One Dozen Science Bites

Teaching the Core of Gen Ed Science

What Is Our Mission?

- From the A-State Office of Assessment:

GOAL: Students should understand how science is conducted and the criteria for scientific evidence so that they will be able to make informed decisions about the health and well-being of their communities and the natural environment. They should be aware of the ethical and political issues raised by science.

OUTCOMES: Students will be able to apply foundational knowledge of the various sciences to make informed decisions.

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When We Teach Introductory Science

- Intro classes often focus on declarative knowledge
  - Especially in our testing
- Declarative knowledge is low on Bloom's taxonomy
- Making informed decisions is high on Bloom's taxonomy
- How do take non-majors all the way towards decision-making without getting lost in the declarative detail?

Bloom's Taxonomy of Measurable Verbs

Benjamin Bloom created a taxonomy of measurable verbs to help us describe and classify observable knowledge, skills, attitudes, behaviors and abilities. The theory is based upon the idea that there are levels of observable actions that indicate something is happening in the brain (cognitive activity.) By creating learning objectives using measurable verbs, you indicate explicitly what the student must do in order to demonstrate learning.

Verbs that demonstrate *Critical Thinking*

KNOWLEDGE	COMPREHENSION	APPLICATION	ANALYSIS	SYNTHESIS	EVALUATION
List	Compare	Apply	Analyze	Arrange	Appraise
Name	Describe	Complete	Appraise	Assemble	Argue
Recall	Discuss	Construct	Categorize	Collect	Assess
Record	Explain	Demonstrate	Compare	Combine	Choose
Relate	Express	Dramatize	Contrast	Comply	Compare
Repeat	Identify	Employ	Debate	Compose	Conclude
State	Recognize	Illustrate	Diagram	Construct	Estimate
Tell	Restate	Interpret	Differentiate	Create	Evaluate
Underline	Tell	Operate	Distinguish	Design	Interpret
	Translate	Practice	Examine	Devise	Judge
		Schedule	Experiment	Formulate	Justify
		Sketch	Inspect	Manage	Measure
		Use	Inventory	Organize	Rate
			Question	Plan	Revise
			Test	Prepare	Score
				Propose	Select
				Setup	Support
					Value

How Do We Get Students Thinking Critically While We Teach the Declarative Basics?

- By helping students understand how science is done, what limitations this process includes, how the process of science corrects for these limitations, and how our work products reflect this process
- At the same time, scientists are human beings — how does our subjective world intersect with the objectivity of science's process?
- Then coming back to these points as we lay out the declarative content of our disciplines as a foundation for discussion

Most Importantly, We Are Colleagues

- In this workshop and in our daily teaching practice, concurrent enrollment and campus faculty are colleagues
- We all teach these classes, and to the same standards
- Many of our concurrent enrollment faculty either have or do teach courses on the Jonesboro or other A-State campuses
- The issue for concurrent faculty is getting adequate collegial interaction
- Please take this opportunity to join in, raise questions or points of discussion that concern you!
    - If we don't get through all these slides but we do have a productive discussion, we have succeeded!

How Do We Get Students Thinking Critically While We Teach the Declarative Basics?

- Let's go through a dozen ideas that are woven throughout every scientist's working life and talk about how to bring these ideas into the classroom
- We need feedback from you all to see how these issues affect your daily practice (if they do) or what your problems really are (if they do not!)
- For many of these topics, some of you likely have equally effective approaches or better!

One Dozen Bites

- One: Personalizing Discovery Science
- Two: Hypothesis Testing
- Three: Studies & Papers as Evidence
- Four: Studies & Papers as Storytelling
- Five: Ever-Expanding Web of Science
- Six: Theory Building is Social
- Seven: Science and Uncertainty
- Eight: Experiments & Causality
- Nine: Observational Study & Correlation
- Ten: Models versus Experiments & Causality
- Eleven: Science & Human Values
- Twelve: Tying Science To Our Broad Society
- Baker's Dozen: Humanizing Scientists

One: Personalizing Discovery Science

- Discovery Science
  - Observation — sometimes structured, often casual or even accidental — leads to questions for which we have no ready answers
  - Observation drives each scientist's personal "To Do" list of hypotheses
    - Observations lead to questions
    - Questions lead to checks through the literature for answers
    - If we find no answers, we create our own hypotheses
  - We even sometimes publish novel observations!
- Illustrating this with stories about women, POC, and paradigm-shattering observation helps make other points!
  - Dr. Goodall hits 2 out of 3!

Jane Goodall from National Geographic

One: Personalizing Discovery Science

- We can also give examples that are recent and local:
  - Video sent to academic herpetologist Dr. David Steen (@AlongsideWild) from citizen scientist Dawn Kelly of St. Joe, AR https://www.youtube.com/watch?v=YHA81Tfk3og&t=3s
  - Or highlight our own discovery science (video clip to right)

Discovery Science in Your Classroom

- How does this fit into your classroom work & experience?
- Let's take a minute or two to discuss

