifiable explanation for an observed phenomenon in nature.

Hypothesis vs. Prediction

How textbooks sometimes screw it up:

Padilla, M.J. (Pearson Education 2009) *Earth Science*

Hypothesis: "A possible explanation for a set of observations or answer to a scientific question." (p. 8)

Example: "If I add salt to fresh water, then the water will freeze at a lower temperature." (p. 788)

Miller, K. R., and J. Levine (Pearson Education 2009) *Biology*

Hypothesis: A scientific explanation for a set of observations that can be tested in ways that support or reject it." (p. 7)

Lab Prompt: "Form a hypothesis: given the objective of this lab and the materials you have to work with, what kind of change, if any, do you expect to see in the pH of the kimchi over the course of several weeks." (p. 266)

McGraw-Hill 2012 Middle School Science Textbook Program: *iScience*

"Form a Hypothesis: Use your data to form a hypothesis relating the amount of light to the rate of photosynthesis. State your hypotheses in this form: if . . . then . . . because."

Using Hypotheses and Predictions in the Scientific Process (from Campbell *Biology* 2008)

Example:

Observation: flashlight doesn't work.

1. Explanation (hypothesis): the batteries are dead.
2. Explanation (hypothesis): the bulb is burned out.

Prediction #1 (with methods): replacing the batteries will make the flashlight work.

"If the dead battery hypothesis is correct, and I replace the batteries with new ones, then the flashlight should work."

Flashlight works! Test of hypothesis #1 supports/does not falsify the hypothesis.

The above hypothesis is both *testable* and *falsifiable*.

Hypothesis testing is natural behavior

Playing with electricity (from Paul Strode's childhood)

Problem (engineering): Battery operated car does not go fast enough.

Engineering goal: Make car go faster.

Hypothesis: Electricity is more powerful than batteries.

Prediction (with methods): Powering car with electricity will make it go faster.

If electricity is more powerful than batteries, and I replace the batteries with electricity from an outlet, then my car will go faster.

Examples of How We Get it Wrong

Cold Hands and Loss of Fine Motor Skills

Observation: When our hands are cold, we lose our fine motor skills.

Teacher: “So breaking toothpicks requires fine motor skills, doesn’t it? Let’s do an experiment with toothpicks where we break them with our hands at two different temperatures and see what happens.”

“Now everyone write a problem statement and hypothesis.”

Examples of How We Get it Wrong

Typical Problem Statement:

What is the effect of temperature on how many toothpicks I can break in one minute?

Example "hypothesis":

I can break more toothpicks with my hand when it is warm than I can when my hand is cold.

No. This is simply a prediction, not a hypothesis in the scientific sense.

This phrasing shifts students' mindsets away from investigating cause and toward simply confirming an observation.

Examples of How We Get it Wrong

Example "hypothesis" 2:

If I break toothpicks for one minute with my warm hand and then with my cold hand, then I will break more toothpicks with my hand when it is warm.

No. This is a method followed by a prediction—there is still no apparent reason for doing this experiment. What explanation is being tested?

This may be the most common wrong way students and their teachers write hypotheses.

Examples of How We Get it Wrong

Example "hypothesis" 3:

If I break toothpicks for one minute with my warm hand and then for one minute with my hand after soaking it in ice water for five minutes, then I will break more toothpicks with my hand when it is warm BECAUSE low temperatures suppress muscle contractions and thus fine motor skills.

Almost. But this form puts the hypothesis being tested, that cold suppresses muscle contractions, at the end of the statement, in the conclusion, rather than in the beginning where the hypothesis belongs. Also, the use of the word 'because' suggests truth and removes the necessarily tentative nature of the hypothesis.

Examples of How We Get it Right!

Example "hypothesis" 4:

If low temperatures suppress muscle contractions and thus fine motor skills, and I break toothpicks for one minute with my warm hand and then for one minute with my hand after soaking it in ice water for five minutes, then I will break more toothpicks with my hand when it is warm.

Yes. This begins with the hypothesis that low temperatures suppress muscle contractions, and beginning with the word 'if' makes the hypothesis tentative. This form also includes how this hypothesis will be tested, and ends with a specific, measurable, predicted outcome of the experiment.

Examples of How We Get it Right!

If low temperatures suppress muscle contractions and thus fine motor skills, and I break toothpicks for one minute with my warm hand and then for one minute with my hand after soaking it in ice water for five minutes, then I will break more toothpicks with my hand when it is warm.

We call this the RESEARCH HYPOTHESIS

(If hypothesis, and method, then prediction)

- Young and Strode Why Evolution Works (and Creationism Fails), June 2009

Examples of How We Get it Right!

Example "hypotheses":

If low temperatures suppress muscle contractions and thus fine motor skills, and I break toothpicks for one minute with my warm hand and then for one minute with my hand after soaking it in ice water for five minutes, then I will break significantly more toothpicks with my hand when it is warm.

Results: In a class of 30 students, students break an average of 36 toothpicks with warm hands and 22 toothpicks with cold hands.

The data can be analyzed with a paired t-Test, or more simply with 95% confidence intervals, and always (5 years so far) show a statistically significant difference between the means.

