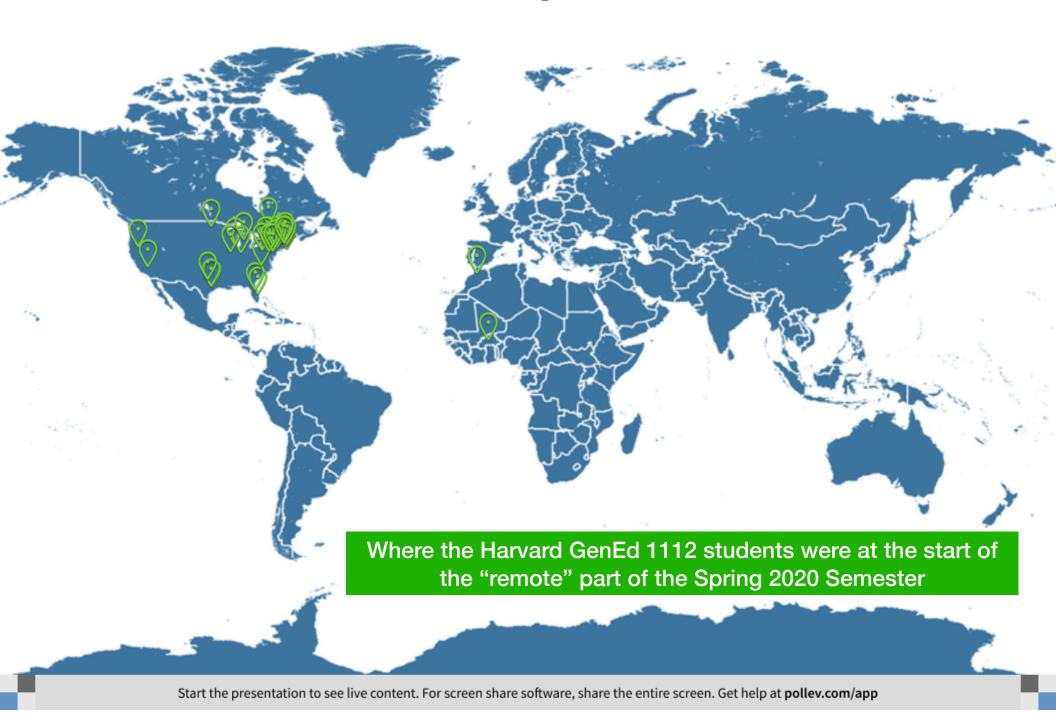If you would like to participate in live polls today... open the camera app on your phone, scan the QR code, or type PollEV.com/prediction, to get ready.

Where are you now?

Where the Harvard GenEd 1112 students were at the start of the "remote" part of the Spring 2020 Semester

Where are you joining from today?
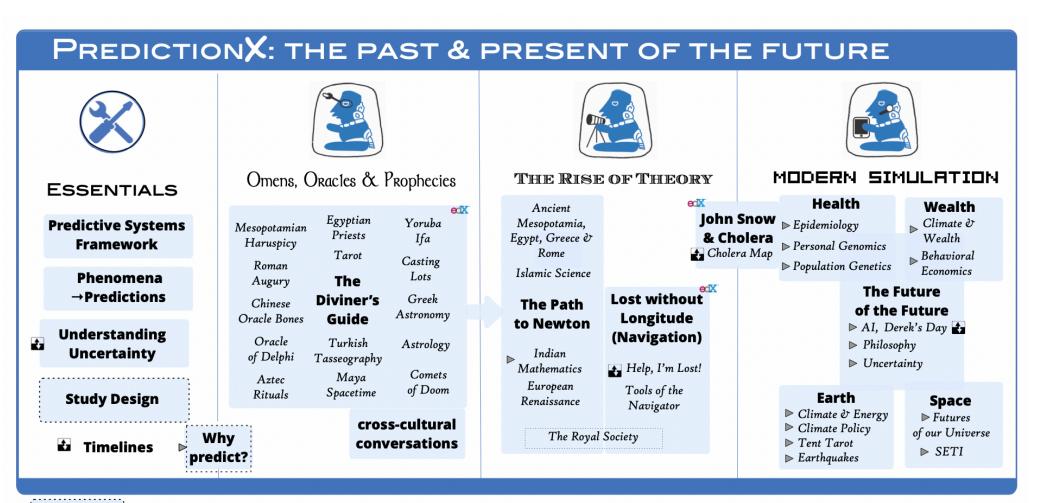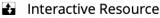
Prediction versus Prophecy

Alyssa A. Goodman

Robert Wheeler Willson Professor of Applied Astronomy • co-Director for Science, Radcliffe Insitute for Advanced Study
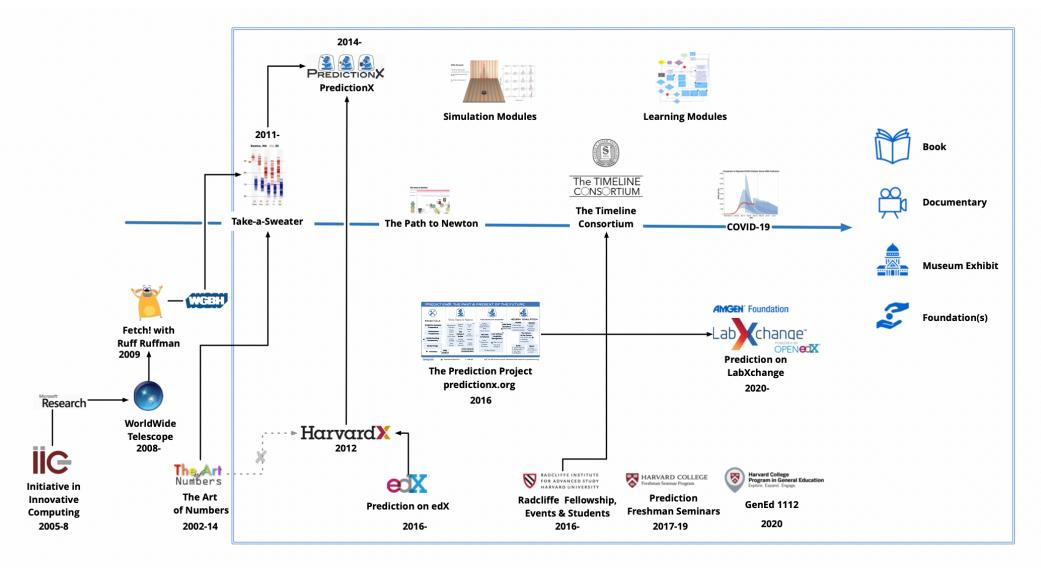
@AlyssaAGoodman

The Prediction Project

PredictionX: the past & present of the future

Essentials

Predictive Systems Framework

Phenomena →Predictions

Understanding Uncertainty

Study Design

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

Turkish Tasseography

Maya Spaceology

Yoruba Ifa

Casting Lots

Greek Astronomy

Astrology

Comets of Doom

cross-cultural conversations

The Rise of Theory

Ancient Mesopotamia, Egypt, Greece & Rome

Islamic Science

The Path to Newton

▷ Indian Mathematics European Renaissance

John Snow & Cholera

Cholera Map

Lost without Longitude (Navigation)

Help, I'm Lost!

Tools of the Navigator

The Royal Society

Modern Simulation

Health
▷ Epidemiology
▷ Personal Genomics
▷ Population Genetics

Wealth
▷ Climate & Wealth
▷ Behavioral Economics

The Future of the Future
▷ AI, Derek's Day
▷ Philosophy
▷ Uncertainty

Earth
▷ Climate & Energy
▷ Climate Policy
▷ Tent Tarot
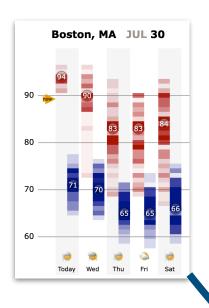▷ Earthquakes

Space
▷ Futures of our Universe
▷ SETI

What's the Prediction Project & where did it come from?

…includes >30 Harvard Faculty interviews; created in collaboration with dedicated staff at HarvardX, Bok Center, GenEd, Freshman Seminar, Radcliffe, Aeon Timeline, and participants from ~20 academic and cultural institutions

Take-a-Sweater

Boston, MA **JUL 30**

PredictionX

predictionx.org

IHME COVID-19

Comparison of Reported COVID19 Deaths Versus IHME Predictions

The Path to Newton

| Phenomenon | Observation* | Data | Rule | Theory | Explanation | Prediction |

takeasweater.com

path-to.org

gluesolutions.io/social-impact

The Prediction Project

PREDICTIONX: THE PAST & PRESENT OF THE FUTURE

ESSENTIALS

- Prediction Systems Framework
- Phenomena →Predictions
- Understanding Uncertainty
- Study Design
- Timelines ▷ Why predict?

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Greek Astronomy

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cross-cultural conversations

THE RISE OF THEORY

The Path to Newton

The Path to Newton

- Indian Mathematics
- European Renaissance

Lost without Longitude (Navigation)

- Help, I'm Lost!
- Tools of the Navigator

The Royal Society

MODERN SIMULATION

Health

John Snow & Cholera
- Cholera Map

Wealth
- Climate & Wealth
- Behavioral Economics

The Future of the Future
- AI, Derek's Day
- Philosophy
- Uncertainty

Earth
- Climate & Energy
- Climate Policy
- Tent Tarot
- Earthquakes

Space
- Futures of our Universe
- SETI

Coming Soon | ⬛ Interactive Resource | ▷ video(s) | edX on edX as mini-course, otherwise find material via predictionx.org

…includes >30 Harvard Faculty interviews; created in collaboration with dedicated staff at HarvardX, Bok Center, GenEd, Freshman Seminar, Radcliffe, Aeon Timeline, and participants from ~20 academic and cultural institutions
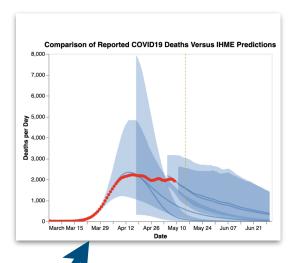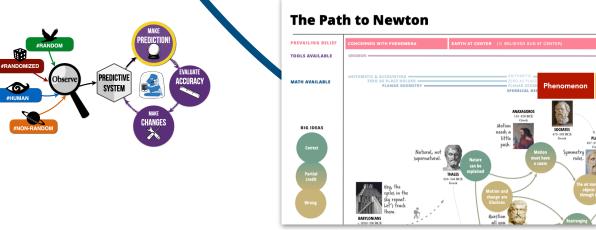
"Take A Sweater"

takeasweater.com
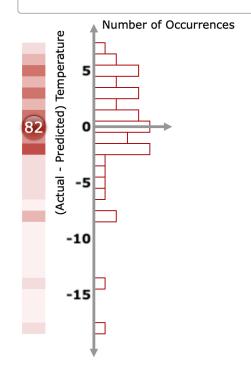
with thanks to Eric **Floehr** of Forecast Watch and Bill **Barthelmy** of HUIT Academic Technology at FAS
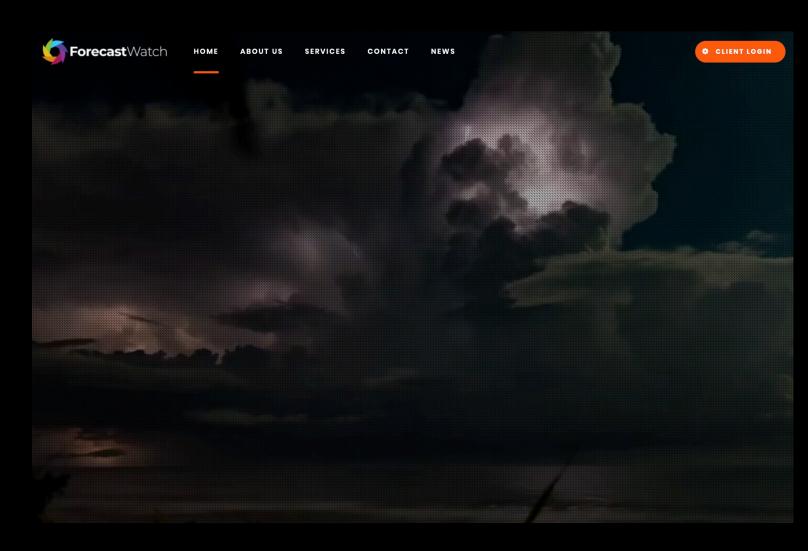
The Cost of Uncertainty

forecastwatch.com

also: uncertainty and risk are not the same
—more on that later...