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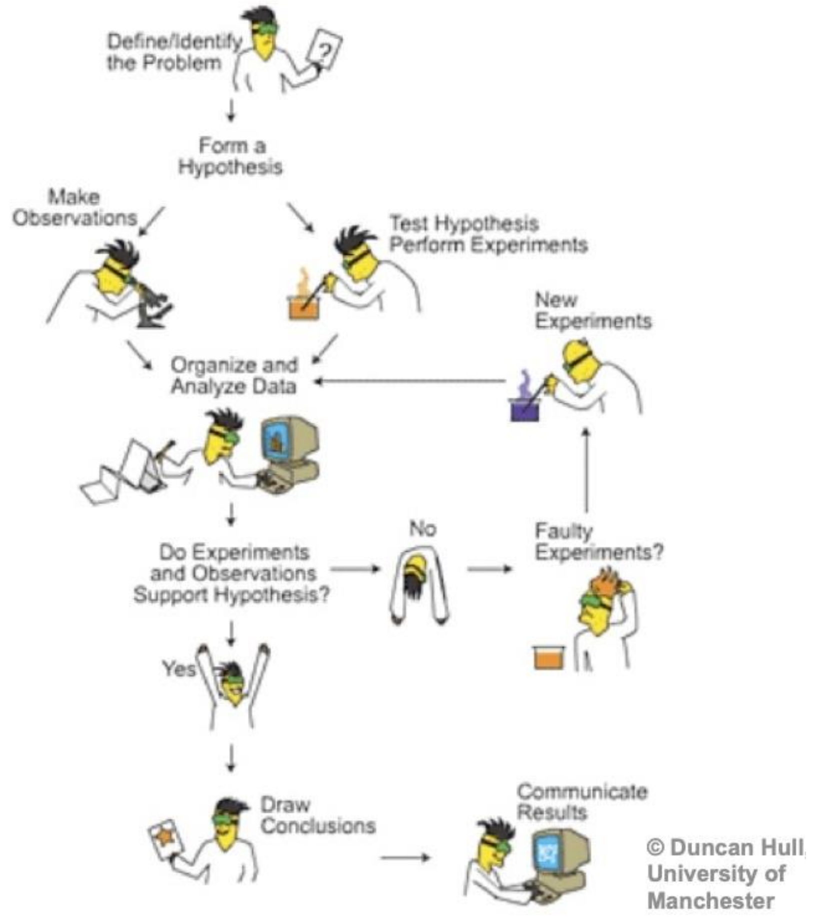
Two: Hypothesis Testing — Making Our Concept of Reality Explicit & Testable

- Define a problem in a way that you can falsify
- Collect data
- Determine if the data
  - Falsifies your hypothesis
    - Because your experiment was faulty?
    - Because your hypothesis was faulty?
  - Supports but can't confirm your hypothesis
- Can also mention that process of science has flaws — journals don't currently publish negative results, this biases our literature



Explaining Hypothesis Testing in Your Classroom

- What issues have you seen in your classroom work & experience?
- Let's take a minute or two to discuss

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Three: Studies & Papers as Evidence

- Even in gen ed classes, we can use title pages and key graphics from journal articles
- Explanation in a gen ed course will be much higher level than in an upper-division majors' course
- This is multipurpose
  - Encourage doubters to look it up for themselves — science is open — make PDF available!
  - Normalize idea that individual studies are basic unit of evidence
  - Demonstrate that basic story IS understandable

RESEARCH ARTICLE SUMMARY

SUSTAINABILITY

Planetary boundaries: Guiding human development on a changing planet

Will Steffen,* Katherine Richardson, Johan Rockström, Sarah E. Cornell, Ingo Fetzer, Elena M. Bennett, Reinette Biggs, Stephen R. Carpenter, Wim de Vries, Cynthia A. de Wit, Carl Folke, Dieter Gerten, Jens Heinke, Georgina M. Mace, Linn M. Persson, Veerabhadran Ramanathan, Belinda Reyers, Sverker Sörlin

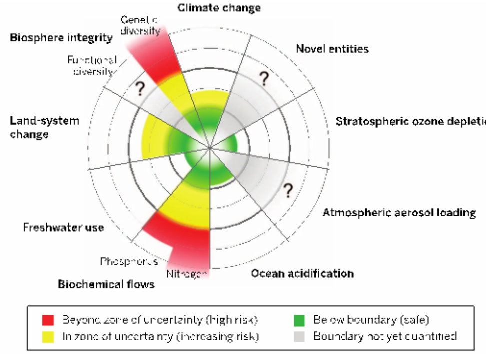
INTRODUCTION: There is an urgent need for a new paradigm that integrates the continued development of human societies and the maintenance of the Earth system (ES) in a resilient and accommodating state. The planetary boundary (PB) framework contributes to such a paradigm by providing a science-based analysis of the risk that human perturbations will destabilize the ES at the planetary scale. Here, the scientific underpinnings of the PB framework are updated and strengthened.

RATIONALE: The relatively stable, 11,700-year-long Holocene epoch is the only state of the ES that we know for certain can support contemporary human societies. There is increasing evidence that human activities are affecting ES functioning to a degree that threatens the resilience of the ES—its ability to persist in a Holocene-like state in the face of increasing human pressures and shocks. The PB framework is based on critical processes that regulate ES functioning. By combining improved scientific understanding of ES functioning with the precautionary principle, the PB framework identifies levels of anthropogenic perturbations below which the risk of destabilization of the ES is likely to remain low—a "safe operating space" for global societal development. A zone of uncertainty for each PB highlights the area of increasing risk. The current level of anthropogenic impact on the ES, and thus the risk to the stability of the ES, is assessed by comparison with the proposed PB (see the figure).