The Research Hypothesis Formula Has Been Around for a Long Time

- Silver salmon (*Oncorhynchus kisutch*) are born in the headwaters of Pacific Northwest streams.
- Young salmon grow and mature sexually in the Pacific Ocean.
- By tagging young salmon, biologists discovered that mature salmon actually return to reproduce in precisely the same headwaters where they were born some years earlier.
- This discovery raised a very interesting causal question: how do returning salmon find their home stream?

By borrowing explanations from other animal taxa, A. D. Hasler (1960) generated three hypotheses for salmon navigation: (1) salmon use sight; (2) salmon smell chemicals specific to their home stream; and (3) salmon use the Earth's magnetic field.

Hasler, Arthur D. 1960. Guideposts of Migrating Fishes. *Science* 132:785-792.

The Research Hypothesis Formula Has Been Around for a Long Time

ANTONE E. LAWSON

THE NATURE AND DEVELOPMENT OF SCIENTIFIC REASONING: A SYNTHETIC VIEW

Lawson (2004) describes Hasler's hypothetico-deductive reasoning:

If . . . salmon find their home stream by sight (sight hypothesis), *and* . . . a group of non-blindfolded salmon and a group of blindfolded salmon from the Issaquah and East Fork streams are released below the fork where the two streams join (planned test), *then* . . . the non-blindfolded salmon should be recaptured in their home stream more frequently than the blindfolded salmon (prediction).

Lawson, Antone E. 2004. The Nature And Development of Scientific Reasoning: a Synthetic View. *International Journal of Science and Mathematics Education* 2:307–338.

Hypothesis and Prediction Confusion

Is it a National, Perhaps International Problem?

Independent Student Research → Science Fair

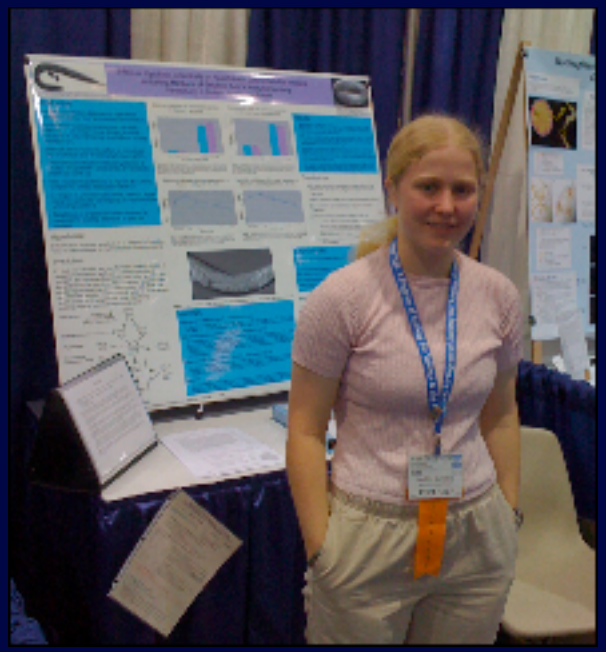
- Students initially explore topics of interest (often unsolved issues in science).
- Students then
  - develop research questions.
  - explore background information.
  - develop a hypothesis that uses the background information as a guide.
- Students then write research proposals, run and analyze experiments, and report their results in the form of scientific reports or at school, regional, and international science fairs.

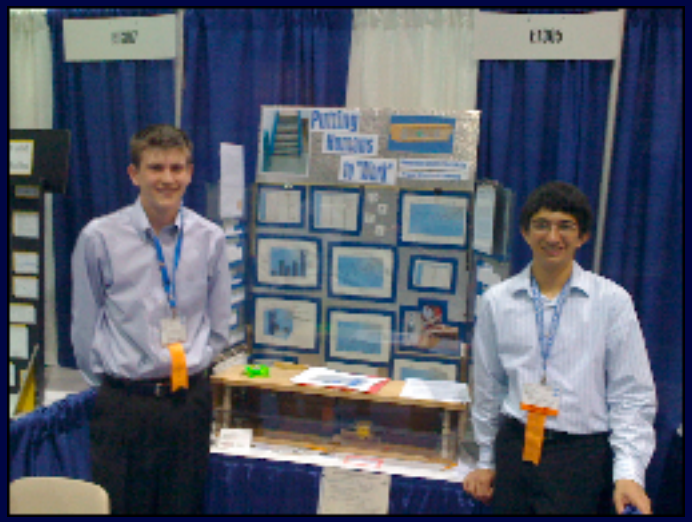
The ISEF Hypothesis Study

- The ISEF Study
  - Five years of data collection at the International Science and Engineering Fair
  - 2006 (Indianapolis), 2008 (Atlanta), 2009 (Reno), 2010 (San Jose), and 2011 (LA)
  - A total of 1,129 student projects randomly surveyed over five years
  - Excluded any projects with problem statements instead of hypotheses (engineering, math, computer science, some physics)

The ISEF Hypothesis Study

- The ISEF Study
  - Surveyed projects for presence or absence of what students identified as hypothesis statements.
  - Assessed student understanding of the meaning of the scientific hypothesis versus the meaning of a prediction.