The Cost of Uncertainty depends on the cost of being wrong.
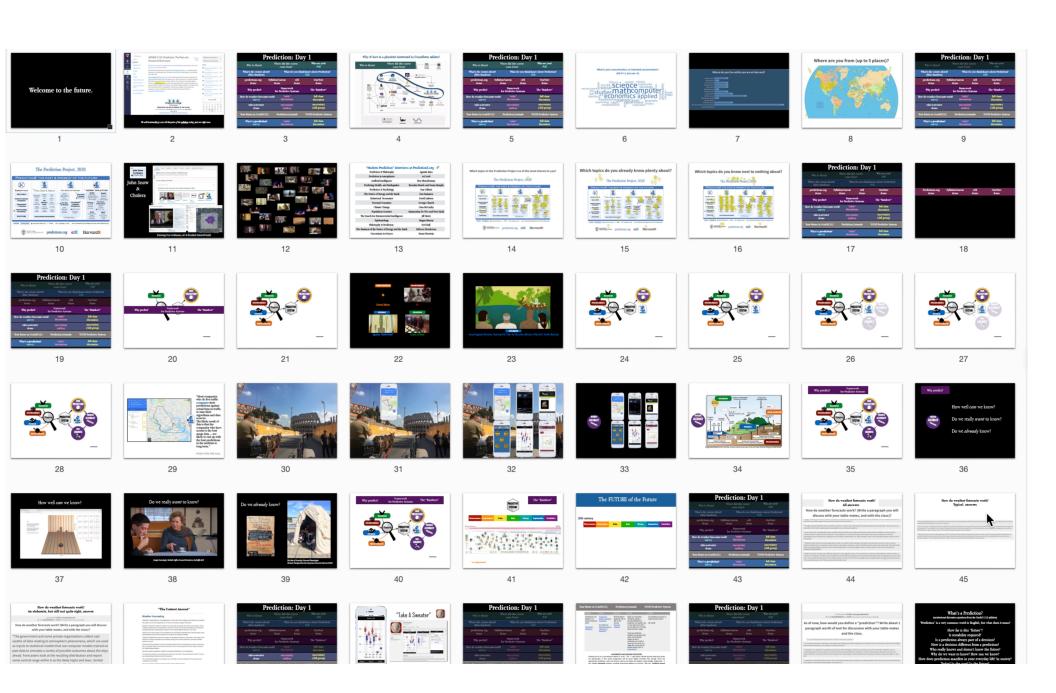
Beheading (ancient oracles)

People die (pandemics)
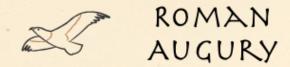
World Ends (climate change)

Don't get tenure (astrophysics)
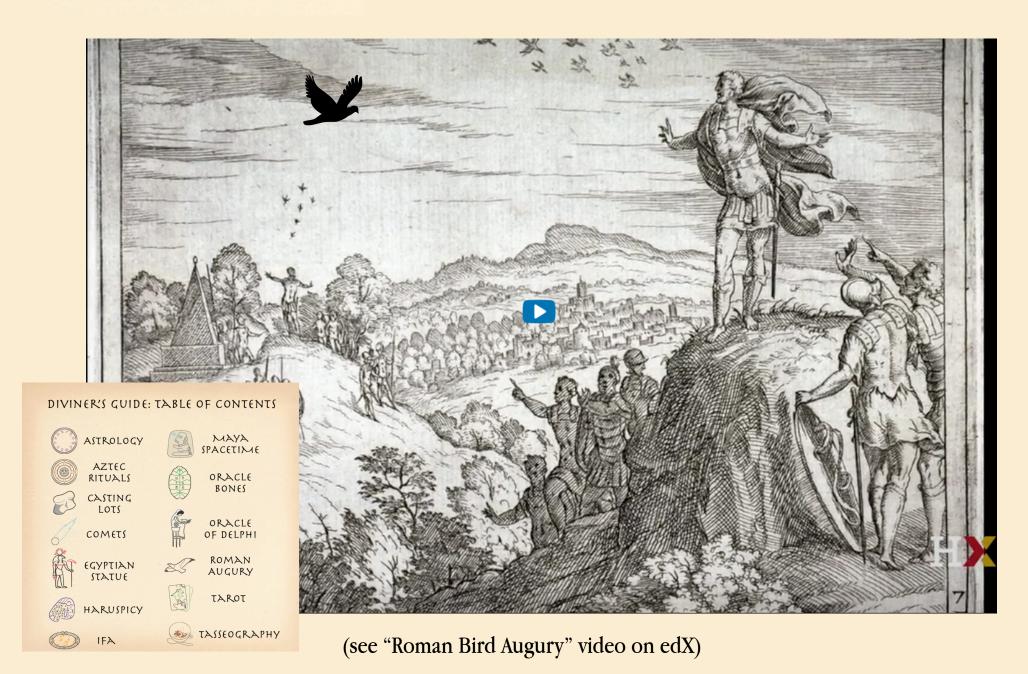
GenEd 1112, Spring 2020

ROMAN AUGURY
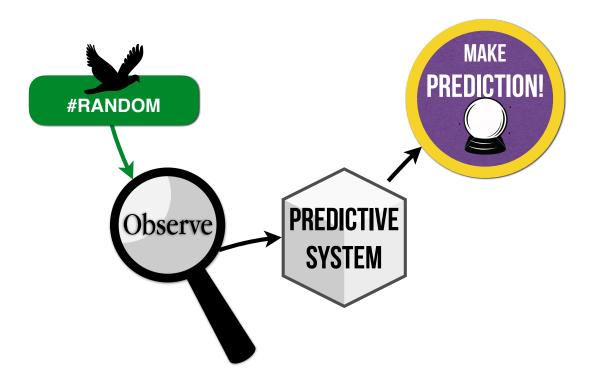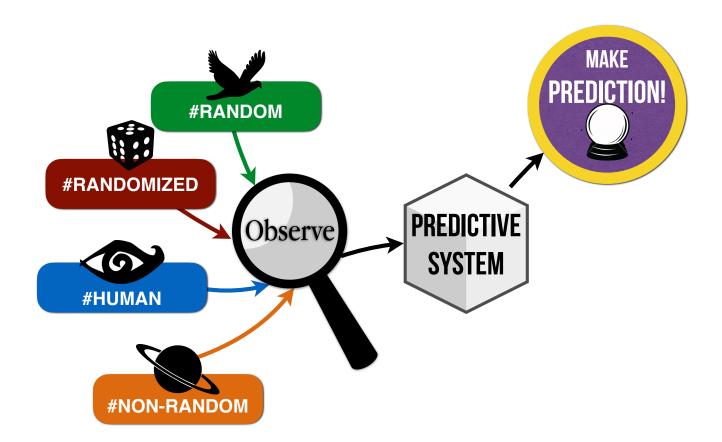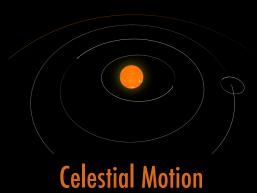
"Senior political officials of the Roman state had to take auspices before any major political event like elections." —Emma Dench

DIVINER'S GUIDE: TABLE OF CONTENTS

(see "Roman Bird Augury" video on edX)

#RANDOM

Observe

PREDICTIVE SYSTEM

MAKE PREDICTION!

https://openclipart.org/

#RANDOM

#RANDOMIZED

#HUMAN

#NON-RANDOM

Observe

PREDICTIVE
SYSTEM

MAKE
PREDICTION!

#NON-RANDOM

Celestial Motion

#RANDOMIZED

Ifa

#HUMAN

Egyptian "Bobble Head"