RESULTS: Three of the PBs (climate change, stratospheric ozone depletion, and ocean acidification) remain essentially unchanged from the earlier analysis. Regional-level boundaries as well as globally aggregated PBs have now been developed for biosphere integrity (earlier "biodiversity loss"), biogeochemical flows, land-system change, and freshwater use. At present, only one regional boundary (south Asian monsoon) can be established for atmospheric aerosol loading. Although we cannot identify a single PB for novel entities (here defined as new substances, new forms of existing substances, and modified life forms that have the potential for unwanted geophysical and/or biological effects), they are included in the PB framework, given their potential to change the state of the ES. Two of the PBs—climate change and biosphere integrity—are recognized as "core" PBs based on their fundamental importance for the ES. The climate system is a manifestation of the amount, distribution, and net balance of energy at Earth's surface; the biosphere regulates material and energy flows in the ES and increases its resilience to abrupt and gradual change. Anthropogenic perturbation levels of four of the ES processes/features (climate change, biosphere integrity, biogeochemical flows, and land-system change) exceed the proposed PB (see the figure).

CONCLUSIONS: PBs are scientifically based levels of human perturbation of the ES beyond which ES functioning may be substantially altered. Transgression of the PBs thus creates substantial risk of destabilizing the Holocene state of the ES in which modern societies have evolved. The PB framework does not dictate how societies should develop. These are political decisions that must include consideration of the human dimensions, including equity, not incorporated in the PB framework. Nevertheless, by identifying a safe operating space for humanity on Earth, the PB framework can make a valuable contribution to decision-makers in charting desirable courses for societal development. ■

ON OUR WEB SITE
Read the full article at http://dx.doi.org/10.1126/science.1259855



Current status of the control variables for seven of the planetary boundaries. The green zone is the safe operating space, the yellow represents the zone of uncertainty (increasing risk), and the red is a high-risk zone. The planetary boundary itself lies at the intersection of the green and yellow zones. The control variables have been normalized for the zone of uncertainty; the center of the figure therefore does not represent values of 0 for the control variables. The control variable shown for climate change is atmospheric CO_2 concentration. Processes for which global-level boundaries cannot yet be quantified are represented by gray wedges; these are atmospheric aerosol loading, novel entities, and the functional role of biosphere integrity.

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Cite this article as W. Steffen et al., Science 347, 1259855 (2015). DOI: 10.1126/science.1259855

Primary Sources Referenced in Your Lecture Content

- Does this fit with your classroom lectures? Are you already doing this?
- Let's take a minute or two to discuss

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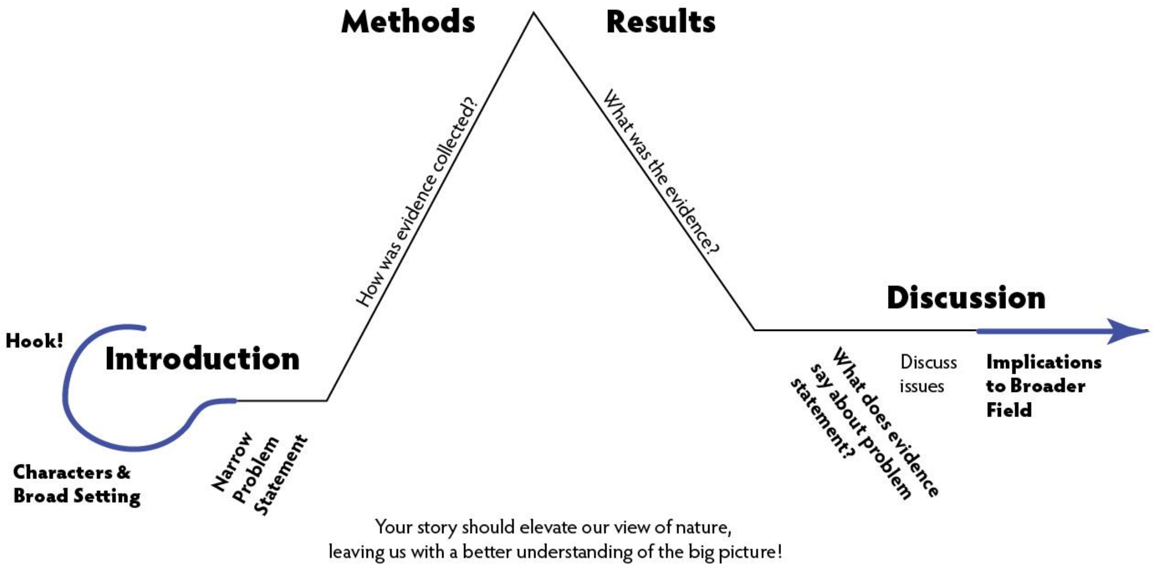
Four: Studies & Papers as Storytelling

- The best science papers tell a story by focusing on key characters (organisms, ecosystems, chemical reactants), their interactions, and important consequences of these interactions
- This is crucially important for our science students, but the gen ed audience benefits from this message, as well



Four: Studies & Papers as Storytelling

- Protagonist: Parrotfish & wrasses
- Antagonist: Gnathiid fish parasite
- Question explored: Do parrotfish mucous cocoons act like a mosquito net? That is, do these cocoons act as a parasite barrier?