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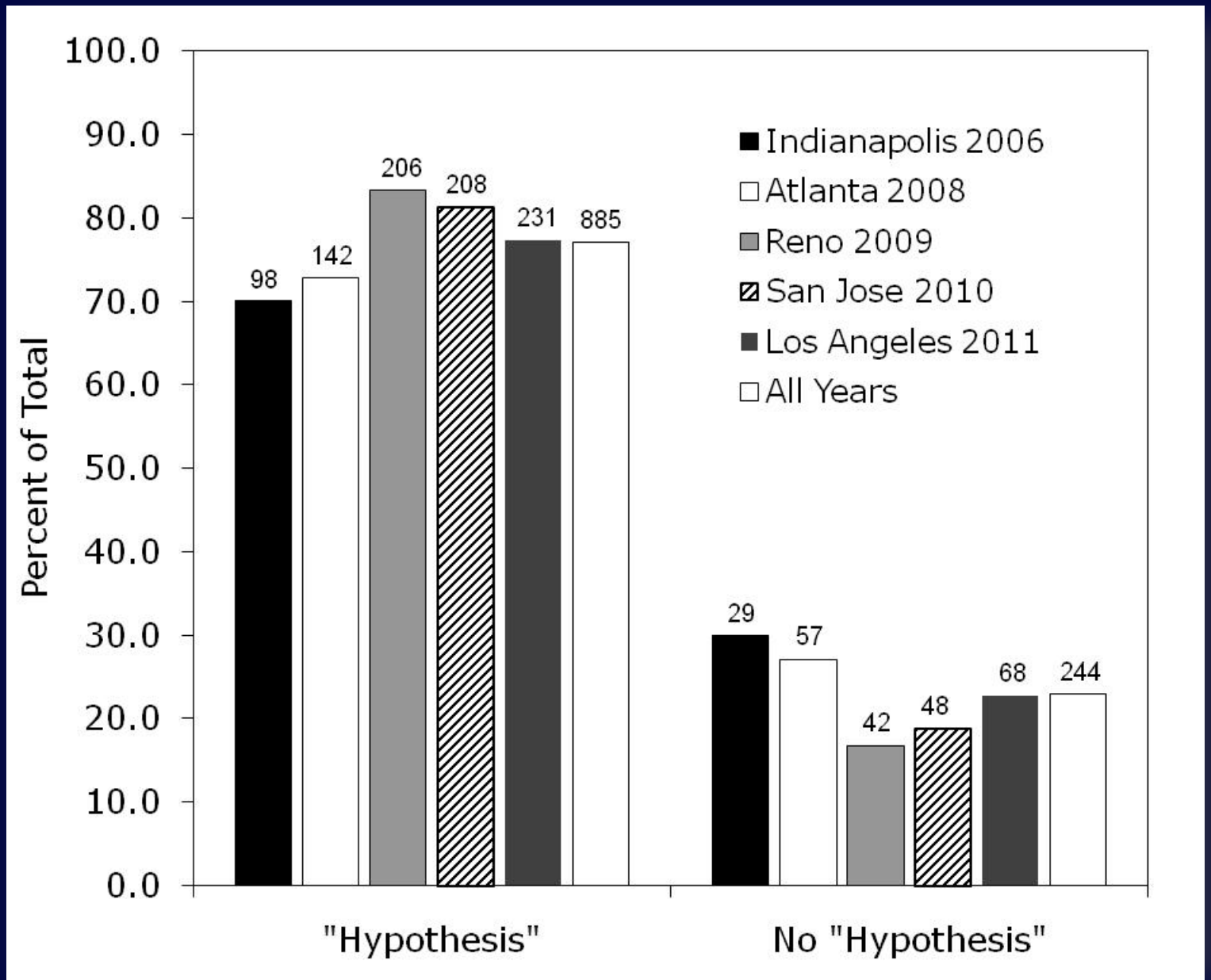