#RANDOM
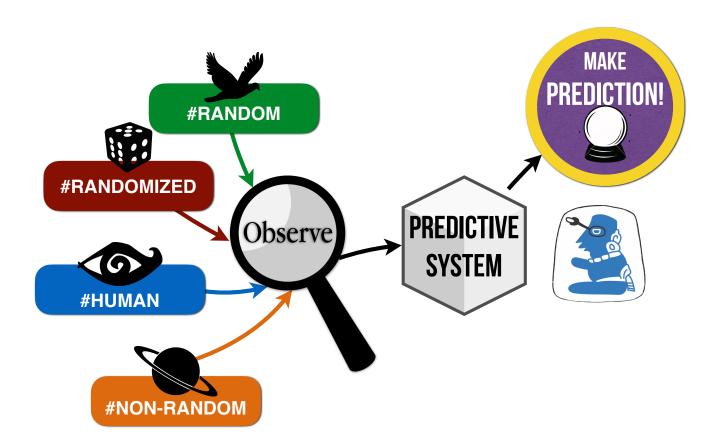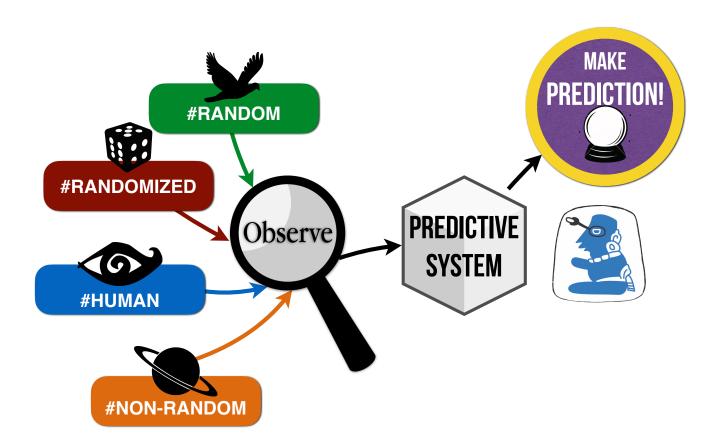
Comets of Doom
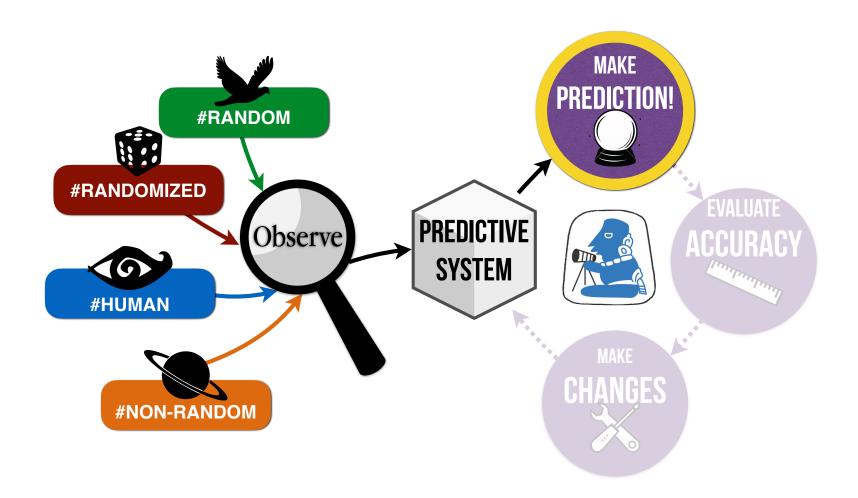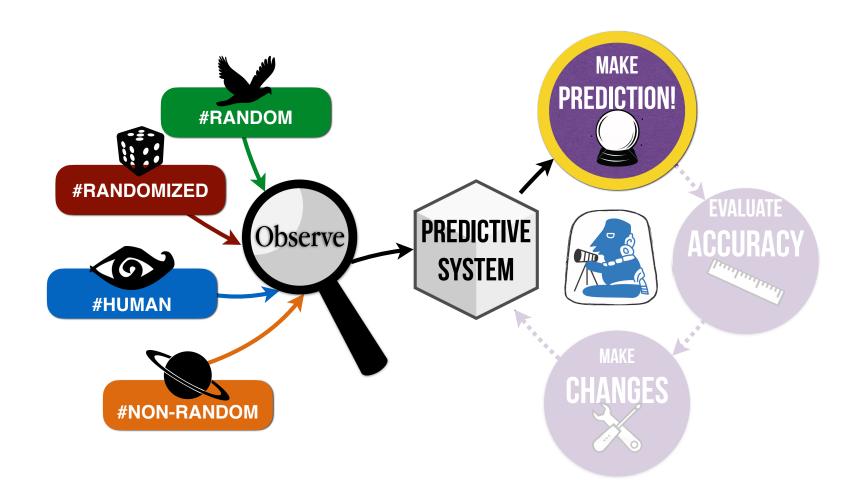
#HUMAN
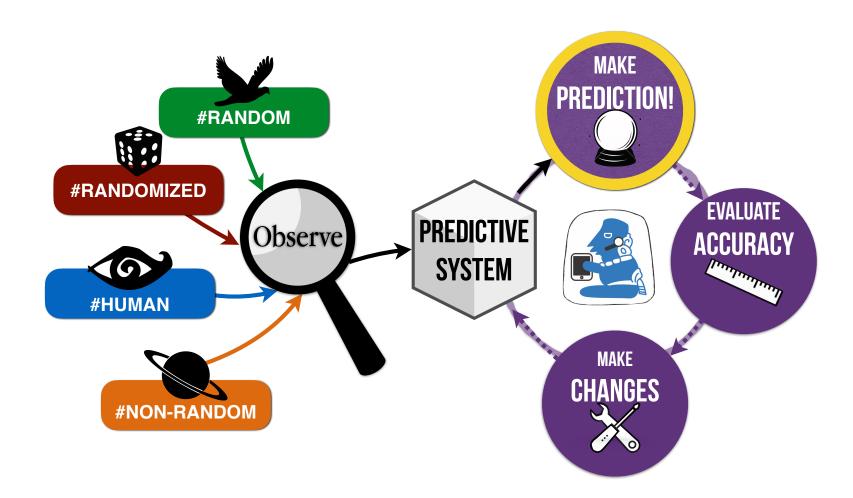
Ancient Egyptian Divination, featuring Prof. Peter der Manuelian (Harvard Semitic Museum)

#RANDOM

#RANDOMIZED

#HUMAN

#NON-RANDOM

Observe

PREDICTIVE SYSTEM

MAKE PREDICTION!

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https://openclipart.org/

#RANDOM

#RANDOMIZED

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Observe

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MAKE PREDICTION!

EVALUATE ACCURACY

MAKE CHANGES

#RANDOM

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MAKE CHANGES

#RANDOM

#RANDOMIZED

#HUMAN

#NON-RANDOM

Observe

PREDICTIVE SYSTEM

MAKE PREDICTION!

EVALUATE ACCURACY

MAKE CHANGES

"Most companies who do live traffic **compare** their predictions against actual time in traffic to tune their algorithms and data sources.
The likely result of this is that the companies who have access to the best usage data ... are likely to end up with the best predictions in the medium to long term."

Forbes Tech, July 2013

Framework for Predictive Systems

PREDICTIVE SYSTEMS

The "Rainbow"

Phenomenon	Observation*	Data	Rule	Theory	Explanation	Prediction

The Path to Newton

PredictionX

PREVAILING BELIEF: CONCERNED WITH PHENOMENA | EARTH AT CENTER (⊙ BELIEVED SUN AT CENTER) | SUN AT CENTER (⊕ BELIEVED EARTH AT CENTER)

TOOLS AVAILABLE: GNOMON / ASTROLABE / PRINTING PRESS / TELESCOPE

MATH AVAILABLE: ARITHMETIC & ACCOUNTING, ZERO AS PLACE HOLDER, PLANAR GEOMETRY, SPHERICAL GEOMETRY, TRIGONOMETRY, SPHERICAL TRIGONOMETRY, ALGEBRA, LOGARITHMS, SPECIAL FORMS, CALCULUS

BIG IDEAS: Correct / Partial credit / Wrong

CONNECTIONS BETWEEN IDEAS
Teacher-Pupil or Senior-Junior Researcher
Travel between cultures

Key figures: BABYLONIANS, THALES, ANAXIMANDER, PYTHAGORAS, PARMENIDES, ANAXAGORAS, SOCRATES, DEMOCRITUS, PLATO, ARISTOTLE, EUDOXUS, EUCLID, ARISTARCHUS, HIPPARCHUS, PTOLEMY, JOHN PHILOPONUS, ARYABHATA, VARAHAMIHIRA, BRAHMAGUPTA, AL-BATTANI, IBN SINA (AVICENNA), IBN AL-HAYTHAM, AL-TUSI, IBN RUSHD (AVERROES), BHASKARA II, JEAN BURIDAN, NICOLE ORESME, ALI QUSHJI, REGIOMONTANUS, NICHOLAS COPERNICUS, TYCHO BRAHE, JOHANNES KEPLER, GALILEO GALILEI, RENE DESCARTES, ISAAC NEWTON, EDMOND HALLEY

GRAVITY GOVERNS ALL

Published works: Astronomical Diaries, On the Heavens, Physics, Elements, The Almagest, Aryabhatiya, On Aristotle's Physics 3, Pañca-siddhāntikā, Brahmasphuta-siddhanta, TRANSLATION MOVEMENT WORKS, Kitāb az-Zīj, Kitāb al-Shifā', Al-Shukūk 'alā Baṭlamyūs, Siddhānta Shiromani, Commentaries on Aristotle, Alfonsine Tables, Al-Tadhkirah fī'ilm al-hay'ah, Epitome of the Almagest, De Revolutionibus, Astronomia Nova, Sidereus Nuncius, Dialogue on the Two Chief Systems of the World, Two New Sciences, Principles of Philosophy, Principia, Synopsis Astronomia Cometicae

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or, Experiment

The FUTURE of the Future

20th century

| Phenomenon | Observation | Data | Rule | Theory | Explanation | Prediction |

Take-a-Sweater

Boston, MA JUL 30

PredictionX

predictionx.org

IHME COVID-19

Comparison of Reported COVID19 Deaths Versus IHME Predictions

The Path to Newton

| Phenomenon | Observation* | Data | Rule | Theory | Explanation | Prediction |

"When Knowledge Conquered Fear"

"When Knowledge Conquered Fear" is the third episode of the American documentary television series Cosmos: A Spacetime Odyssey.
It premiered on March 23, 2014 on Fox, and premiered on March 24, 2014 on National Geographic Channel. [Wikipedia]. IMDB link

The Path to Newton

CONCERNED WITH PHENOMENA

EARTH AT CENTER   (☉ BELIEVED SUN AT CENTER)

GNOMON

GNOMON
ASTRO

ARITHMETIC & ACCOUNTING
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY

ARITHMETIC
ZERO AS PLACE HOLDER
PLANAR GEOMETRY

ARITHMETIC
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY

SPHERICAL TRIGONOMETRY

BIG IDEAS

Correct

Partial credit

Wrong

CONNECTIONS BETWEEN IDEAS

Teacher-Pupil or Senior-Junior Researcher

Travel between cultures

Published works

ANAXAGOROS
510–428 BCE
Greek

Motion needs a little push.

SOCRATES
470–399 BCE
Greek

PLATO
427–347 BCE
Greek

Symmetry rules.

💕 Circles spheres, beauty, eternity...

...oh, and you're SO wrong about motion, Plato.

ARISTOTLE
383–322 BCE
Greek

I can prove it!

EUCLID
300? BCE
Greek

Circles ARE the best! We just need more!

PTOLEMY
100–170
Greek living in Roman Egypt

Celes
an
terres
phenom
simi

Natural, not supernatural.

Nature can be explained

THALES
624–546 BCE
Greek

Motion must have a cause

The air moves objects through it

All things move to their natural place

A single framework for all geometry

Hey, the cycles in the sky repeat. Let's track them.

Motion and change are illusions

Question all you "see."

PARMENIDES
515–450 BCE
Greek

Rearranging "atoms" allows motion

Earth is stationary center of the universe

Epicycles, equants, eccentrics

BABYLONIANS
c. 2000–300 BCE

The universe is WAY bigger than you might think.

Earth generated by boundless eternity

STUFF on Earth and in the Heavens is all the same... just atoms.

DEMOCRITUS
460–370 BCE
Greek

EUDOXUS
390–337 BCE
Greek

It's spheres all the way down.

ARISTARCHUS
310–230 BCE
Greek

With one little function, I'll give you the Moon!

ANAXIMANDER
610–546 BCE
Greek

If circles are perfect, spheres are sublime.

Universe is spherical

Planets, Moon, Sun, move on spheres

☉ Hello? Is this thing on?

Sun at center

Math can model the universe

HIPPARCHUS
190-120 BCE
Greek living in Rome

I'm not sure Earth is exactly in the center?

Some "stars" move more than others

PYTHAGORAS
570–495 BCE
Greek

Astronomical Diaries

On the Heavens
Aristotle
c. 350 BCE

Physics
Aristotle
c. 320 BCE

Elements
Euclid
c. 300 BCE

The Almagest
Ptolemy
c. 150

Aryab
Aryab
c. 4

GNOMON
ASTROLABE

ARITHMETIC
ZERO AS PLACE HOLDER
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPRERICAL TRIGONOMETRY
ALGEBRA

ARITHMETIC
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPRERICAL TRIGONOMETRY
ALGEBRA

TUSI COUPLE AND OTHER SPECIAL FORMS

Motion caused by self-exhausting force

Celestial and terrestrial phenomena similar

Aristotle is wrong about space, time, and matter.