Fish mucous cocoons: the 'mosquito nets' of the sea[1]

Alexandra S. Grutter, Jennifer G. Rumney, Tane Sinclair-Taylor, Peter Waldie and Craig E. Franklin

Abstract[2]

Mucus performs numerous protective functions in vertebrates, and in fishes may defend them against harmful organisms, although often the evidence is contradictory[3]. The function of the mucous cocoons that many parrotfishes and wrasses sleep in, while long used as a classical example of antipredator behaviour, remains unresolved. Ectoparasitic gnathiid isopods (Gnathiidae), which feed on the blood of fish, are removed by cleaner fish during the day; however, it is unclear how parrotfish and wrasse avoid gnathiid attacks at night[4]. To test the novel hypothesis that mucous cocoons protect against gnathiids, we exposed the coral reef parrotfish Chlorurus sordidus (Scaridae) with and without cocoons to gnathiids overnight and measured the energetic content of cocoons. Fish without mucous cocoons were attacked more by gnathiids than fish with cocoons[5]. The energetic content of mucous cocoons was estimated as 2.5 per cent of the fish's daily energy budget fish[6]. Therefore, mucous cocoons protected against attacks by gnathiids[7], acting like mosquito nets in humans, a function of cocoons and an efficient physiological adaptation for preventing parasite infestation that is not used by any other animal[8].

Science as Storytelling in Our Classrooms

- Does this fit with your classroom lectures? Is writing (and critical reading) ability an issue for your students? Might this help?
- Let's take a minute or two to discuss

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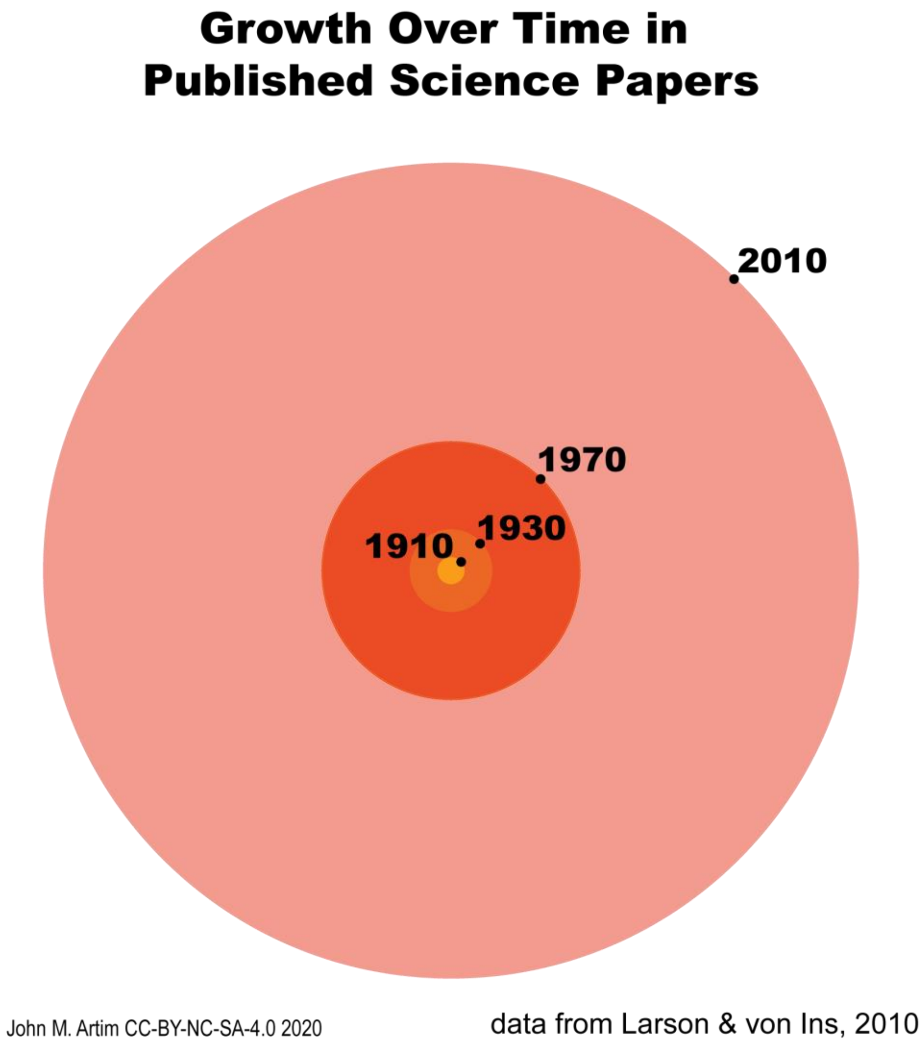
Five: Ever-Expanding Web of Science

- Science advances by refinement, not perfection
- Total number of science papers increased by factor of 10 every few decades for a century
    - In 1910 there were ~10,000 publications in science
    - By 2010 there were 10,000,000+ science publications
- Many of these publications refine what we already know
- Each scientist shares some of this knowledge sphere with all scientists, some with colleagues across a discipline, and even less with quirky few studying shared problems
    - Any one scientist has sampled a unique & small subset
    - A scientist might read few thousand abstracts in 10 years (<<0.1% of total), perhaps a few hundred of these in detail
    - Quirkiness plays outsized role in multidisciplinary areas like EVS