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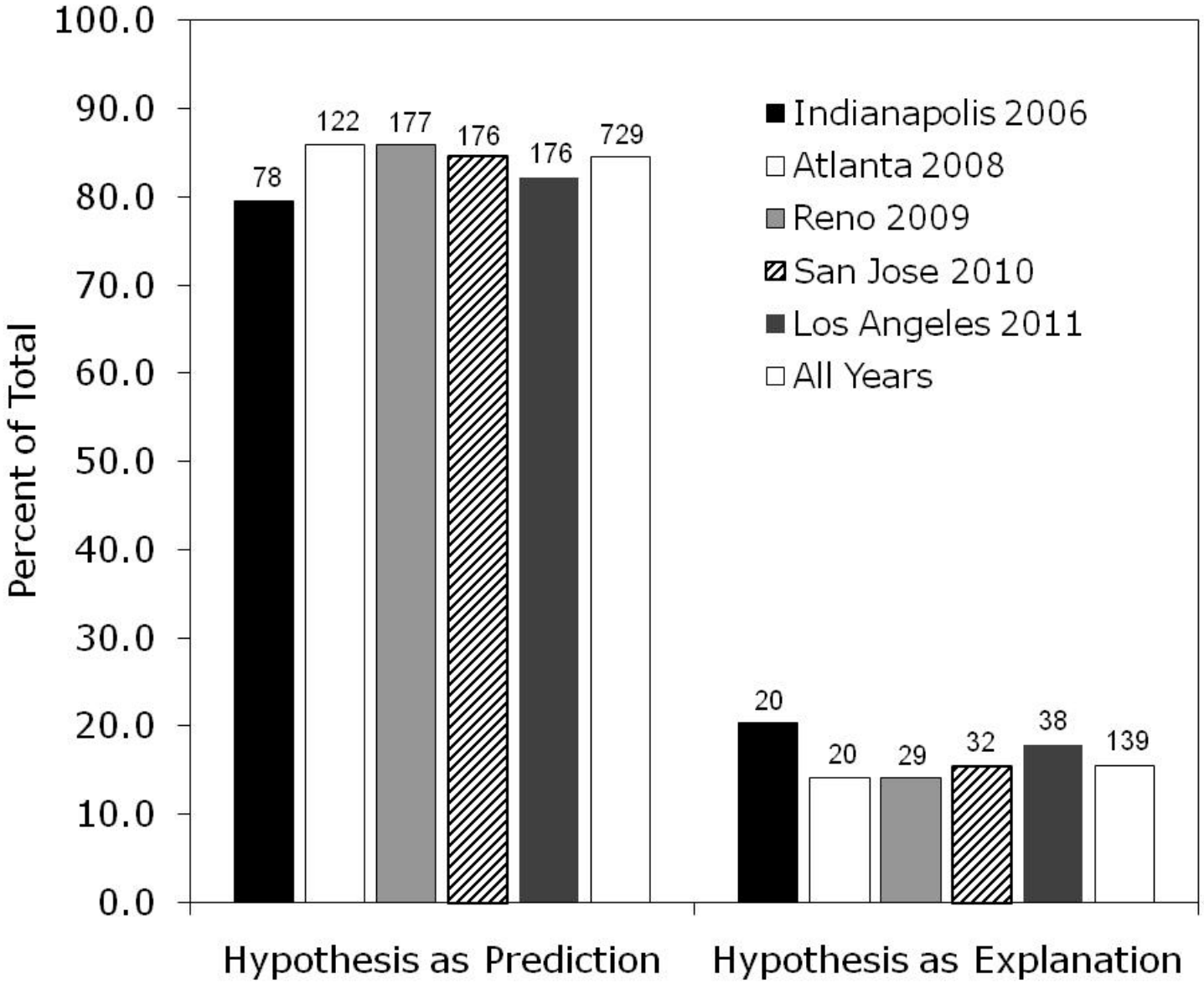

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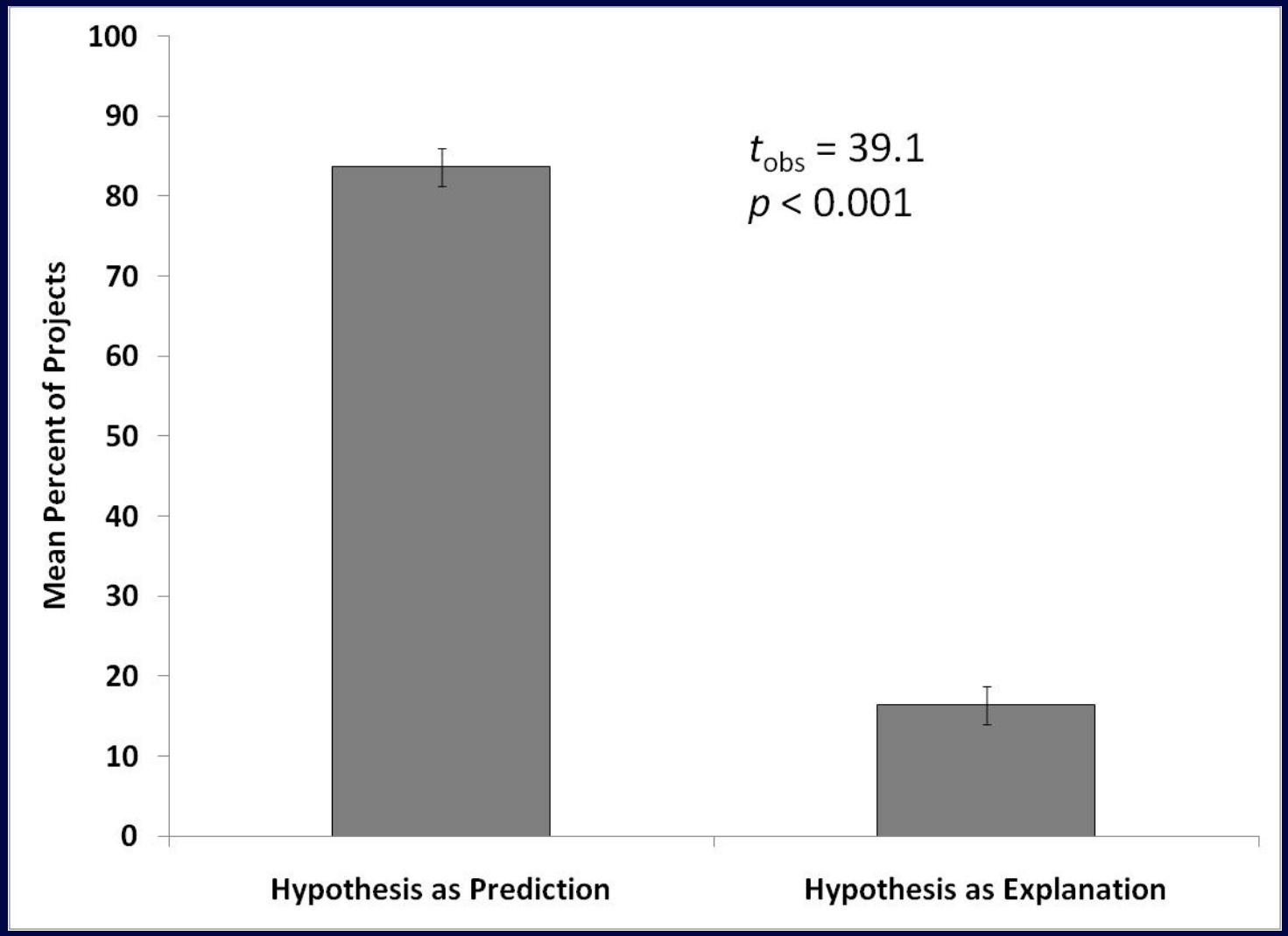