JOHN PHILOPONUS
490–570
Greek living in Roman Egypt

I must gather more information for better astrology, and I shall share what I learn!

VĀRĀHAMIHIRA
505–587
Indian

It just keeps going, and going… but not really.

IBN SINA (AVICENNA)
980–1037
Persian

What did Aristotle really mean? We need to question.

IBN RUSHD (AVERROES)
1126–1198
Arab

Come on! You can't "give" an object motion.

NICOLE ORESME
1320–1382
French

Objects are "set into" motion

Circles ARE the best! We just need more!

PTOLEMY
100–170
Greek living in Roman Egypt

Motion is indefinite without external forces

Bigger observatories, better observations.

AL-TUSI
1201–1274
Persian

Math first, philosophy later.

NICHOLAS COPERNICUS
1473–1543
Polish

Years from now, Copernicus will love me.

AL-BATTANI
858–929
Arab

Metaphysics? Hooey! Give me evidence and math.

IBN AL-HAYTHAM
965–1040
Arab

Motion is a chain of an object's locations

Motion explained with "impetus theory"

Epicycles, equants, eccentrics

With one little function, I'll give you the Moon!

ARYABHATA
476–550
Indian

Who knew nothing could be so useful?

BRAHMAGUPTA
598–668
Indian

Accuracy is key (e.g., 365.24 days in a year)

Models matching data is paramount

If I use a teeny unit of time…

BHĀSKARA II
1114–1185
Indian

Simple circular orbits work with better math

This is math, not philosophy.

JEAN BURIDAN
1295–1358
French

The Earth might actually rotate

Earth need not be at rest, Ptolemy!

ALI QUSHJI
1403–1474
Turkic

Sun at center of Earth's & planets' orbits

…can …d the …erse

I'm not sure Earth is exactly in the center?

…PARCHUS
…120 BCE
…eek living …n Rome

Sines improve accuracy

Zero is a numeral unto itself

Much of what we today call calculus

I can improve Ptolemy! To the printing press!

REGIOMONTANUS
1436–1476
German

The Almagest
Ptolemy
c. 150

Aryabhatiya
Aryabhata
c. 499

On Aristotle's Physics 3
Philoponus
c. 520

Pañca-siddhāntikā
Vārāhamihira
c. 575

Brahmasphuta-siddhanta
Brahmagupta
c. 628

TRANSLATION MOVEMENT WORKS

Kitāb az-Zīj
al-Battani
c. 900

Kitāb al-Shifa'
Ibn Sīnā
c. 1020

Al-Shukūk 'alā Batlamyūs
Ibn al-Haytham
c. 1025

Siddhānta Shiromani
Bhāskara II
c. 1150

Commentaries on Aristotle
Ibn Rushd
c. 1150-1200

Alfonsine Tables
1252

Al-Tadhkirah fi'ilm al-hay'ah
al-Tusi
1261

Epitome of the Almagest
Regiomontanus
1496

De Revolutionibus
Copernicus
1543

SUN AT CENTER (⊕ BELIEVED EARTH AT CENTER)

GNOMON · GNOMON
ASTROLABE · ASTROLABE
PRINTING PRESS · PRINTING PRESS
TELESCOPE

ARITHMETIC · ARITHMETIC · RAL · ARITHMETIC
ZERO AS NUMERAL · ZERO AS NUMERAL · ZERO AS NUMERAL
PLANAR GEOMETRY · PLANAR GEOMETRY · PLANAR GEOMETRY
SPHERICAL GEOMETRY · SPHERICAL GEOMETRY · SPHERICAL GEOMETRY
TRIGONOMETRY · TRIGONOMETRY · TRIGONOMETRY
SPRERICAL TRIGONOMETRY · SPERHICAL TRIGONOMETRY · SPHRERICAL TRIGONOMETRY
ALGEBRA · ALGEBRA · ALGEBRA
TUSI COUPLE AND OTHER SPECIAL FORMS · SPECIAL FORMS · SPECIAL FORMS
LOGARITHMS · LOGARITHMS
CALCULUS

Did [...] tle [...] an? [...] to [...] on.

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Come on! You can't "give" an object motion.

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1320–1382
French

Objects are "set into" motion

Bigger observatories, better observations.

AL-TUSI
1201–1274
Persian

With giant spendy instruments, I can get GREAT data.

Math first, philosophy later.

NICHOLAS COPERNICUS
1473–1543
Polish

Planets orbit the Sun, but Sun orbits Earth ⊕

TYCHO BRAHE
1546–1601
Danish

Oooh, I like this Dutch spyglass!

Sorry, Aristotle, you're just wrong.

GALILEO GALILEI
1564–1642
Italian

Aristotle, mon ami, above and below, it's all matter in motion.

We're gonna need better math.

ISAAC NEWTON
1642–1726
British

This apple. That moon. Could they feel the same pull?

Motion is a chain of an object's locations

Motion explained with "impetus theory"

This is math, not philosophy.

JEAN BURIDAN
1295–1358
French

Simple circular orbits work with better math

The Earth might actually rotate

Sun at center of Earth's & planets' orbits

Jupiter has moons, which orbit like our Moon

All bodies on Earth have (circular) inertia

RENÉ DESCARTES
1596–1650
French

GRAVITY GOVERNS ALL

Earth need not be at rest, Ptolemy!

ALI QUSHJI
1403–1474
Turkic

I can improve Ptolemy! To the printing press!

REGIOMONTANUS
1436–1476
German

I have Tycho's fancy data!

JOHANNES KEPLER
1571–1630
German

Hmm... circles are a problem.

Sun is the center

All bodies have inertia

I must make Newton publish!

EDMOND HALLEY
1656–1742
British

Orbits are ellipses, not circles

Some comets return, predictably

Commentaries on Aristotle
Ibn Rushd
c. 1150–1200

Alfonsine Tables
1252

Al-Tadhkirah fi'ilm al-hay'ah
al-Tusi
1261

Epitome of the Almagest
Regiomontanus
1496

De Revolutionibus
Copernicus
1543

Astronomia Nova
Johannes Kepler
1609

Siderius Nuncius
Galileo
1610

Dialogue on the Two Chief Systems of the World
Galileo
1632

Two New Sciences
Galileo
1638

Principles of Philosophy
Descartes
1644

Principia
Isaac Newton
1687

Synopsis Astronomia Cometicae
Edmond Halley
1705

Path to

PATH TO

A project to track the evolution of science

TRY THE PATH TO NEWTON

coming soon: The Path to Darwin from Prof. Immaculata De Vivo,
special Harvard Library site, and more.

Take-a-Sweater
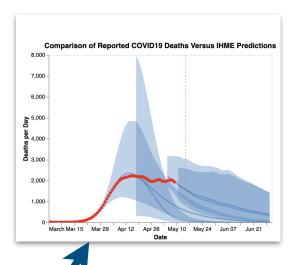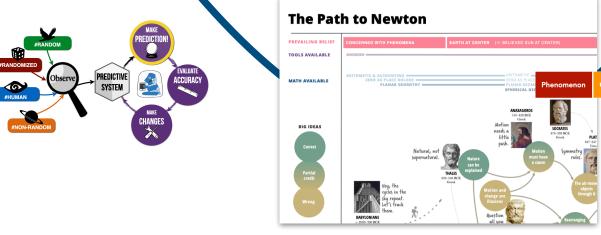
PredictionX
predictionx.org

IHME COVID-19

Boston, MA JUL 30

94
90
90
now
83 83 84
80
71 70
70
65 65 66
60

Today Wed Thu Fri Sat

Comparison of Reported COVID19 Deaths Versus IHME Predictions

Deaths per Day

8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0

March Mar 15 Mar 29 Apr 12 Apr 26 May 10 May 24 Jun 07 Jun 21

Date

The Path to Newton

#RANDOM
#RANDOMIZED
Observe
PREDICTIVE SYSTEM
MAKE PREDICTION!
EVALUATE ACCURACY
#HUMAN
MAKE CHANGES
#NON-RANDOM

The Path to Newton

PREVAILING BELIEF CONCERNED WITH PHENOMENA EARTH AT CENTER (☉ BELIEVED SUN AT CENTER)

TOOLS AVAILABLE GNOMON

MATH AVAILABLE ARITHMETIC & ACCOUNTING ARITHMETIC
ZERO AS PLACE HOLDER ZERO AS PLACE
PLANAR GEOMETRY PLANAR GEOM
SPHERICAL GEO

| Phenomenon | Observation* | Data | Rule | Theory | Explanation | Prediction |

BIG IDEAS

Correct

Partial credit

Wrong

ANAXAGORAS
510–428 BCE
Greek

Motion needs a little push.

SOCRATES
470–399 BCE
Greek

PLAT
427–347
Gree

Natural, not supernatural.

THALES
624–546 BCE
Greek

Nature can be explained

Motion must have a cause

Symmetry rules.

The air moves objects through it

Hey, the cycles in the sky repeat. Let's track them.

BABYLONIANS
c. 2000–300 BCE

Motion and change are illusions

Question all you

Rearranging

Opinion

No One Knows What's Going to Happen

Stop asking pundits to predict the future after the coronavirus. It doesn't exist.

By Mark Lilla
Dr. Lilla is a professor of humanities at Columbia.

May 22, 2020

f 𝕏 ✉ ➤ 🔖 💬 790

The best prophet, Thomas Hobbes once wrote, is the best guesser. That would seem to be the last word on our capacity to predict the future: We can't.

But it is a truth humans have never been able to accept. People facing immediate danger want to hear an authoritative voice they can draw assurance from; they want to be told what will occur, how they should prepare, and that all will be well. We are not well designed, it seems, to live in uncertainty. Rousseau exaggerated only slightly when he said that when things are truly important, we prefer to be wrong than to believe nothing at all.