Expanding Sphere of Science in Our Classrooms

- How does this fit with your classroom content and lectures?
- Let's take a minute or two to discuss

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Six: Theory Building is Social

- Theories are the end-points of the process of science
  - We refine theories over time
  - But these theories represent our best explanations for our collective observations
- Biases by individual scientists or even by a generation of scientists will eventually be diluted by the vast expansion in work done
  - Even when there are grave errors in a theory, we eventually root them out
  - Plate tectonics was a "correct" but implausible theory until Einstein's $e=mc^2$
- **Moral of the story: objectivity of science is not found in individual studies, it is found in a process that weeds out subjective bias, error**

Social Aspect of Science & Theory in Our Classrooms

- How does this fit with your classroom content and lectures?
- Let's take a minute or two to discuss

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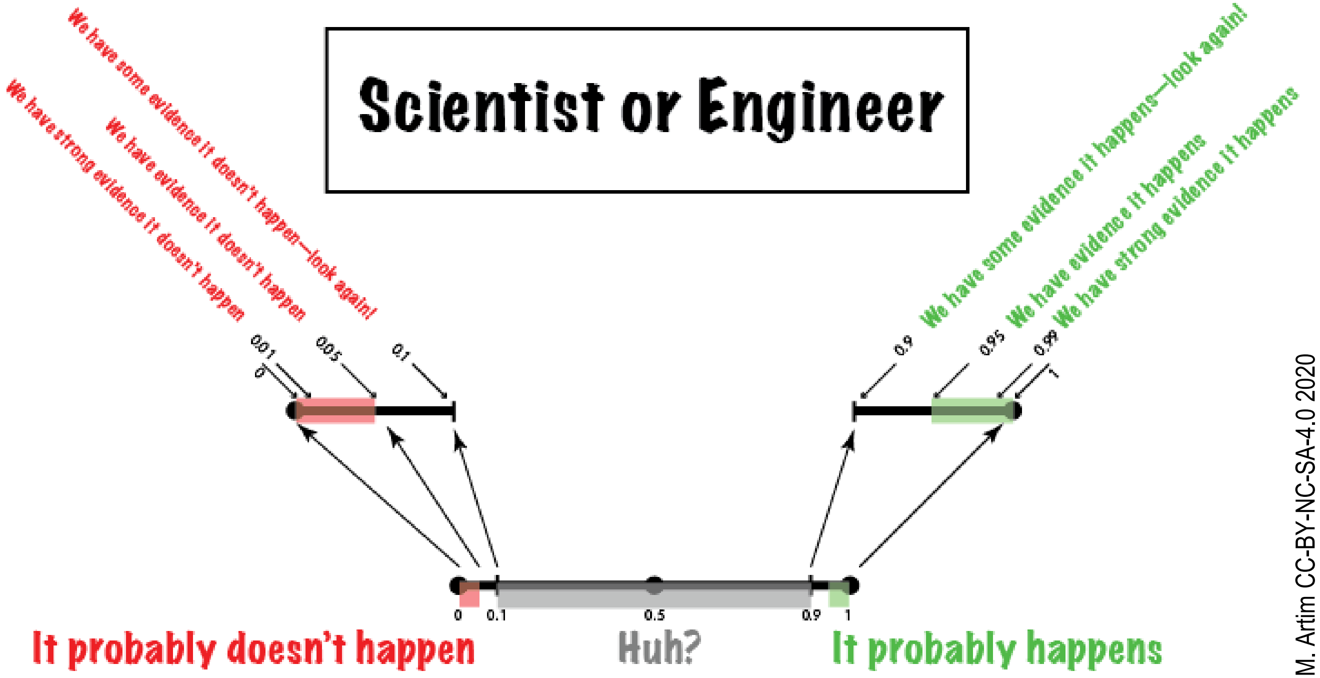
Seven: Science and Uncertainty

- Probability and statistics are deeply-woven into both science and engineering
- Take some time to explain how this works in practice
- And how this relates to the self-correcting nature of the process of science
    - Guaranteed ~1-in-20 studies will falsely generate a positive conclusion
    - Duplicating other labs' work is the only way to catch these "errors" that are not errors
- Climate modeling an excellent topic to illustrate this



Teaching Uncertainty in Our Classrooms

- How does this fit with your classroom content and lectures?
- Let's take a minute or two to discuss

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Eight: Experiments & Causality

- We (rightly!) exalt experimental studies as the backbone of science
  - When one factor occurs, another factor shifts in a predetermined way
- How do we convey this notion of causation?
  - Simple thought experiments? (see example on right)

- Example Hypothesis: Vitamin C makes studying more effective
  - Manipulation — pill with 1000mg of vitamin C (ascorbic acid)
  - Control — placebo pill
  - Procedure — give subjects a biology text chapter to read along with a pill; one hour later, give them a test
    - Some students get Vitamin C, others get a placebo
  - Measure — the test scores
  - Hypothesis — test $\text{score}_{\text{VitC}}$ > test $\text{score}_{\text{placebo}}$

Teaching Limits & Power of Experimental Studies in Our Classrooms

- How does this fit with your classroom content and lectures?
- Let's take a minute or two to discuss

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Nine: Observational Study & Correlation