Mean percent of projects (n = 5 years) with hypotheses written as predictions and hypotheses written as explanations. Error bars are 95% confidence intervals. Statistics are the results of a students *t*-Test.

Examples from Student Projects

1. How would YOU categorize each of these?

Prediction only -- Prediction (with methods) -- Hypothesis only -- Hypothesis and Prediction -- Research Hypothesis (Hypothesis, Methods, Prediction)

2. Does the student understand the meaning of *hypothesis*, or confuse it with *prediction*?

- "If a plant receives fertilizer, then they will grow to be bigger than a plant that doesn't receive fertilizer."

- "The hypothesis of this study was that cattle presence would have an adverse impact on the terrestrial salamander population."

- "It is hypothesized that in the early time intervals of data collection, the cells fed with TGF Beta will at first be suppressed by the hormone."

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2. Does the student understand the meaning of *hypothesis*, or confuse it with *prediction*?

- "Ground level ozone will be higher in areas of Fairfield, Iowa, with more traffic."

- "Earthworm activity will alter the chemical trajectory of leaf litter from background fungal dominated decay paths."

- "If pH is a factor in the decomposition of H_2O_2, then lowering the pH will inhibit the rate."

Examples from Student Projects

1. How would YOU categorize each of these?

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2. Does the student understand the meaning of *hypothesis*, or confuse it with *prediction*?

- "It is hypothesized that if the bridge's structural width is changed from 40 mm to 30 mm to 20 mm, then the structural efficiency will increase respectively."

- "Dye affects the efficiency of a solar cell by being able to absorb more light into the solar cell as opposed to no dye. Thus, the cell with no dye should not be able to conduct electricity."

Examples from Student Projects

1. How would YOU categorize each of these?

Prediction only -- Prediction (with methods) -- Hypothesis only -- Hypothesis and Prediction -- Research Hypothesis (Hypothesis, Methods, Prediction)

2. Does the student understand the meaning of *hypothesis*, or confuse it with *prediction*?

- "Because a prescribed burn is lower in intensity than a wildfire, prescribed burns can significantly reduce mercury emissions from a subsequent fire."

- "It is hypothesized that the structural and functional integrity of the system as a whole is dependent on nerve activity."

Examples from Student Projects

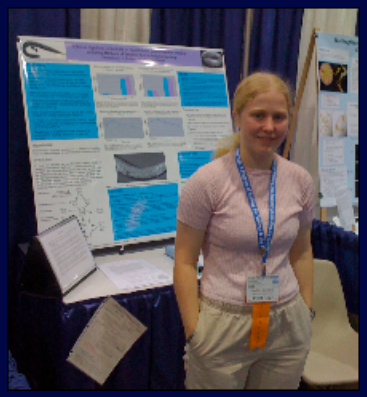
1. How would YOU categorize each of these?

Prediction only -- Prediction (with methods) -- Hypothesis only -- Hypothesis and Prediction -- Research Hypothesis (Hypothesis, Methods, Prediction)

2. Does the student understand the meaning of *hypothesis*, or confuse it with *prediction*?

- "If parthenolide is a substrate specific inhibitor in signal transduction, and I examine the effects of parthenolide on the secretion of 5-HT through two independent pathways using a platelet-based model, then parthenolide should inhibit the secretion of 5-HT only through the PKC pathway."

Examples from Student Projects



Research Hypothesis

"If parthenolide is a substrate specific inhibitor in signal transduction, and I examine the effects of parthenolide on the secretion of 5-HT through two independent pathways using a platelet-based model, then parthenolide should inhibit the secretion of 5-HT only through the PKC pathway."

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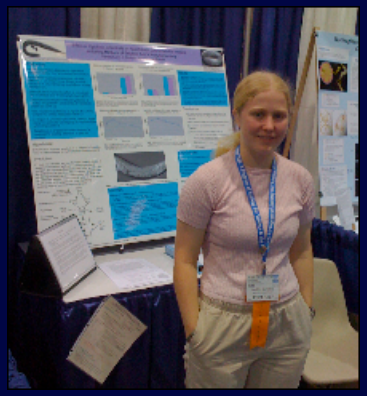

Hypothesis

"parthenolide is a substrate specific inhibitor in signal transduction, and I examine the effects of parthenolide on the secretion of 5-HT through two independent pathways using a platelet-based model, then parthenolide should inhibit the secretion of 5-HT only through the PKC pathway."

