Beyond-the-Book Thinking in Modern (STEM) Education

Alyssa A. Goodman
“The more I learn, the less I know.”
To paraphrase Louis Pasteur, sometimes luck favors the prepared mind, as when Alexander Fleming discovered penicillin by noticing that mold growing accidentally in his lab seemed to kill bacteria. At other times, new instruments offer unanticipated revelations: Galileo trained his telescope on Jupiter and found it to have moons. And, occasionally, methodical experiments find exactly the opposite of what they sought to prove. Scientists intending to measure the deceleration of the Universe’s expansion, for example, found acceleration instead.

The Undiscovered— the 2018 Radcliffe Institute science symposium—will focus on how scientists explore realities they cannot anticipate. Speakers from across the disciplines of modern science will present personal experiences and discuss how to train scientists, educators, and funders to foster the expertise and open-mindedness needed to reveal undiscovered aspects of the world around us. Many great discoveries in science are surprises.
Barnstable High-School Senior Ceili Magnus at “The Undiscovered”
Radcliffe Institute for Advanced Study, October 26, 2018
https://youtu.be/BUifWQ0U7IsU?t=834
Orion, Viennese Style
a WorldWide Telescope Tour to accompany the physical 3D model of Orion created collaboratively by expert astrophysicists at ‘Orion (Un)Plugged’ held at the University of Vienna, July 2015

with original medieval harp musical ‘interConnective’ tribute to Orions by Scott Wallace.
VISION – Vienna survey on Orion

I. VISTA Orion A Survey

Stefan Meingast\textsuperscript{1}, João Alves\textsuperscript{2}, Diego Mardones\textsuperscript{2}, Paula Stella Teixeira\textsuperscript{1}, Marco Lombardi\textsuperscript{3}, Josefa Großschedl\textsuperscript{1}, Joana Ascenso\textsuperscript{4,5}, Herve Bouy\textsuperscript{6}, Jan Forbrich\textsuperscript{7}, Alyssa Goodman\textsuperscript{7}, Alvaro Hacar\textsuperscript{1}, Birgit Hasenberger\textsuperscript{1}, Jouni Kainulainen\textsuperscript{8}, Karolina Kubik\textsuperscript{1}, Charles Lada\textsuperscript{2}, Elizabeth Lada\textsuperscript{9}, André Moitinho\textsuperscript{10}, Monika Petr-Gotzens\textsuperscript{11}, Lara Rodrigues\textsuperscript{2}, and Carlos G. Román-Zúñiga\textsuperscript{12}

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Received 10 August 2015 / Accepted 1 December 2015

ABSTRACT

Orion A hosts the nearest massive star factory, thus offering a unique opportunity to resolve the processes connected with the formation of both low- and high-mass stars. Here we present the most detailed and sensitive near-infrared (NIR) observations of the entire molecular cloud to date.

With the unique combination of high image quality, survey coverage, and sensitivity, our NIR survey of Orion A aims at establishing a solid empirical foundation for further studies of this important cloud. In this first paper we present the observations, data reduction, and source catalog generation. To demonstrate the data quality, we present a first application of our catalog to estimate the number of stars currently forming inside Orion A and to verify the existence of a more evolved young foreground population.

Methods. We used the European Southern Observatory’s (ESO) Visible and Infrared Survey Telescope for Astronomy (VISTA) to survey the entire Orion A molecular cloud in the NIR $J$, $H$, and $K_s$ bands, covering a total of $\sim 18.3$ deg$^2$. We implemented all data reduction recipes independently of the ESO pipeline. Estimates of the young populations toward Orion A are derived via the $K_s$-band luminosity function.

Results. Our catalog (799,995 sources) increases the source counts compared to the Two Micron All Sky Survey by about an order of magnitude. The 90\% completeness limits are 20.4, 19.9, and 19.0 mag in $J$, $H$, and $K_s$, respectively. The reduced images have 20\% better resolution on average compared to pipeline products. We find between 2300 and 3000 embedded objects in Orion A and confirm that there is an extended foreground population above the Galactic field, in agreement with previous work.
The Undiscovered, yesterday
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Many great discoveries in science are surprises.

Friday, October 26, 2018
9:30 AM
Knafel Center

www.radcliffe.harvard.edu
This event is free and open to the public.