- We hold up experimental studies as the gold standard of science, providing us evidence of causal relationships
- But observational studies look at the full complexity of unmanipulated systems
  - In fields like ecology, real gold standard is combination of observational studies, field experiments, & lab experiments
- Example
  - In the lab, we can put a tiny fish parasite in a glass dish with living coral and see that the parasite occasionally blunders into the coral and is eaten by the coral—photo to right
  - In the field, we can measure the negative correlation between amount of living coral in an area and the abundance of this fish parasite

Teaching Limits & Power of Correlational Studies in Our Classrooms

- How does this fit with your classroom content and lectures?
- Let's take a minute or two to discuss

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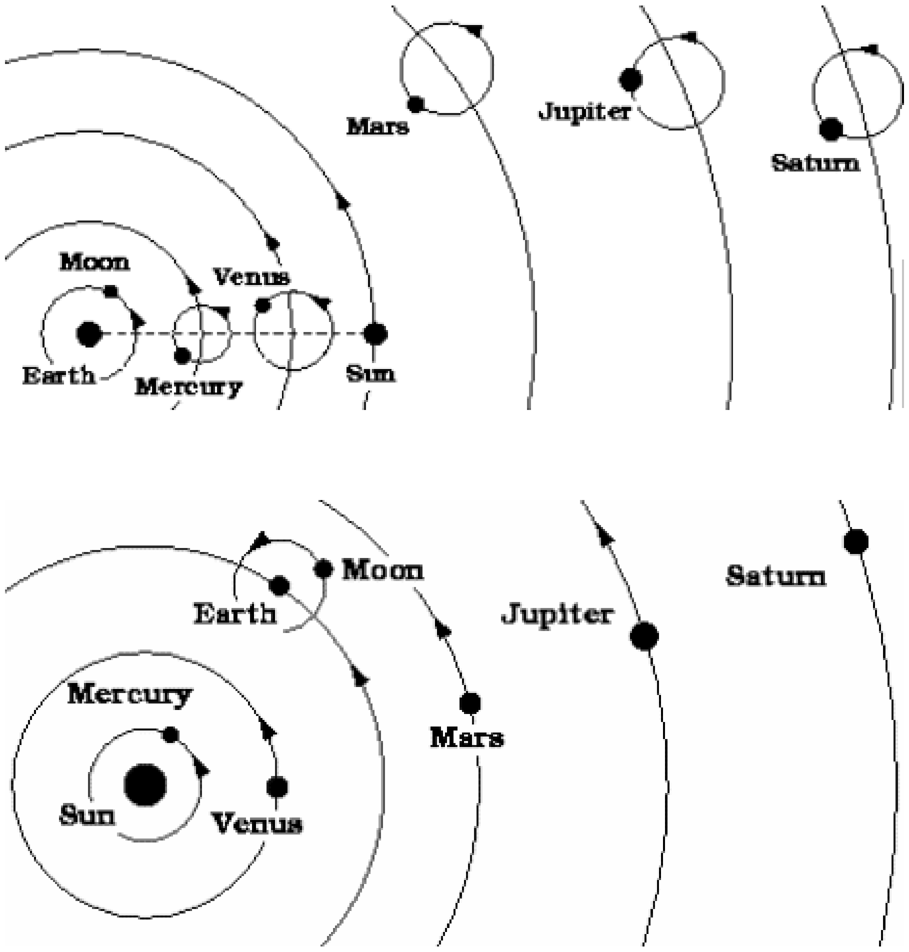
Ten: Models versus Experiments & Causality

- Experiments exploring causality are crucial, but computational models making quantitative predictions also important
- Example
  - Ptolemy's model of the solar system (right-top figure) predicts position of celestial objects using Earth-centered orbits & epicycles
  - Copernicus/Keppler modeled sun-centric orbits
  - Sun-centric orbits are computationally simple, fit well with basic physical concepts through the 21st century
  - But Earth-centric orbits can, in certain circumstances, simplify calculations
  - Apollo on-board guidance computer was tiny — Ptolemy's equations fit nicely to calculate celestial sightings!



Teaching Value of Models in Our Classrooms

- How does this fit with your classroom content and lectures?
- Let's take a minute or two to discuss

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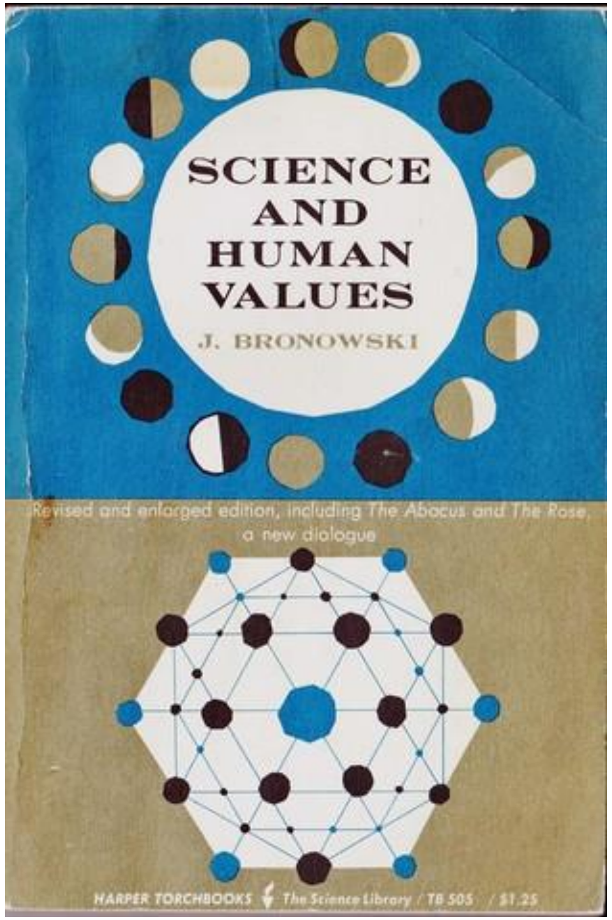
Eleven: Science & Human Values