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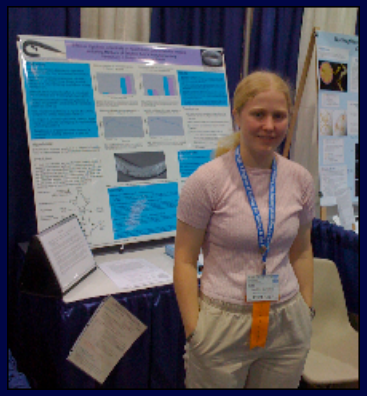
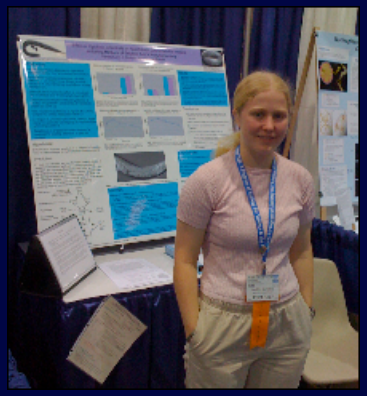


Methods

"If parthenolide inhibits 5-HT secretion from dense platelet granules through the inactivation of the PKC pathway, and I examine the effects of parthenolide on the secretion of 5-HT through two independent pathways using a platelet-based model, then parthenolide should inhibit the secretion of 5-HT only through the PKC pathway."

Examples from Student Projects



Prediction

"If parthenolide inhibits 5-HT secretion from dense platelet granules through the inactivation of the PKC pathway, and I examine the effects of parthenolide on the secretion of 5-HT through two independent pathways using a platelet-based model, then parthenolide should inhibit the secretion of 5-HT only through the PKC pathway."

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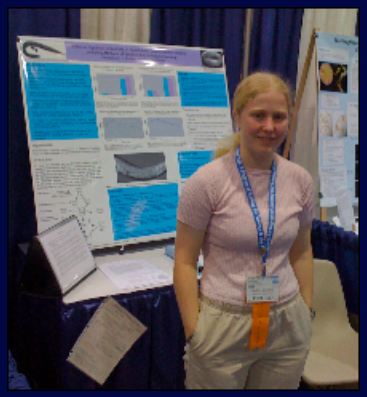

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What is the source of this problem?

Misuse of the Term Hypothesis in Textbooks

Analyzed all 66 science textbook used in Boulder Valley School District middle and high schools.

Books were grouped by middle level (gray), high school (pink), and college (blue).

If at least one of the three categories (hypothesis definition, hypothesis example, lab prompt for students to write a hypothesis) was or prompted a prediction, the book failed in its teaching of correct hypothesis writing.