SPEAKERS AND DISCUSSANTS
David Charbonneau
Immaculata DeVivo
Joel Dudley
Alyssa Goodman
Stuart Firestein
Debra Fischer
Robinson W. Fulweiler
Lisa Kaltenegger
Daniel M. Kammen
Jill Tarter
Conevery Bolton Valencius

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(Paths to) today.
"Take A Sweater"

takeasweater.com, and “TakeASweater” in the Apple App Store

with thanks to Eric Floehr of Forecast Watch and Bill Barthelmy of HUIT Academic Technology at FAS
To paraphrase Louis Pasteur, sometimes luck favors the prepared mind, as when Alexander Fleming discovered penicillin by noticing that mold growing accidentally in his lab seemed to kill bacteria. At other times, new instruments offer unanticipated revelations: Galileo trained his telescope on Jupiter and found it to have moons. And, occasionally, methodical experiments find exactly the opposite of what they sought to prove. Scientists intending to measure the deceleration of the Universe’s expansion, for example, found acceleration instead.

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(Paths to) today.
ISM and Star Formation

Our Jointly-Edited Online "Book"

This "book" accompanies the Harvard University graduate course Astronomy 201b, "The Interstellar Medium and Star Formation." The first incarnation was created in 2011 by Prof. Alyssa Goodman, Teaching Fellow Chris Beaumont, and the 21 Harvard graduate students who took the course at that time. The "book" will continue to evolve throughout Spring 2013 as student contributions from this new instance of the course are added.

Links at the top of each section (in orange) are slides and notes from this year (2013), sorted by date. They will be posted within one day of the class date. Links in red are transcriptions of Alyssa Goodman’s notes, originally from 2011 and updated throughout the semester as we discuss each topic. Links in green are student contributions from 2011. Links in blue are transcriptions from guest lecturers. Links in violet are the class handouts and weblinks which can (hopefully!) be posted here without copyright violation.

Student contributions from 2011 are shown in dark green. Online modules developed by the AY201b students at Harvard in 2013 are listed here.

Topical Modules

Harvard Astronomy 201b: Interactive Software Modules Created by Students

Click here to see modules created by students in the Spring 2013 term.

For a full description of the module creation process, motivations, and outcomes, see our article arXiv:1308.1908.
Stephen

Yuan-Sen Ting

Interstellar Absorption and the Lyman Alpha Forest

JavaScript

https://www.cfa.harvard.edu/~yuan-sen.ting/lyman_alpha.html

JavaScript

http://portillo.ca/nebula/

see: A New Approach to Developing Interactive Software Modules through Graduate Education, Sanders, Faesi & Goodman 2013
“Do kids read?”

“Textbooks are stupid—Wikipedia is way better!”
(Caveats: may be different in different subjects—science textbooks may be useful; novels, history books, etc. still awesome.)

“People my age are digesting way more information, e.g. many YouTube videos way more intelligent & philosophically complex than television news.”

What about evaluation?

“More effort & time required.”
“Un-assessed work, like blog posts, are fine.”
“Factory system doesn’t prepare you for the real world.”
“Why expect everyone to learn exactly the same thing?”

Thanks to Joan Najita, Sharmila Dey & Abby Schwartz for insights here.
Sample ThinkSpace results...
Pre (*green*) vs. Post (*blue*) Content Scores for Moon Phases and Seasons, compared with National Averages of delayed post- “business as usual” instruction (N>500) from Sadler et al., 2010 (*gray*).
To paraphrase Louis Pasteur, sometimes luck favors the prepared mind, as when Alexander Fleming discovered penicillin by noticing that mold growing accidentally in his lab seemed to kill bacteria. At other times, new instruments offer unanticipated revelations: Galileo trained his telescope on Jupiter and found it to have moons. And, occasionally, methodical experiments find exactly the opposite of what they sought to prove. Scientists intending to measure the deceleration of the Universe’s expansion, for example, found acceleration instead.

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Many great discoveries in science are surprises (Paths to) today.
with many thanks to HarvardX course producer Drew Lichtenstein,
research assistant Jais Brohinsky + dozens of other experts at Harvard and beyond
Framework for Predictive Systems

Observe

#HUMAN
#RANDOMIZED
#RANDOM
#NON-RANDOM

PREDICTIVE SYSTEM

MAKE PREDICTION!