- Science provides tools to explore, describe, and predict aspects of the objective world
- Human values — often embodied in organized religion — provides a framework for making ethical decisions



Eleven: Science & Human Values

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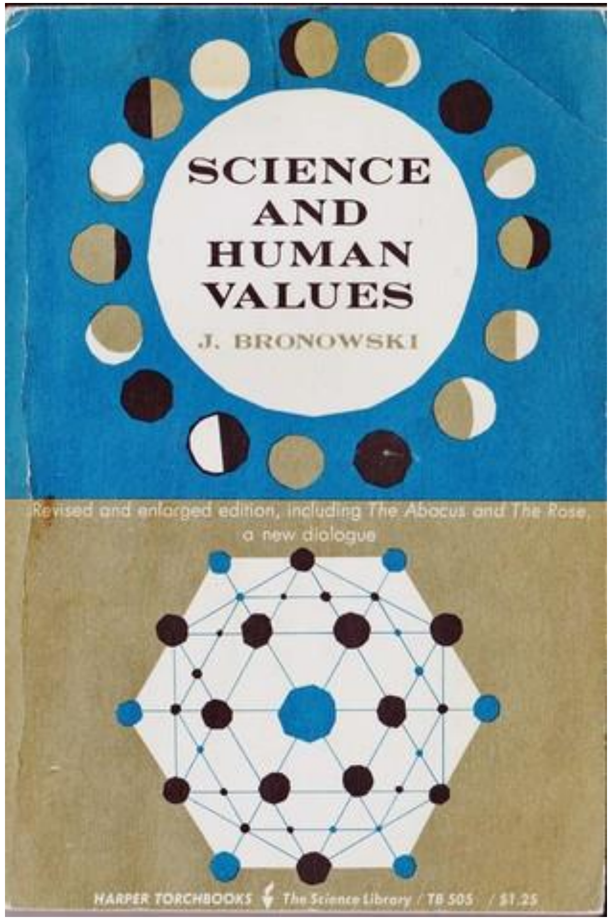
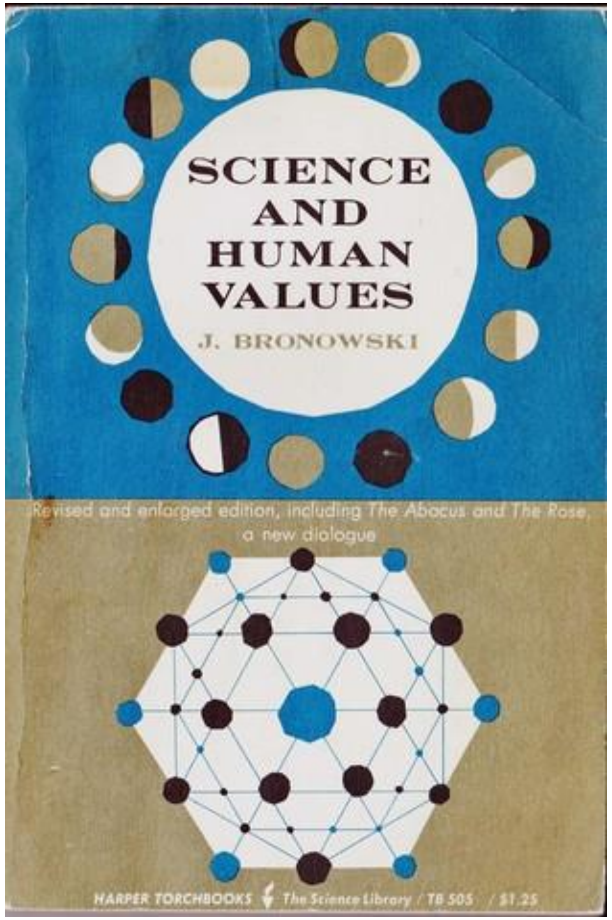
- **This is probably the single most important bite for all students to understand!**



Eleven: Science & Human Values

- Jacob Bronowski was a PhD in mathematics who, at close of WWII, was a military analyst and an observer at Hiroshima & Nagasaki, Japan
  - Seeing the devastation of these two Japanese cities led to his crisis in faith in science as an ethical enterprise
  - Nearly a decade later he published *Science and Human Values*, an extended essay that:
    - Argues that science can only address questions relating to that which can be measured (objective reality), but cannot inform us about what is ethically right
    - Whereas ethical philosophy & religions provide a set of rules or principles that guide human decisions & action which can address questions about why we should or shouldn't do something, but cannot inform us about how the universe works (predictions about objective reality)
    - This essay is quite readable — aside: Bronowski pursued both mathematics and literary analysis throughout his life (original essay available as PDF)



Teaching Relationship of Science & Ethics in Our Classrooms

- How does this fit with your classroom content and lectures?
- Are you constrained in addressing this topic?
- Let's take a minute or two to discuss