Level	Course	Title	Authors	Publisher	Year	Place	Hypothesis	Example H	Example H	Prediction	Def H, P, or	Example H	Prompt H or P	
Middle Scho	Earth Scienc	Earth Scienc	Feather, R. J	Glencoe/McG	1999	Columbus, O	A prediction	You might hy	State a hypo	None	P	P	P	Fail
Middle Scho	Earth Scienc	Earth Scienc	Feather, R. J	Glencoe/McG	2008	Columbus, O	An educated	You might hy	State a hypo	None	EG	P	P	Fail
Middle Scho	Earth Scienc	Earth Scienc	Todd, R. W.	Holt, Rinehar	2001	Austin, Texa	Sometimes c	The bones c	None	None	EG	H	N	
Middle Scho	Earth Scienc	Earth Scienc	Padilla, M. J.	Pearson Edu	2001	Upper Saddle	A possible ex	If I add salt	How do you	None	H	P	P	Fail
Middle Scho	Earth Scienc	Earth Scienc	Padilla, M. J.	Pearson Edu	2009	Upper Saddle	A possible ex	If I add salt	Which do yo	Making a for	H	P	P	Fail
Middle Scho	Earth Scienc	Earth Scienc	Tarbuck, E.	Pearson Pren	2009	Boston, Mas	A possible ex	Hypothesizin	None	None	H	P	N	Fail
Middle Scho	Life Science	Life Science	Todd, R. W.	Holt, Rinehar	2001	Austin, Texa	A possible ex	The deformit	None	A statement	H	H	N	
Middle Scho	Life Science	Life Science	Padilla, M. J.	Pearson Edu	2009	Upper Saddle	A possible ex	If I add salt	Write a hypo	A forecast o	H	P	H	Fail
Middle Scho	Life Sci										H	P	N	Fail
Middle Scho	Life Sci										P	H	P	Fail
Middle Scho	Physica									for	H	H	P	Fail
Middle Scho	Physica										H	P	P	Fail
Middle Scho	Physica										N	N	N	
Middle Scho	Physica										H	N	N	
Middle Scho	Physica									s us	H	P	H	Fail
Middle Scho	Physica									t m	H	H	P	Fail
Middle Scho	Physica										P	H	P	Fail
High School	Biology										H	H	N	
High School	Physics										N	N	N	
High School	Physics										N	N	N	
High School	Astronc										H	H	N	
High School	Astronc										H	H	N	
High School	Biology										EG	N	N	
High School	Biology										H	H	N	
High School	Biology										H	H	N	
High School	Biology									ment	H	H	N	
High School	Biology										H	H	P	Fail
High School	Chemist										H	P	P	Fail
High School	Chemist										H	H	N	
High School	Chemist										N	N	N	
High School	Environ									stat	H	H	N	
High School	Environ										H	N	N	
High School	Environ										H	H	N	
High School	General										EG	N	P	Fail
High School	General										H	N	P	Fail
High School	General										H	N	N	
High School	Geology										H	H	N	
High School	Geology										H	H	N	
High School	Geology										H	H	N	
High School	Marine										H	P	N	Fail
High School	Marine										H	H	N	
High School	Physica									enc	EG	H	N	
High School	Physica										N	N	N	
High School	Physica										EG	H	N	
High School	Physica										H	P	H	Fail
High School	Physics										EG	H	N	
High School	Physics									of h	EG	H	N	
High School	Physics										EG	N	N	
High School	Physics										H	H	N	
High School	Physics										N	N	N	
High School	Physics										EG	H	N	
High School	Physics	Physics for t	Tsokos, K. A	Cambridge U	2008	Cambridge, U	None	None	None	None	N	N	N	
College	Biology	Biology: The	Starr, C., et	Brooks/Cole,	2009	Belmont, Cal	A testable a	Smoking ciga	None	A statement	H	H	N	
College	Biology	Biology	Campbell, N.	Peason Benj	2008	San Francisc	A tentative	The batterie	None	None	H	H	N	
College	Biology	Biological Sc	Freeman, S.	Peason Benj	2008	San Francisc	A proposed	Long necks	None	Something t	H	H	N	
College	Biology	Life	Lewis, R., et	McGraw-Hill	2007	New York, N	Based on so	Elephants co	None	None	P	H	N	Fail
College	Chemistry	Chemistry: F	Masterson, V	Brooks/Cole	2009	Belmont, Cal	None	None	None	None	N	N	N	
College	Chemistry	Chemistry: S	Spencer, J.	John Wiley a	2008	Hoboken, Ne	None	None	None	None	N	N	N	
College	Chemistry	Chemistry: T	Brown, T. L.	Pearson Edu	2009	Upper Saddle	A tentative	None	None	None	H	N	N	
College	Chemistry	Chemistry	Zumdahl, S.	Brooks/Cole	2010	Belmont, Cal	A possible ex	None	None	None	H	N	N	
College	Chemistry	Introductory	Zumdahl, S.	Houghton Mi	2008	Boston, Mas	A possible ex	The disease	None	None	H	H	N	
College	Physics	Physics: a S	Knight, R. D.	Pearson Add	2008	San Francisc	None	None	None	None	N	N	N	
College	Physics	University Ph	Young, H. D.	Pearson Add	2008	San Francisc	None	None	None	None	N	N	N	
College	Physics	Fundamenta	Walker, J.	John Wiley a	2008	Hoboken, Ne	None	None	None	None	N	N	N	
College	Plant Biology	Introductory	Stern, K. R.,	McGraw-Hill	2008	New York, N	A tentative,	All ripe citrus	None	None	H	H	N	
College	Plant Biology	Introduction	Nabors, M. V	Pearson Ben	2004	San Francisc	A tentative	Leaves enab	None	None	H	H	N	

Middle School Textbooks:

13 of 17 (76%) Failed

High School Textbooks:

6 of 35 (17%) Failed

College Textbooks:

1 of 14 (7%) Failed

How big is this problem?

Use and Misuse of the Term Hypothesis in Scientific Papers

Journal of Educational Psychology
2004, Vol. 96, No. 3, 536–544

Copyright 2004 by the American Psychological Association
0022-0663/04/$12.00 DOI: 10.1037/0022-0663.96.3.536

Elementary School Children's Ability to Distinguish Hypothetical Beliefs From Statements of Preference

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University of Cyprus

Christos Ioannides
University of Pireaus

The authors examined students' understanding of hypotheses as beliefs that can be empirically verified. Thirty second graders and 30 sixth graders considered cases of disagreement about foods and colors that reflected either alternative hypotheses or different preferences. Their task was to decide whether the validity of each expressed belief could be determined and to justify their decision. Younger students considered both hypotheses and preferences as empirically verifiable, whereas older students were better able to recognize in some cases that preferences are legitimately variable. This lack of distinction may reflect limited metaconceptual ability or a deterministic epistemological view, both of which might interfere with the understanding of the hypothesis-testing process.

How big is this problem?

Use and Misuse of the Term Hypothesis in Scientific Papers

Hypothesis

Research has shown that prior knowledge and personal beliefs can influence reasoning (see, e.g., Stanovich & West, 1997), the extent to which hypotheses are perceived as plausible (Klahr et al., 1993), and the way evidence is interpreted and evaluated (see, e.g., Chinn & Brewer, 1993). Specifically, Klaczynski (2000) found that although adolescents used higher order analytic reasoning to evaluate evidence that was inconsistent with their beliefs, they relied on simple heuristics to evaluate evidence that was consistent. We reasoned, therefore, that favoring one alternative belief might influence decisions concerning the extent to which its validity could be tested and, more importantly, proposals concerning the way it could be tested. To control for possible prior belief biases in the present study, half of all the disagreements involved one alternative hypothesis or preference that students had been found to favor, whereas the other half involved neutral alternatives.