EVALUATE ACCURACY

MAKE CHANGES

https://openclipart.org/
Astrology

Egyptian “Bobble Head”

Ifa

Comets of Doom
Ancient Egyptian Divination, featuring Prof. Peter der Manuelian (Harvard Semitic Museum)
Framework for Predictive Systems

Observe

PREDICTIVE SYSTEM

MAKE PREDICTION!

EVALUATE ACCURACY

MAKE CHANGES

#RANDOMIZED

#HUMAN

#NON-RANDOM

#RANDOM
*or, Experiment*
The Path to Newton

Alyssa Goodman
Jais Brohinsky
Drew Lichtenstein
& Katie Peek
on behalf of Harvard University

tinyurl.com/aas-path-to-newton
The Path online interacts with a narrative

doctor

In 1687, Isaac Newton published his *Principia Mathematica* and inaugurated a revolution in physics that would reign supreme until the introduction of Einstein’s relativity in the early 20th century. Even though relativity shook some of the foundations of Newtonian gravity, its modifications are negligible in nearly all Earth-bound situations. To this day, in classrooms all around the world, Newton’s principles and physics continue to be taught and undergird fundamental assumptions about how the universe works.

At the heart of Newton’s work was a rigorous definition and mathematical description of force. Up until this point, force was theorized qualitatively and used as a noun to describe something being acted upon by something else; however, with Newton, force became an entity unto itself. Since the days of

doctor

screencast courtesy of PredictionX course producer Drew Lichtenstein
PredictionX: the past & present of the future

Tools
- Framework for Predictive Systems
- Framework for Study Design
- Understanding Uncertainty
  - Timelines
  - Why predict?

Omens, Oracles & Prophecies
- Mesopotamian Haruspicy
- Roman Augury
- Chinese Oracle Bones
- Oracle of Delphi
- Aztec Rituals
- Egyptian Priests
- Tarot

The Diviner’s Guide
- Yoruba Ifa
- Casting Lots
- Greek Astronomy
- Astrology
- Comets of Doom
- Mayan Spacetime
- Tasseography

The Rise of Theory
- The Royal Society
- Islamic Science
- The Path to Newton
- Indian Mathematics
- Tools of the Navigator
- Help, I’m Lost!

Modern Simulation
- John Snow & Cholera
- Cholera Map
- Earthquakes
- Climate Change
- Earth
- Health
- Epidemiology
- Personal Genomics
- Wealth
- Personal Finance
- World Economy
- Space
- Futures of our Universe
- The Future of the Future
- Artificial Intelligence

Finished  Coming Soon  Planned  🎥 Interactive Resource  ➤ video(s)  edx link to edX (often contains videos + interactives, not marked separately here)
“Lost without Longitude”

Help, I’m lost!

- Take out iPhone
- iPhone has power, signal & GPS?
  - Yes
    - Measured longitude
    - Measured latitude
  - No
    - Find latitude
      - Find location (N or S of equator) using the Sun or stars.
      - Clear skies?
        - Yes
          - Use the Sun to find local (solar) time at your location.
        - No
          - Daytime?
            - Yes
              - Use Jupiter’s moons’ positions as a clock.
            - No
              - Full moon?
                - Yes
                  - Use Jupiter’s moons’ positions as a clock.
                - No
                  - No moon?
                    - Yes
                      - Use the Sun to find local (solar) time at your location.
                    - No
                      - Look for stars.

- Find longitude
  - For latitudes between 22° and 67° using the Earth’s 24-hour rotation as a clock.

- Have a super-accurate timepiece?
  - Yes
    - Use the time at a remote, reference location.
  - No
    - Do you know the exact location where it was set?
      - Yes
        - Use Jupiter’s moons’ positions as a clock.
      - No
        - Look for stars.

- Clear skies?
  - Yes
    - Use the Sun to find local (solar) time at your location.
  - No
    - WAIT

- Use the stars. Your latitude is equal to the elevation of the celestial pole above the horizon. At present, Polaris marks the North Celestial Pole. There is no bright star at the South Celestial Pole now, so more astronomical expertise will be required if you can’t see Polaris.

- Use Jupiter’s moons’ positions as a clock.

- Use the Sun. Longitude is the difference between the Sun’s declination and its maximum elevation.

- Add/subtract to find offset in time from zero-longitude (today, Greenwich).

- Use the difference between local (solar) time and the time at zero longitude (Greenwich) is your longitude.

- The difference between local (solar) time and the time at zero longitude (Greenwich) is your longitude.
“Lost without Longitude”

Help, I’m lost!