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Twelve: Tying Science To Our Broad Society

- Science describes — as best it can — the objective reality around us
  - Objective reality does not rely on human society
  - But human society exists in context of objective reality
- Science often seems to be practiced in isolation and purity
  - But human subjectivity is woven into and accounted for throughout science
  - Other aspects of society use different processes
- In our classrooms, we can illustrate this by highlighting:
  - How science & scientists interact with other disciplines to implement human goals

- Climate modelers can estimate how much global & regional temperatures will rise in coming decades
- Ecologists can estimate warming impacts on wild & engineered (cities, farms) ecosystems
- Engineers can design mitigation strategies for some impacts
- Economists can devise strategies to distribute costs of mitigations
- Sociologists study how people might react to warming & mitigations
- Anthropologists & historians report on comparable situations faced by past cultures & the outcomes
- International studies explores strategies for ensuring multinational cooperation & compliance

Twelve: Tying Science To Our Broad Society

- It can be especially important to highlight distinction between science and engineering
  - Scientists organize (causal) explanations for and predictions about objective (measurable) aspects of nature
  - Engineers take a human problem and create a technical solution for that problem based on real-world technical and resource constraints
- This can be especially confusing when talking about ecosystem restoration — biology research that may fluidly switch back and forth between these paradigms
  - Academic scientists and engineers often unclear about this distinction and its importance. See Ross, M. R., Bernhardt, E. S., Doyle, M. W., & Heffernan, J. B. (2015). Designer ecosystems: Incorporating design approaches into applied ecology. *Annual review of environment and resources*, 40, 419-443.

Twelve: Tying Science To Our Broad Society

- The relevance of this "bite" varies by class
  - Rarely brought up in *BIOL 1003: Biology*
  - But comes up daily in *BIOL 1063: People and the Environment*
- *People and the Environment* is really a gen ed Environmental Sciences course, not just a gen ed Biology course
  - **Environmental Sciences is multidisciplinary in nature**
    - Intradisciplinary — working within the practices of one discipline only
    - Interdisciplinary — workers in many disciplines working together to achieve a goal by each working within the practices of their own discipline only
    - **Multidisciplinary — workers in many disciplines drawing on the practices of their respective disciplines to create an integrated approach to work that goes beyond any one discipline**

Teaching Science & Society in Our Classrooms

- How does this fit with your classroom content and lectures?
- Let's take a minute or two to discuss

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Baker's Dozen: Humanizing Scientists & Using Our Own Stories

- For gen ed classes, conveying that scientists are people as diverse as any other profession is crucial
  - Our biases are reduced when we are a more diverse community
  - Women and people of color still report being discouraged from studying math & science because — often for such absurd reasons as, "your brain simply isn't wired for this"
  - The only way to overcome this is to bring some of this diversity into the classroom and put it front-and-center
  - And even old white males sometimes fail to match scientist stereotypes!

Photos of ASU Undergraduates Involved In Research

- Ask any A-State faculty for their personal photos
- Or find our faculty on social media — for example
  - Brook Fluker @BLFluker
  - Lori Neuman-Lee @CheloniaGirl

#ActualLivingScientist Tweets

#ActualLivingScientist, Me
(photo from one of my Twitter posts)

Historical Examples

- Dr. Rosalind Franklin, Research Chemist robbed of proper credit for discovery of geometry of DNA molecules
- Watson & Crick have been accused of colluding with Dr. Franklin's adviser to steal her x-ray crystallography data — the basis for determining the shape and therefore the functional properties of DNA
- Similar examples abound in other fields — Lise Meitner in physics & chemistry comes to mind

Jewish Chronicle Archive/Heritage-Images

Humanizing Scientists in Our Classrooms

- How does this fit with your classroom content and lectures?
- Let's take a minute or two to discuss

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We Are Really Talking About & Teaching at Intersection of Philosophy & Science

- What are the philosophical underpinnings of how we, as individual scientists, do our (science) work?
- How does my ethical philosophy affect my science work?
- What must I leave out of my science in order to maintain objectivity?
- What I am obligated to keep in my science in order to flag possible consequences for my larger society?

Philosophy of Science in Our Classrooms

- What do you think?
- Let's take a minute or two to discuss

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Assessment

- How do we assess "mastery" of decision making for a gen ed class?
- The bar for mastery is not the same for gen ed classes as for our classes for the major
  - A student in a major must be able to think critically about their subject matter in order to make professional decisions
  - Our gen ed students must be able to think critically to incorporate a basic knowledge of science into their decisions as a citizen

Assessment in Our Gen-Ed Classrooms

- This could be construed as provocative. What do you think?
- Let's take a minute or two to discuss

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Any Closing Thoughts, Questions, or Issues?

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Interested in Any Graphics or Sources Used?

- If you are interested in any of the graphics or sources used today, please contact John Artim (jartim@astate.edu)
- John will put these slides, the National Academy of Sciences 1998 report on teaching evolution and the process of science, and the PDF of the Bronowski *Science and Human Values* essay in Dropbox folder
  - John will also add any other materials or graphics you request into this same folder for sharing
  - The folder is here: https://www.dropbox.com/sh/m0pzvm154f6pbtv/AABQ_60Nv-dIi8500EEIWDo6a?dl=0

Thank you so much!

We are a community of practice. Thank you for being a part of our community!