Prediction versus Prophecy

Take-a-Sweater
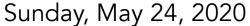
Boston, MA JUL 30

PredictionX
predictionx.org

IHME COVID-19

Comparison of Reported COVID19 Deaths Versus IHME Predictions

The Path to Newton

| Phenomenon | Observation* | Data | Rule | Theory | Explanation | Prediction |

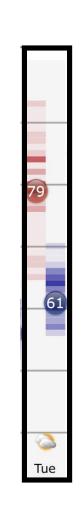takeasweater.com

path-to.org

gluesolutions.io/social-impact

May 26, 2020 weather for Boston, predicted in the past...
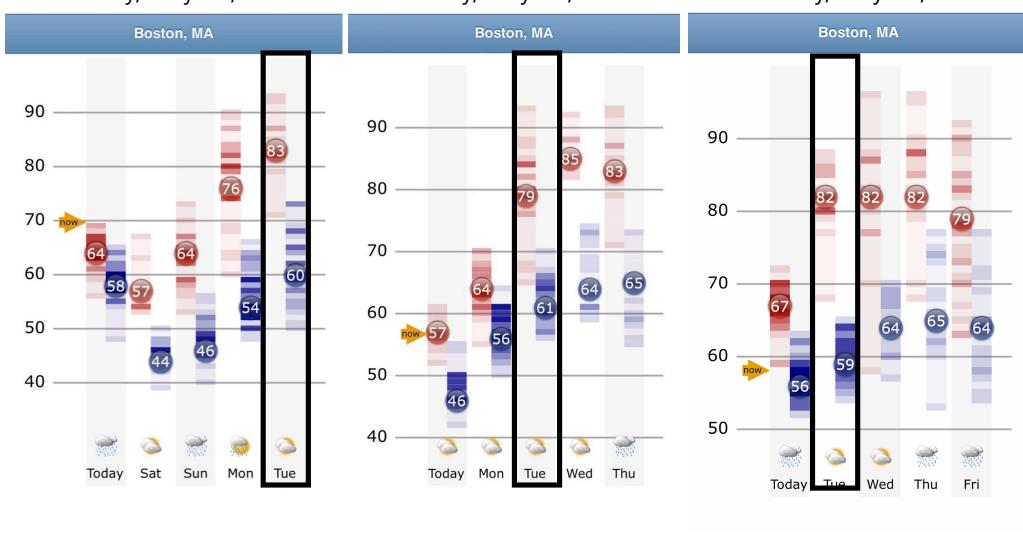
Friday, May 22, 2020
Sunday, May 24, 2020
Monday, May 25, 2020

from takeasweater.com

May 26, 2020 weather for Boston, predicted in the past...

Friday, May 22, 2020

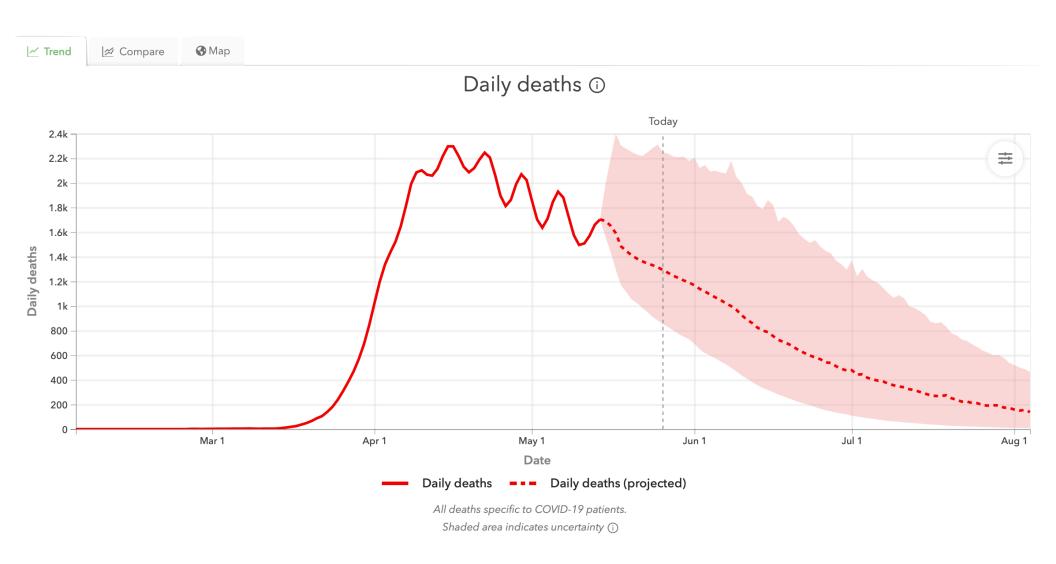Sunday, May 24, 2020
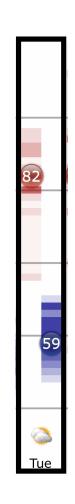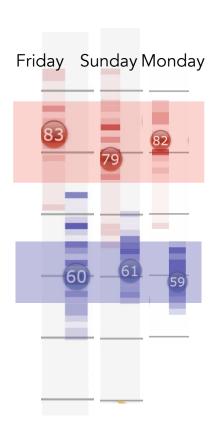
Monday, May 25, 2020

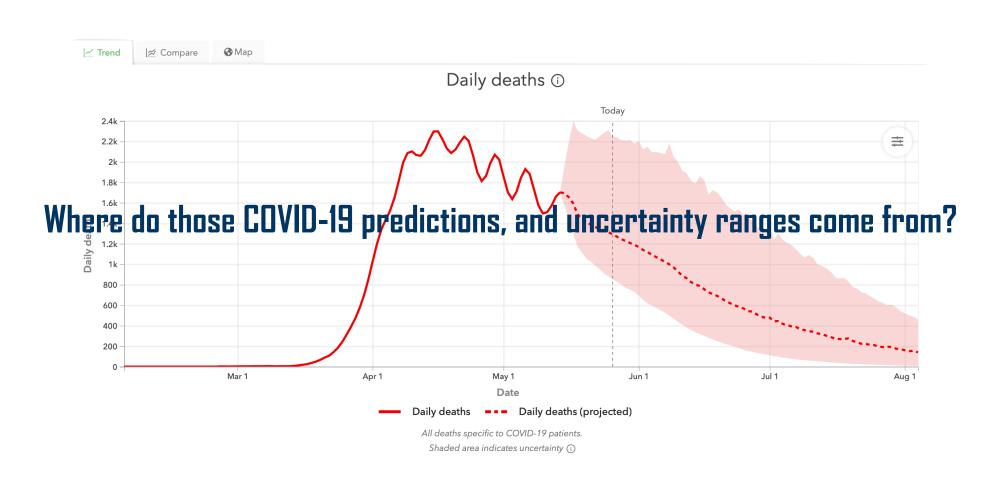# May 26, 2020 weather for Boston, predicted in the past...

Friday   Sunday Monday

83   79   82

60   61   59
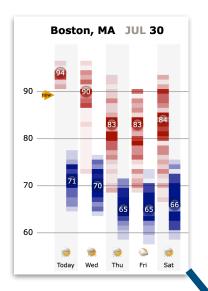
Predictions ~fall within "expected" uncertainty ranges.

May 26, 2020 IHME forecast for US COVID-19 Daily Deaths, with Uncertainty

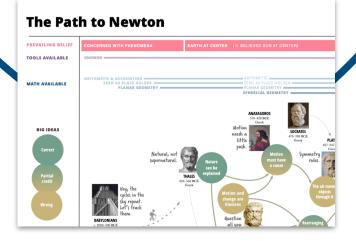**Predictions are shown with "expected" uncertainty ranges.**

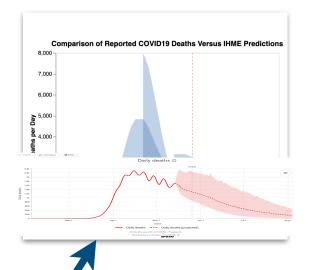Where do those COVID-19 predictions, and uncertainty ranges come from?

Take-a-Sweater

Boston, MA JUL 30

PredictionX

predictionx.org

The Path to Newton

The Path to Newton

PREVAILING BELIEF	CONCERNED WITH PHENOMENA	EARTH AT CENTER (☉ BELIEVED SUN AT CENTER)

TOOLS AVAILABLE — GNOMON

MATH AVAILABLE — ARITHMETIC & ACCOUNTING / ZERO AS PLACE HOLDER / PLANAR GEOMETRY — ARITHMETIC / ZERO AS PLACE HOLDER / PLANAR GEOMETRY / SPHERICAL GEOMETRY

BIG IDEAS
- Correct
- Partial credit
- Wrong

IHME COVID-19

Comparison of Reported COVID19 Deaths Versus IHME Predictions

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takeasweater.com   **path-to.org**   **gluesolutions.io/social-impact**

March 11, 2020 was definitely the most surreal day of my life teaching at Harvard, so far.

Prediction: Day 7

opening remarks on COVID-19 & plans for the rest of GenEd1119

quick review of outdoor **Navigation Exercise**

questions about **"Prediction in Space & Time"** re:Navigation, *and Epidemiology*

John Snow & Cholera (edX highlights & more)

Student research/discussion re:COVID-19 using survey at **tinyurl.com/gened1112covid19**

Modeling the spread of epidemics, and uncertainty
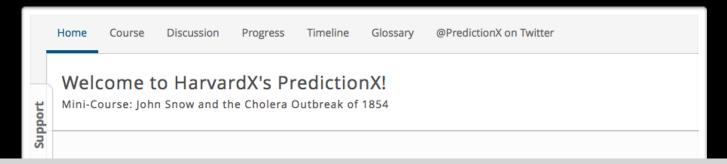
Bookkeeping **SIR Models** **SEIR Models** **Agent-based models** **AI models**

Prediction and decision in the face of **uncertainty**: COVID-19 and Harvard (discussions)
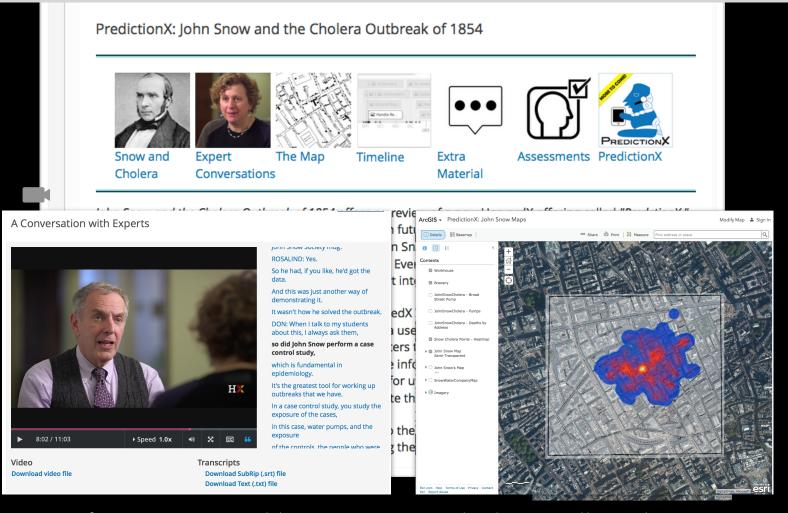
Logistics post-Spring-Break