To summarize, the primary goal of the present study was to determine the extent to which elementary school children distinguished hypotheses from preferences as belief statements whose truth value can be determined and to examine the kinds of tests that

Prediction

they proposed. We hypothesized that older children would be more likely than younger children (a) to indicate that only hypotheses, as opposed to preferences, could be tested and (b) to propose empirical tests, although not necessarily well designed or correct, as opposed to subjective evaluations or references to authority. An

How big is this problem?

Use and Misuse of the Term Hypothesis in Scientific Papers

Finger length ratio (2D:4D) correlates with physical aggression in men but not in women

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Received 8 November 2003; accepted 20 May 2004
Available online 29 July 2004

Abstract

Finger length ratio (2D:4D) is a sexually dimorphic trait. Men have relatively shorter second digits (index fingers) than fourth digits (ring fingers). Smaller, more masculine, digit ratios are thought to be associated with either higher prenatal testosterone levels or greater sensitivity to androgens, or both. Men with more masculine finger ratios are perceived as being more masculine and dominant by female observers, and tend to perform better in a number of physical sports. We hypothesized that digit ratio would correlate with propensity to engage in aggressive behavior. We examined the relationship between trait aggression, assayed using a questionnaire, and finger length ratio in both men and women. Men with lower, more masculine, finger length ratios had higher trait physical aggression scores ($r_{partial} = -0.21$, $N = 134$, $P = 0.028$). We found no correlation between finger length ratio and any form of aggression in females. These results are consistent with the hypothesis that testosterone has an organizational effect on adult physical aggression in men.

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How big is this problem?

Use and Misuse of the Term Hypothesis in Scientific Papers

score higher than women on the physical, verbal and hostility (but not anger) subscales of an aggression questionnaire (Buss and Perry, 1992). We examined the relationship between 2D:4D and scores on the four subscales of the aggression questionnaire. We hypothesized that testosterone organizes human aggressive behavior and that digit ratio will correlate with the most sexually dimorphic forms of trait aggression.

If testosterone organizes human aggressive behavior, and we examine the relationship between 2D:4D and scores on the four subscales of the aggression questionnaire, then digit ratio will correlate with the most sexually dimorphic forms of trait aggression.

How big is this problem?

Use and Misuse of the Term Hypothesis in Scientific Papers

PNAS

Testosterone increases bioavailability of carotenoids: Insights into the honesty of sexual signaling

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Communicated by John R. Krebs, Jesus College, Oxford, United Kingdom, October 17, 2006 (received for review December 12, 2005)

Androgens and carotenoids play a fundamental role in the expression of secondary sex traits in animals that communicate information on individual quality. In birds, androgens regulate song,

dent lines, with little success at integrating potential proximate links. In birds, circulating levels of both testosterone and carotenoids show vernal elevations that coincide with the mating

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Table 1. Brief explanation of the main framework hypotheses (in bold) and predictions

Hypothesis	Framework hypotheses description/prediction
h1	**Testosterone elevates circulating levels of carotenoids**
	Circulating carotenoids will be higher in testosterone-treated birds compared with controls. Within testosterone-treated birds, circulating carotenoids will increase after an increase in the hormone.
h2	**Circulating carotenoids explain external coloration**
	Positive association between plasma carotenoids and integument color.
h3	**There are tradeoffs in the use of carotenoids for ornamentation and immune function**
	Positive association between residual carotenoids (i.e. circulating carotenoids not explained by external coloration) and immune response.
h4	**Testosterone levels decrease immune function (ICHH)**
	Immune function will be reduced in testosterone-treated birds compared with controls.
h5	**Testosterone-dependent elevations in plasma carotenoids buffer immunosuppression**
	Immune function will not be reduced in testosterone-treated birds compared controls, because the former will show elevated carotenoid levels (according to *h1*) with immunoenhacing activity (according to *h3*). Further predictions involve manipulation of testosterone among groups that differ in individual quality (carotenoids will be used for ornamentation rather than immune function only in the high-quality group).

Practicing Hypothesis Writing

If we could only get our students to write good research questions…

1. Are brightly colored leaves in the fall a warning to potential herbivores?

2. Are brightly colored leaves in the fall evidence of sunscreen against damaging radiation?

3. Why do some bird species arrive at their breeding grounds at the same time every spring, regardless of spring conditions?

4. Does temperature affect the rate of cellular respiration? (think of yeast)

5. Can plasmids transform phenotype in *E. coli*?

Take Home Messages

1. As science teachers, we are in the business of teaching the process of science, which begins with correct hypothesis writing and testing.

2. Hypothesis writing can be challenging, but is an essential tool for keeping students (and scientists!) focused on exactly what they are doing and why they are doing it.

3. Misuse of “hypothesis” is a problem throughout the profession.

4. Help students start their scientific thinking with good research questions.

Acknowledgments:

Haydee Ayi-Bonte
Kristin Donley
Helen Petach
Boulder Valley School District

Paul K. Strode

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