The Global Epidemic of Confusing Hypotheses with Predictions
Fixing an International Problem

Paul Strode
Fairview High School
Boulder, Colorado

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.

How textbooks define the hypothesis:


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.

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)


“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.”

“No one 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.

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).


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.
The ISEF Hypothesis Study

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The ISEF Hypothesis Study
The ISEF Hypothesis Study

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.”
Examples from Student Projects

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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 H₂O₂, then lowering the pH will inhibit the rate.”

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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

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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.”
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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.”

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.”
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.”

What is the source of this problem?

*Misuse of the Term Hypothesis in Textbooks*

Analyzed all 66 science textbooks 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.

- **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*

**Title:** Elementary School Children’s Ability to Distinguish Hypothetical Beliefs From Statements of Preference

**Authors:** Irene-Anna N. Dishidoy, University of Cyprus; Christos Ioannides, University of Paros

The authors examined students' understanding of hypotheses as beliefs that can be empirically verified. Thirty-second graders and 30 third 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 metacognitive ability or a deterministic epistemological view, both of which might interfere with the understanding of the hypothesis-testing process.

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**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, Klahr (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. Therefore, 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 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

**Prediction:**
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

Allison A. Bailey*, Peter L. Hurd*#

*Department of Psychology, University of Alberta, Edmonton, Alberta, Canada T6G 2E9

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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, assessed 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 ($r_{trait} = -0.21$, $N = 134$, $p = 0.028$). 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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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

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

J. Blas**, L. Pérez-Rodriguez*, G. R. Bortolotti*, J. Vílhuela*, and T. A. Marchant*

*Department of Biology, University of Saskatchewan, 1-3 Science Place, Saskatoon, SK, Canada S7N 5E9; and **Instituto de Investigación en Recursos Cignéticos, Consejo Superior de Investigaciones Científicas, Universidad de Cartagena La Marisma, Federico de Horno 6, 3009 Ciudad Real, Spain

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Androgens and carotenoids play a fundamental role in the expression of secondary sex traits in animals that communicate information on testosteronic quality. In birds, androgens regulate song,
dent lines, with little success of integrating potential proximate

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

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Framework hypothesis description</th>
<th>prediction</th>
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<tbody>
<tr>
<td>h1</td>
<td>Testosterone elevates circulating levels of carotenoids</td>
<td></td>
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<tr>
<td>h2</td>
<td>Circulating carotenoids are higher in testosterone-treated birds compared to controls. Within testosterone-treated birds, circulating carotenoids will increase after an increase in the hormone.</td>
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<tr>
<td>h3</td>
<td>Positive association between plasma carotenoids and integument color.</td>
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<td>h4</td>
<td>There are tradeoffs in the use of carotenoids for ornamentation and immune function.</td>
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<tr>
<td>h5</td>
<td>Circulating carotenoids explain external coloration.</td>
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<td>h6</td>
<td>Positive association between residual carotenoids (i.e., circulating carotenoids not explained by external coloration) and immune function.</td>
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<td>h7</td>
<td>Testosterone levels decrease immune functions (ICR)</td>
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<td>h8</td>
<td>Immune function will be reduced in testosterone-treated birds compared to controls.</td>
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<tr>
<td>h9</td>
<td>Testosterone-dependent elevations in plasma carotenoids buffer immunosuppression</td>
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<tr>
<td>h10</td>
<td>Immune function will not be reduced in testosterone-treated birds compared to controls, because the former will show elevated carotenoid levels (according to h1) with immunoregulatory 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).</td>
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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.
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paul.strobe@bvsd.org
http://www.fairviewhs.org/staff/paul-strobe