Special Guest: geneticist **Dr. Immaculata DeVivo,** Professor in the Department of Epidemiology at the Harvard T.H. Chan School of Public Health and at Harvard Medical School
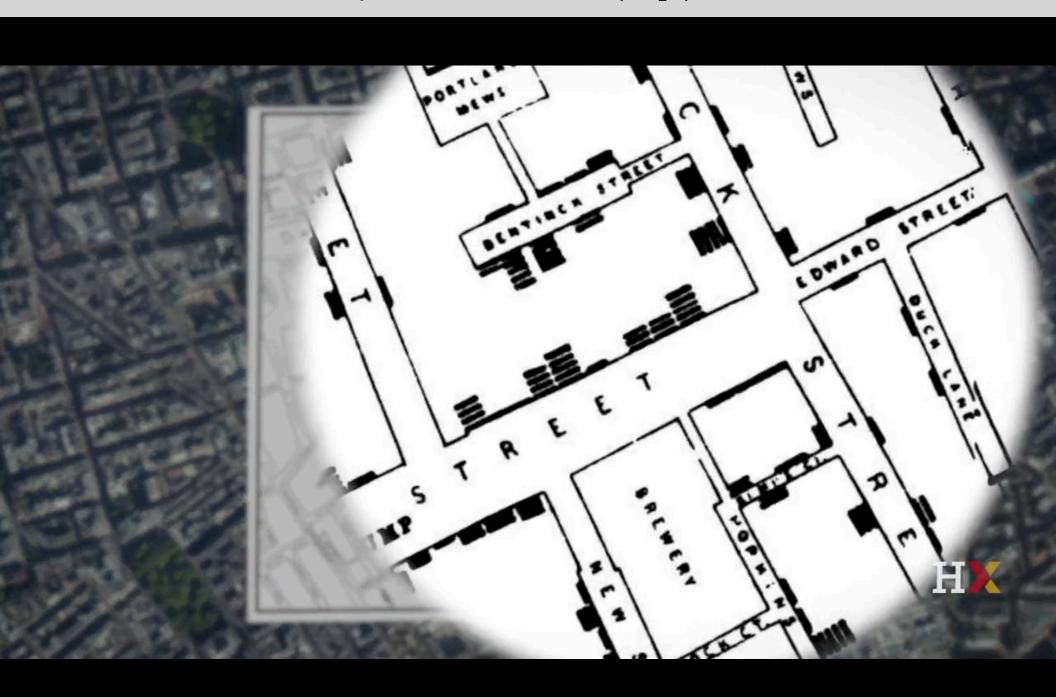
John Snow & Cholera (edX highlights & more)

featuring Don Goldmann, AG & Rosalind Stanwell-Smith
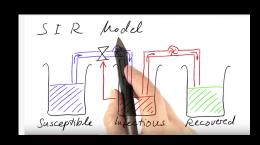
Modeling the spread of epidemics, and UNCERTAINTY

Bookkeeping   e.g. (#infected) x (%fatal (age group, region))=probability of death

**SIR Models
(Susceptible-
Infected-
Removed)**
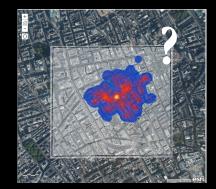
SEIR Models   like SIR, but allowing for "Exposed" uninfected group

Agent-based models   account for spatial & behavioral factors…

AI models   e.g. Blue Dot prediction

Info from these links: "Modern Predictive Systems", OneNote collection (available via Canvas)

Modeling the spread of epidemics, and UNCERTAINTY

Bookkeeping for COVID-19: consider a x b x d

a: Probability of exposure = high
b: Probability of any symptoms = medium
c: also consider probability of diagnosis at all = medium/high
d: Probability of "death," see below

a: 0.7 (70%)
b: 0.2 (20%)
c: 0.7 (70%)
d: 0.002 (0.2%)

a x b x d = 0.03%

update—this simple estimate from 3/11/20 gives ~100K deaths for US, which ~is the actual value for 5/26/20

Age of Coronavirus Deaths

COVID-19 Fatality Rate by AGE:

*Death Rate = (number of deaths / number of cases) = **probability of** c
This probability differs depending on the age group. The percentages sh
to 100%, as they **do NOT represent share of deaths by age** group. R
given age group, the **risk of dying** if infected with COVID-19.

AGE	DEATH RATE confirmed cases	DEATH RATE all cases
80+ years old	21.9%	14.8%
70-79 years old		8.0%
60-69 years old		3.6%
50-59 years old		1.3%
40-49 years old		0.4%
30-39 years old		0.2%
20-29 years old		0.2%
10-19 years old		0.2%
0-9 years old		no fatalities

medical conditions (comorbidities)

re-existing ("comorbid") medical conditions had a case fatality rate of 0.9%. Pre-
atients at higher risk of dying from a COVID-19 infection are:
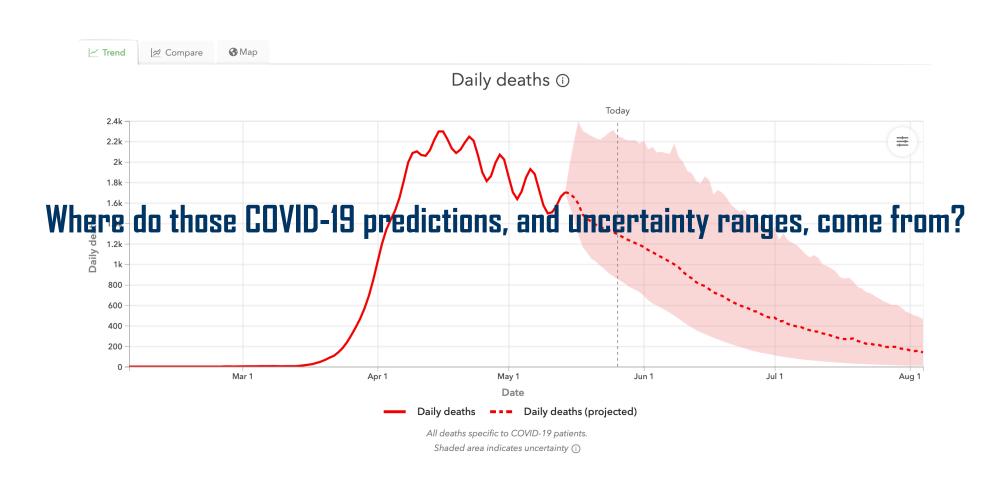
e by COMORBIDITY:

eaths / number of cases) = **probability of dying if infected by the virus** (%).
nding on pre-existing condition. The percentage shown below does **NOT**
share of deaths by pre-existing condition. Rather, it represents, for a patient
with a given pre-existing condition, the **risk of dying** if infected by COVID-19.
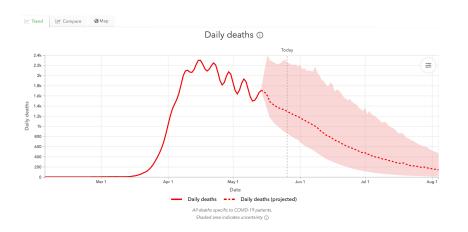
PRE-EXISTING CONDITION	DEATH RATE confirmed cases	DEATH RATE all cases
Cardiovascular disease	13.2%	10.5%
Diabetes	9.2%	7.3%
Chronic respiratory disease	8.0%	6.3%
Hypertension	8.4%	6.0%
Cancer	7.6%	5.6%
no pre-existing conditions		0.9%

*Death Rate = (number of deaths / number of cases) = **probability of
dying if infected by the virus** (%). The percentages **do not have to add
up to 100%**, as they **do NOT represent share of deaths by condition.**

https://www.worldometers.info/coronavirus/coronavirus-age-sex-demographics/

Daily deaths ⓘ

Today

Where do those COVID-19 predictions, and uncertainty ranges, come from?

Mar 1   Apr 1   May 1   Jun 1   Jul 1   Aug 1

Date

—— Daily deaths   - - - Daily deaths (projected)

All deaths specific to COVID-19 patients.
Shaded area indicates uncertainty ⓘ

Where do those COVID-19 predictions, and uncertainty ranges, come from?

covid19.healthdata.org/
united-states-of-america

And how uncertain are the uncertainties?

gluesolutions.io/
social-impact

Where do those COVID-19 predictions, and uncertainty ranges, come from?

gluesolutions.io/social-impact

predictionx.org/uncertainty-covid19

PredictionX
predictionx.org

Essays

UNCERTAINTY ABOUT UNCERTAINTY

Data-Driven Dilemmas posed by COVID-19

HOME / COMMENTARY / UNCERTAINTY ABOUT UNCERTAINTY /

Data-Driven Dilemmas posed by COVID-19

This commentary was submitted on April 21, 2020 as a proposed Op-Ed for the NYT, by Prof. Alyssa A. Goodman, Harvard University. It represents the personal views of the author, not an official position of Harvard University.

I teach "Prediction." At Harvard. But I cannot predict the outcome of the current pandemic. I am equipped, as a scientist, to understand, evaluate, and potentially act upon, the infection and death statistics we all now read every day. But as a person, I can also act out of fear. The constant dialogue in my mind between my rational self and my emotional self helps me appreciate the dilemma facing our leaders now, as they try quite literally, to save the world.

"Data-Driven Dilemmas posed by COVID-19"

Both groups—epidemiologists using infectious disease expertise to model a pandemic's course and data scientists making predictions...

Physicists are taught to always consider limiting cases. At one limit, if no country had done anything to slow the epidemic's spread when it began, humanity, after millions of COVID-related deaths worldwide, we would have acquired "herd immunity" quite quickly, in a matter of months. The disease would have caused tens of millions of deaths—potentially as much as 1% of the population. At the other limit, we could prevent all deaths in the short-run with total lockdowns, but the social

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HARVARD.EDU

The Prediction Project
Thoughts, Resources, Course, Seminar and Someday a Book

WELCOME   CONTENT▾   COURSES▾   TALKS+▾   COMMENTARY▾   CREDITS

Section Navigation

PREDICTIONX

▸ Essentials: Ways to Frame Discussions about Prediction

▸ Omens & Oracles

▸ Rise of Theory

▾ Modern Predictive Systems

▸ Sneak PREVIEW videos

▾ Modern Prediction Essays

HOME / PREDICTIONX / CONTENT / MODERN PREDICTIVE SYSTEMS

Modern Prediction Essays

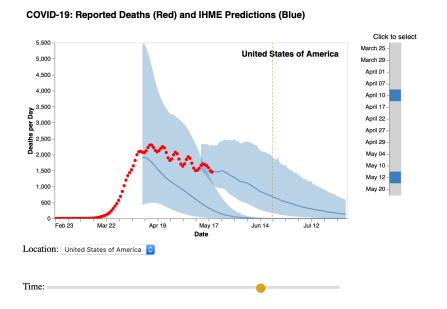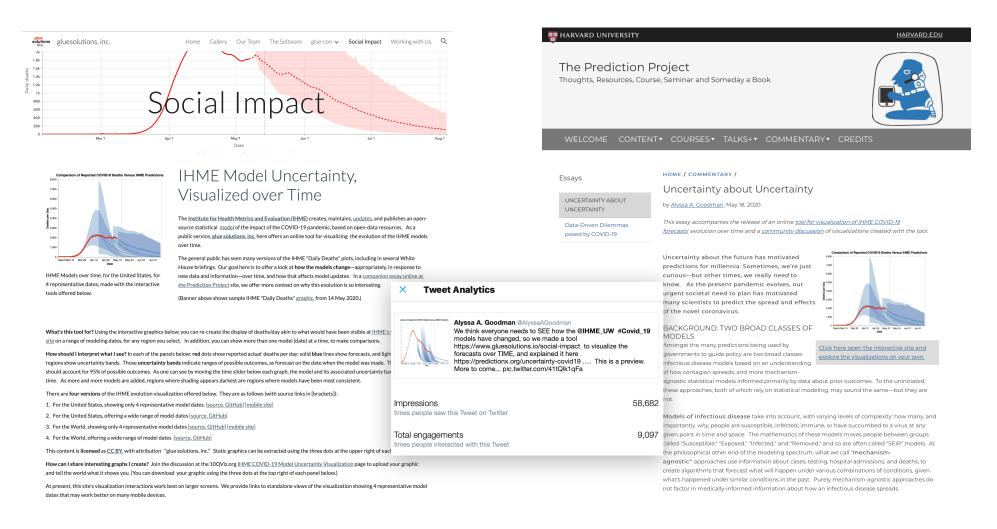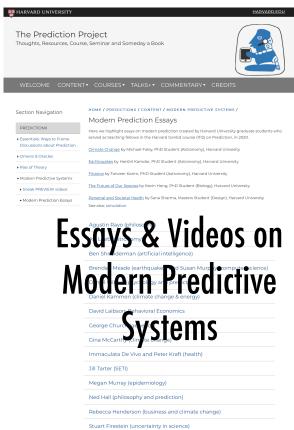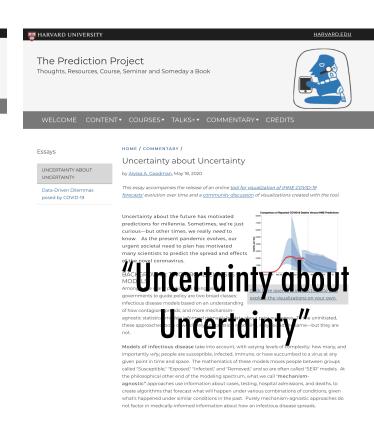Here we highlight essays on modern prediction created by Harvard University graduate students who served as teaching fellows in the Harvard GenEd course (1112) on Prediction, in 2020.