Take out iPhone → iPhone has power, signal & GPS?

Yes → measured longitude

No → measured latitude

Phew—now I’m found!

Find latitude (N or S of equator) using the Sun or stars.

Find longitude (E or W of Greenwich) using the Earth’s 24-hour rotation as a clock.

Clear skies?

Yes → Daytime?

Yes → Use the Sun to find local (solar) time at your location

No → celestial horizon.

Use the Sun’s center to mark the North celestial pole.

There is no nautical astrolabe required if you have an iPhone.
PredictionX: the past & present of the future

Tools
- Framework for Predictive Systems
- Framework for Study Design
- Understanding Uncertainty

Omens, Oracles & Prophecies
- Egyptian Priests
- Tarot
- Yoruba Ifa
- Casting Lots
- Greek Astronomy
- The Diviner's Guide
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- Roman Augury
- Chinese Oracle Bones
- Oracle of Delphi
- Aztec Rituals
- Turkish Tasseography
- Comets of Doom
- Maya Spacetime

The Rise of Theory
- The Royal Society
- Islamic Science
- Lost without Longitude (Navigation)
- John Snow & Cholera
- Cholera Map
- The Path to Newton
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- Help, I'm Lost

Modern Simulation
- Epidemiology
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- Earthquakes
- Climate Change
- Earth
- Futures of our Universe

Health
- Personal Finance
- World Economy

Wealth
- Space

The Future of the Future
- Artificial Intelligence
- Derek's Day

Finished  Coming Soon  Planned  Interactive Resource  video(s)  edX link to edX (often contains videos + interactives, not marked separately here)
Temperatures before and after Hansen's Senate testimony

Temperature anomaly (°F), 1901-2000 baseline

1959–1988

1988–2017

Data: NASA's Goddard Institute for Space Studies; Graphic: Harry Stevens/Axios

https://www.axios.com/how-much-earth-has-warmed-since-hansen-testified-b6f8f6b4-484e-477f-b8b6-6ee320994dc0.html
Title

Click on the cells to start playing! If at any point you get bored, we can do the rest for you!

Once you have finished, you can explore different realizations by moving the slider below.
How technologies can combined at Harvard now (from Freshman Seminar 27J)

Resources for Harvard FS27J

- Live syllabus, student collaborations
- Google docs
- Readings in books

- PREDICTIONX
  - The big picture
  - Allows student contributions
- OpenScholar
  - Topical modules
  - Pieces of modules
  - Digital Assets for Reuse in Teaching
- Canvas
  - Assignments
  - Announcements
  - Calendar
  - etc.
- edX
- Harvard DART

https://canvas.harvard.edu/courses/43639
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(Paths to) today.
Coming to Harvard GenEd in 2020 (ask Jais!)
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(Paths to) today.
Which apple did you like the best?

- Granny Smith Apples
  1. Jaiden
  2. Victoria
  3. Nahira
  4. Arely
  5. Anahi
  6. Julian
  7. Jose
  8. Giovanni
  9. Eliazar

- Golden Apples
  1. Jimena
  2. Paige
  3. Alan

- Red Delicious Apples
  1. Gurkirat
  2. Alex
  3. Steve
  4. Isabela
  5. Andrea
  6. Neha
  7. Kristian
  8. Ms. Alma
  9. Ms. Maria
My favorite kind of apple is...

The most: green
The least: yellow

Karandeep, Caser, Mar slut, Alex, Ruby
Our Favorite Apples

Directions: Make a graph by dragging the apples:

10
9
8
7
6
5
4
3
2
1

Read the bar graph and answer the questions.

Kid’s Favourite Fruits

- Apples ____?
- Oranges ____?
- Bananas ____?
- Pears ____?
Temperatures before and after Hansen's Senate testimony

Temperature anomaly (°F), 1901-2000 baseline

1959–1988

1988–2017

Spin me

Data: NASA's Goddard Institute for Space Studies; Graphic: Harry Stevens/Axios

https://www.axios.com/how-much-earth-has-warmed-since-hansen-testified-b6f8f6b4-4f8e-477f-b8b6-6ee320994dc0.html
The 10 Questions