Climate Change by Michael Foley, PhD Student (Astronomy), Harvard Univesity

Earthquakes by Harshil Kamdar, PhD Student (Astronomy), Harvard University

Finance by Tanveer Karim, PhD Student (Astronomy), Harvard University

The Future of Our Species by Kevin Hong, PhD Student (Biology), Harvard University

Personal and Societal Health by Sana Sharma, Masters Student (Design), Harvard University

See also: simulation

Agustin Rayo (philosophy)

Essays & Videos on Modern Predictive Systems

Ben Shneiderman (artificial intelligence)

Brendan Meade (earthquakes) and Susan Murphy (computer science)

Daniel Kammen (climate change & energy)

David Laibson Behavioral Economics

George Church

Gina McCarthy (climate change)

Immaculata De Vivo and Peter Kraft (health)

Jill Tarter (SETI)

Megan Murray (epidemiology)

Ned Hall (philosophy and prediction)

Rebecca Henderson (business and climate change)

Stuart Firestein (uncertainty in science)

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The Prediction Project
Thoughts, Resources, Course, Seminar and Someday a Book

WELCOME   CONTENT▾   COURSES▾   TALKS+▾   COMMENTARY▾   CREDITS

Essays

UNCERTAINTY ABOUT UNCERTAINTY

Data-Driven Dilemmas posed by COVID-19

HOME / COMMENTARY /

Uncertainty about Uncertainty

by Alyssa A. Goodman, May 18, 2020

This essay accompanies the release of an online tool for visualization of IHME COVID-19 forecasts' evolution over time and a community discussion of visualizations created with the tool.

Uncertainty about the future has motivated predictions for millennia. Sometimes, we're just curious—but other times, we really need to know. As the present pandemic evolves, our urgent societal need to plan has motivated many scientists to predict the spread and effects of the novel coronavirus.

"Uncertainty about Uncertainty"

Models of infectious disease take into account, with varying levels of complexity: how many, and importantly why, people are susceptible, infected, immune, or have succumbed to a virus at any given point in time and space. The mathematics of these models moves people between groups called "Susceptible," "Exposed," "Infected," and "Removed," and so are often called "SEIR" models. At the philosophical other end of the modeling spectrum, what we call "mechanism-agnostic" approaches use information about cases, testing, hospital admissions, and deaths, to create algorithms that forecast what will happen under various combinations of conditions, given what's happened under similar conditions in the past. Purely mechanism-agnostic approaches do not factor in medically-informed information about how an infectious disease spreads.

Coming next: "Risk & uncertainty not the same."

HISTORY OF PANDEMICS

PAN·DEM·IC (of a disease) prevalent over a whole country or the world.

medium.com/nightingale/what-i-learned-from-covid-19-data-visualization-5c684eaa4698

THROUGHOUT HISTORY, as humans spread across the world, infectious diseases have been a constant companion. Even in this modern era, outbreaks are nearly constant.

Here are some of history's most deadly pandemics, from the Antonine Plague to COVID-19.

Death toll

Antonine Plague	165–180	**5M**
Plague of Justinian	541-542	**30-50M**
Japanese Smallpox Epidemic	735-737	**1M**

Black Death (Bubonic Plague) **200M**
1347-1351

Throughout the 17th and 18th centuries, a series of "Great Plagues" routinely ravaged cities across Europe.

Smallpox **56M**
1520

17th Century Great Plagues **3M**
1600

18th Century Great Plagues **600K**
1700

Cholera 6 outbreak **1M**
1817-1923

The Third Plague **12M**
1855

Yellow Fever **100-150K**
LATE 1800s

Spanish Flu **40-50M**
1918-1919

Russian Flu **1M**
1889-1890

HIV/AIDS **25-35M**
1981-PRESENT

Asian Flu **1.1M**
1957-1958

Hong Kong Flu **1M**
1968-1970

March to May 2020

SARS **770**
2002-2003

Swine Flu **200K**
2009-2010

MERS **850**
2012-PRESENT

Ebola **11.3K**
2014-2016

COVID-19 **23.1K**
2019-MAR 26 2020* [ON-GOING]

Time axis: 0, 200, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1450, 1500, 1550, 1600, 1650, 1700, 1725, 1750, 1775, 1800, 1825, 1850, 1875, 1900, 1925, 1950, 1975, 2000

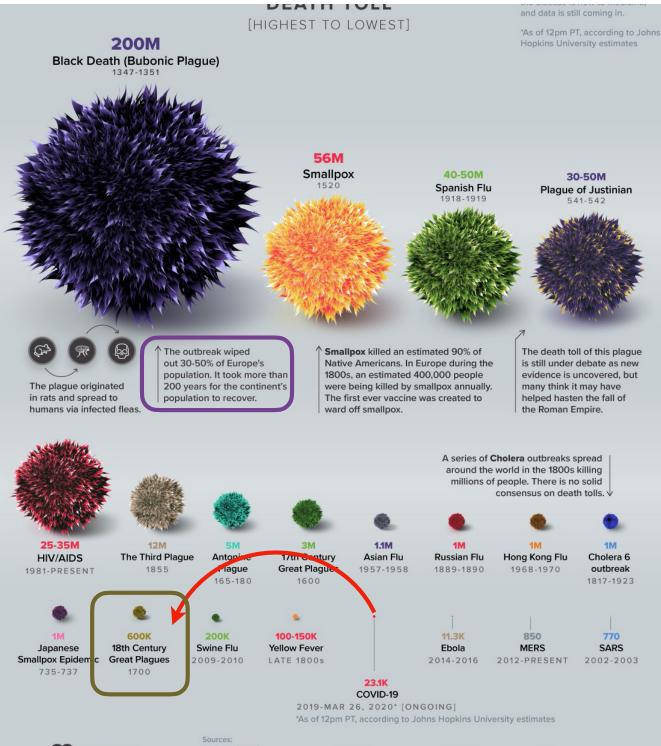**BUT...let's do the RISK calculation properly**

18th Century Great Plagues
600K in 1750
800 million/600K=
1 person in 1,300 dead

COVID-19
300K (so far) in 2020
8 billion/300K=
1 person in 27,000 dead

So, *per capita*, the risk of dying from the 18th Century Great Plague was 27,000 /1,300 = **20x worse** than COVID-19 (so far).

And that was for a relatively "mild" plague.

DEATH TOLL
[HIGHEST TO LOWEST]

the disease is new to medicine, and data is still coming in.

*As of 12pm PT, according to Johns Hopkins University estimates

200M
Black Death (Bubonic Plague)
1347-1351

56M
Smallpox
1520

40-50M
Spanish Flu
1918-1919

30-50M
Plague of Justinian
541-542

The plague originated in rats and spread to humans via infected fleas.

The outbreak wiped out 30-50% of Europe's population. It took more than 200 years for the continent's population to recover.

Smallpox killed an estimated 90% of Native Americans. In Europe during the 1800s, an estimated 400,000 people were being killed by smallpox annually. The first ever vaccine was created to ward off smallpox.

The death toll of this plague is still under debate as new evidence is uncovered, but many think it may have helped hasten the fall of the Roman Empire.

A series of **Cholera** outbreaks spread around the world in the 1800s killing millions of people. There is no solid consensus on death tolls.

25-35M
HIV/AIDS
1981-PRESENT

12M
The Third Plague
1855

5M
Antonine Plague
165-180

3M
17th Century Great Plague
1600

1.1M
Asian Flu
1957-1958

1M
Russian Flu
1889-1890

1M
Hong Kong Flu
1968-1970

1M
Cholera 6 outbreak
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600K
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770
SARS
2002-2003

23.1K
COVID-19
2019-MAR 26, 2020* [ONGOING]
*As of 12pm PT, according to Johns Hopkins University estimates

Sources:
CDC, WHO, BBC, Wikipedia, Historical records, Encyclopedia Britannica, Johns Hopkins University

VISUAL CAPITALIST

/visualcapitalist   @visualcap   visualcapitalist.com

PredictionX

predictionx.org

Slide-the-puck

1. Decide how rough your table is

0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5

2. Click anywhere on the grid to throw the puck

3. Click here to finish the game for you

Height = 0.8, Width = 0.8	Height = 1.7, Width = 0.6	Height = 3.9, Width = 0.5	Height = 8.1, Width = 0.5
Height = 1.2, Width = 0.2	Height = 1.4, Width = 0.5	Height = 4.0, Width = 0.5	Height = 8.1, Width = 0.5
Height = 0.4, Width = 0.2	Height = 1.7, Width = 0.7	Height = 4.6, Width = 1.0	Height = 8.2, Width = 0.5
Height = 0.4, Width = 0.2	Height = 2.1, Width = 1.2	Height = 2.8, Width = 1.2	Height = 4.7, Width = 0.2

Number of games — Number of pucks

Flowchart

Help, I'm lost! → Take out iPhone → iPhone has power, signal & GPS?

- Yes → **Phew—now I'm found!**
  - Measured **longitude** ✔
  - Measured **latitude** ✔
- No → Find my coordinates w/o iPhone

Find **latitude** (N or S of equator) using the Sun or stars → Clear skies?
- Yes → Daytime?
  - Yes → Use the **Sun**. Latitude is the difference between the Sun's declination and its maximum elevation.
  - No → 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.
- No → WAIT

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

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

Use the time at a remote, reference, location.

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

Have a super-accurate timepiece?
- Yes
- No → Do you know the exact location where it was set?
  - No → Clear skies? → Yes / No → WAIT
  - Yes → See Jupiter & its moons?

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

Use **Jupiter's** moons' positions as a clock.

Lunars. Use the known path of the Moon to determine time.

See the moon?

DEREK'S DAY
Algorithmic Forecasting in Everyday Life
The board game

START / FINISH

- WAKE UP — You slept 9 hours — Mental health
- PERFORM MORNING ROUTINE — Reorder today! — items in your cart — Your next box is on the way
- CHECK EMAIL — Inbox (8), Spam (23) — Spam filtering
- GO TO CLASS — ESSAYS DUE TODAY — 0 matches — Plagiarism checker
- EAT LUNCH — Calories 950/2000
- ATTEND SEMINAR — Longevity assessment
- GET COFFEE — REWARDS Buy 9, get 1 free — You have a new message
- PERFORM CIVIC DUTY — JURY DUTY — Austin Court SUMMONS — Bayesian theory in juries
- FLY HOME — BOS AUS — Landing optimization
- Watch Next — AI and Algorithms — The Adpocalypse
- Sales forecasting

Morning — Afternoon — Evening

Climate Change discussed in interviews with Rebecca Henderson (business), Gina McCarthy (policy) Dan Kammen (energy), James Leonard (performance art), Dan Gilbert (psychology)

#RANDOM

#NON-RANDOM

#HUMAN

#RANDOMIZED

PredictionX

Framework for Predictive Systems

#RANDOM

#RANDOMIZED

#HUMAN

#NON-RANDOM

Observe

PREDICTIVE SYSTEM

MAKE PREDICTION!

EVALUATE ACCURACY

MAKE CHANGES

Which parts of PredictionX interest you most?

PREDICTIONX: THE PAST & PRESENT OF THE FUTURE

ESSENTIALS

- Predictive Systems Framework
- Phenomena →Predictions
- Understanding Uncertainty
- Study Design
- 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
Turkish Tasseography
Maya Spacetime

Yoruba Ifa
Casting Lots
Greek Astronomy
Astrology
Comets of Doom

cross-cultural conversations

THE RISE OF THEORY

Ancient Mesopotamia, Egypt, Greece & Rome
Islamic Science

The Path to Newton
- Indian Mathematics
- European Renaissance

Lost without Longitude (Navigation)
- Help, I'm Lost!
- Tools of the Navigator

The Royal Society

MODERN SIMULATION

Health
▷ Epidemiology
▷ Personal Genomics
▷ Population Genetics

John Snow & Cholera
Cholera Map

Wealth
▷ Climate & Wealth
▷ Behavioral Economics

The Future of the Future
▷ AI, Derek's Day
▷ Philosophy
▷ Uncertainty

Earth
▷ Climate & Energy
▷ Climate Policy
▷ Tent Tarot
▷ Earthquakes

Space
▷ Futures of our Universe
▷ SETI

Coming Soon   Interactive Resource   ▷ video(s)   edX on edX as mini-course, otherwise find material via predictionx.org

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LEARNERS

Use LabXchange to enhance your personal learning experience. Explore the library and engage with a supportive learning community.

EDUCATORS

Use LabXchange to grow as an educator. Help others discover science with our flexible content creation tools. Create classes for groups of learners, and guide their progress.

Start your journey in science

Explore the scientific process

Hear stories from real scientists

Think like a scientist

Remix learning content

Collaborate with others

Chart your own path

So many thanks!

Newton's *Principia*
(the real one from 1687)

HarvardX (especially Drew Lichtenstein, Jais Brohinsky, Colin Fredericks, Annie Valva, Mirac Suzgun, Bharat Anand, and Rob Lue)

GenEd TFs (Michael Foley, Sana Sharma, Harshil Kamdar, Kevin Hong, Tanveer Karim)

Freshman Seminars (Ofrit Liviatan)

Harvard Libraries and Museums

LabXchange (Gaurav Vazirani, Rob Lue)

The Faculty (see predictionx.org/about)

The Radcliffe Institute (especially Becky Wassarman & Immaculata De Vivo)

The Academic Technology Group (especially Bill Barthelmy)

The Corporation

So many others, including Katie Peek, Howard Cutler, Curtis Wong, and F. Ortiz.
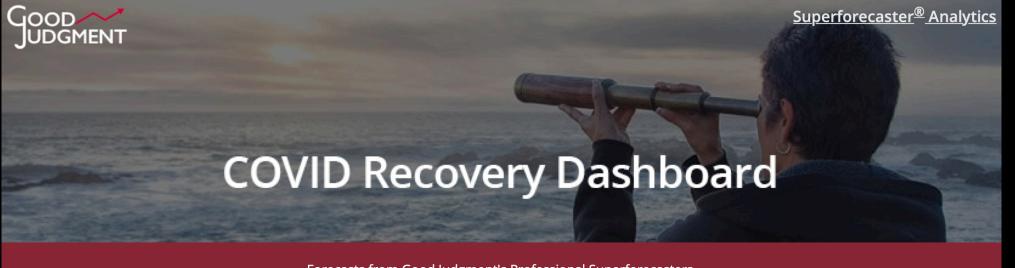
Prediction *versus* Prophecy

Alyssa A. Goodman

Robert Wheeler Willson Professor of Applied Astronomy • co-Director for Science, Radcliffe Insitute for Advanced Study
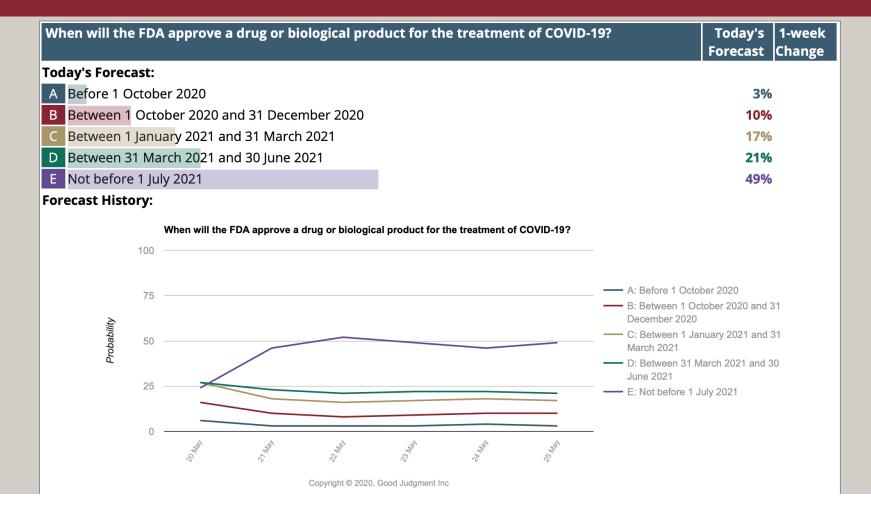
@AlyssaAGoodman

Next few slides show some "Answers" to a few questions submitted in advance of the talk (not shown live)

"This spring, faculty members had essentially 10 days to pivot from their normal pedagogy to online teaching, and as a result, they were pressed to master new technology and to adapt their classes very very quickly," he said. "If we are online in the fall, it will be with courses — at least a majority of courses — that have been designed to be taught online."

https://www.thecrimson.com/article/2020/5/24/harvard-coronavirus-bacow-fall-planning/
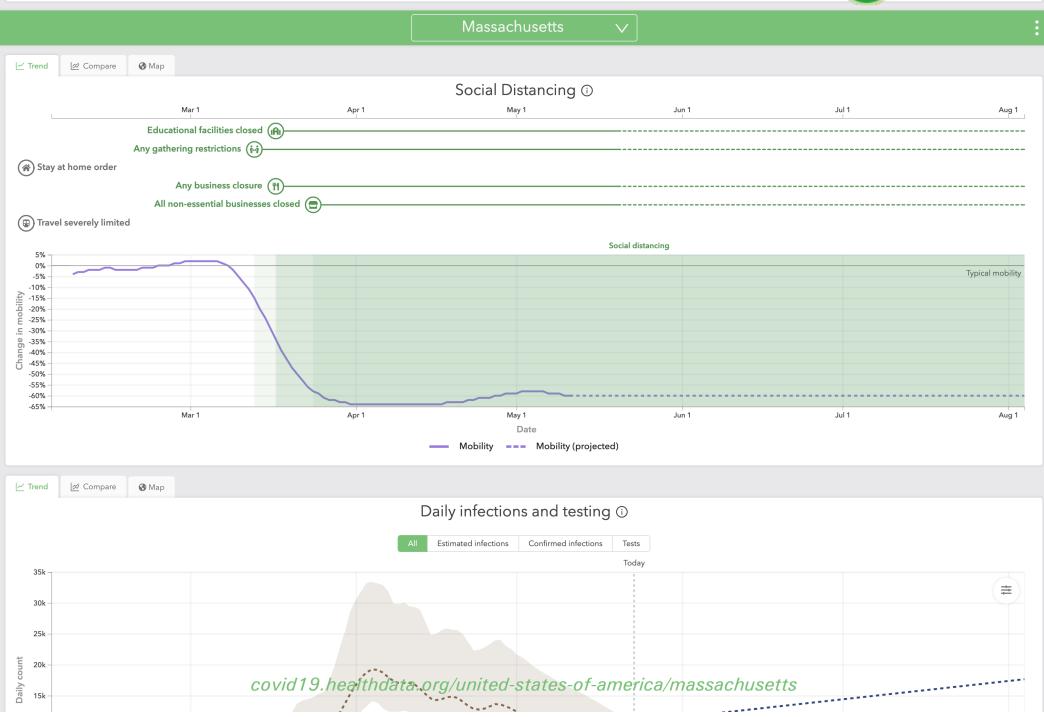
COVID Recovery Dashboard

Forecasts from Good Judgment's Professional Superforecasters.
Probability values are updated daily at 7:00AM US Eastern time.

When will the FDA approve a drug or biological product for the treatment of COVID-19?	Today's Forecast	1-week Change
Today's Forecast:		
A Before 1 October 2020	**3%**	
B Between 1 October 2020 and 31 December 2020	**10%**	
C Between 1 January 2021 and 31 March 2021	**17%**	
D Between 31 March 2021 and 30 June 2021	**21%**	
E Not before 1 July 2021	**49%**	

Forecast History:

When will the FDA approve a drug or biological product for the treatment of COVID-19?

Legend:
- A: Before 1 October 2020
- B: Between 1 October 2020 and 31 December 2020
- C: Between 1 January 2021 and 31 March 2021
- D: Between 31 March 2021 and 30 June 2021
- E: Not before 1 July 2021

Last updated May 20, 2020 (Pacific Time).
FAQ | Update Notes | Article

IHME

Massachusetts ⌄

⚬⚬⚬

📈 Trend   📊 Compare   🌐 Map

Social Distancing ⓘ

Mar 1   Apr 1   May 1   Jun 1   Jul 1   Aug 1

Educational facilities closed 🏛 ───────────────────────────────────────
Any gathering restrictions 👥 ───

🏠 Stay at home order

Any business closure 🍴 ──
All non-essential businesses closed 🏪 ───────────────────────────────

🚆 Travel severely limited

Social distancing

Typical mobility

5%
0%
-5%
-10%
-15%
-20%
-25%
-30%
-35%
-40%
-45%
-50%
-55%
-60%
-65%

Change in mobility

Mar 1   Apr 1   May 1   Jun 1   Jul 1   Aug 1

Date

━━━ Mobility   ┅┅┅ Mobility (projected)

📈 Trend   📊 Compare   🌐 Map

Daily infections and testing ⓘ

[All | Estimated infections | Confirmed infections | Tests]

Today

35k

30k

25k

20k

Daily count

15k

covid19.healthdata.org/united-states-of-america/massachusetts

Highly recommended books on $ Economics

(your textbook)   Behavioral Economics   AI & Economics