1. **Who** | Who is your audience? How expert will they be about the subject and/or display conventions?
2. **Explore-Explain** | Is your goal to explore, document, or explain your data or ideas, or a combination of these?
3. **Categories** | Do you want to show or explore pre-existing, known, human-interpretable, categories?
4. **Patterns** | Do you want to identify new, previously unknown or undefined patterns?
5. **Predictions & Uncertainty** | Are you making a comparison between data and/or predictions? Is representing uncertainty a concern?
6. **Dimensions** | What is the intrinsic number of dimensions (not necessarily spatial) in your data, and how many do you want to show at once?
7. **Abstraction & Accuracy** | Do you need to show all the data, or is summary or abstraction OK?
8. **Context & Scale** | Can you, and do you want to, put the data into a standard frame of reference, coordinate system, or show scale(s)?
9. **Metadata** | Do you need to display or link to non-quantitative metadata? (including captions, labels, etc.)
10. **Display Modes** | What display modes might be used in experiencing your display?

---

The 10 Questions for creating effective visualizations.

Our Favorite Apples

Directions: Make a graph by dragging the apples.
TEN QUESTIONS TO ASK WHEN CREATING A VISUALIZATION

The 10 Questions

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Now, visit the 10QViz conversation! There’s so much more to talk about.

Curious about the **origins** of 10QViz? Try the **About** page.
Want to learn **how best to use** and **participate** in 10QViz? Try the **How to** page.
Want to read about the **scholarship** behind 10QViz.org’s questions? **Write** to ask for a draft of our research paper, Coltekin & Goodman 2019.
Beyond-the-Book Thinking in Modern (STEM) Education

Alyssa A. Goodman
ThinkSpace Labs: Teaching Seasons and Moon Phases with WorldWide Telescope

Patricia Udomprasert, Harry Houghton, Susan Sunbury, Erin Johnson, Erika Wright, Alyssa Goodman, Philip Sadler
Harvard-Smithsonian Center for Astrophysics

Julia Plummer, Abha Vaishampayan, Kyungjin Cho
Pennsylvania State University

Helen Zhihui Zhang
Boston College

This work has been funded by NSF awards DRL-1503395 & 1502798
Project OVERVIEW

ThinkSpace labs teach astronomy while supporting spatial thinking skills, like imagining a scene from multiple viewpoints.
7:12 AM
Sunrise: 7:14am
EAST
DECEMBER 21 in BOSTON
PATH OF THE SUN
Distractor-driven multiple choice (DDMC) questions from the Astronomy and Space Science Concept Inventory (Sadler et al, 2009): 10 questions about Seasons on pre/post assessments.

8. The main reason for it being hotter in summer than in winter is:
   a. the Earth’s distance from the Sun changes.
   b. the Sun is higher in the sky.
   c. the distance between the northern hemisphere and the Sun changes.
   d. ocean currents carry warm water north.
   e. the Sun produces heat and light at a faster rate in the summer.

   ✔

   Post
   “typical”
   Instruction
   (Sadler et al)

   Post
   ThinkSpace
   Instruction

   8%
   9%  55%
   33%
Distractor-driven multiple choice (DDMC) questions from the Astronomy and Space Science Concept Inventory (Sadler et al, 2009): 9 questions about Moon Phases & Eclipses on pre/post assessments.

2. One night you looked at the Moon and saw this:

![Moon Image]

A few days later you looked again and saw this:

![Moon Image]

Why did the Moon change shape?

A. Clouds covered a different amount of the Moon.
B. The Moon moved out of the Earth’s shadow.
C. The Moon moved out of the Sun’s shadow.
D. The Moon is black and white and rotates on its axis once a month.
E. We see a different amount of the lit up side of the Moon.

Post “typical” Instruction (Sadler et al)

- 20%
- 13%
- 33%

Post ThinkSpace Instruction

- 65%
Student Gains: Moon Phases & Seasons Questions

Cohen’s d
Effect Size = \frac{\text{Average}(\text{Posttest Score} - \text{Pretest Score})}{\text{stdev}(\text{Pretest Score})}

WWT Moon Phases: Cohen’s d=1.2\pm0.2; N=330
WWT Seasons: Cohen’s d=1.5\pm0.2; N=290

Cohen’s d \sim 0.2 \quad \text{small effect}
Cohen’s d \sim 0.5 \quad \text{medium effect}
Cohen’s d >0.7 \quad \text{large effect}
Download ThinkSpace Curriculum: 
wwtambassadors.org

Use WWT: 
worldwidetelescope.org

Questions?
email: pudompra@cfa.harvard.edu
Also use Jais’ spreadsheet