

ME 240: Fundamentals of Instrumentation & Measurement



University
of Rochester

Eratosthenes of Cyrene



Alternate interior
angles are
equal

Centre
of the
Earth

Angle from lengths of the
pole and its shadow:
 $1/50$ of a circle
($\sim 7^\circ$)

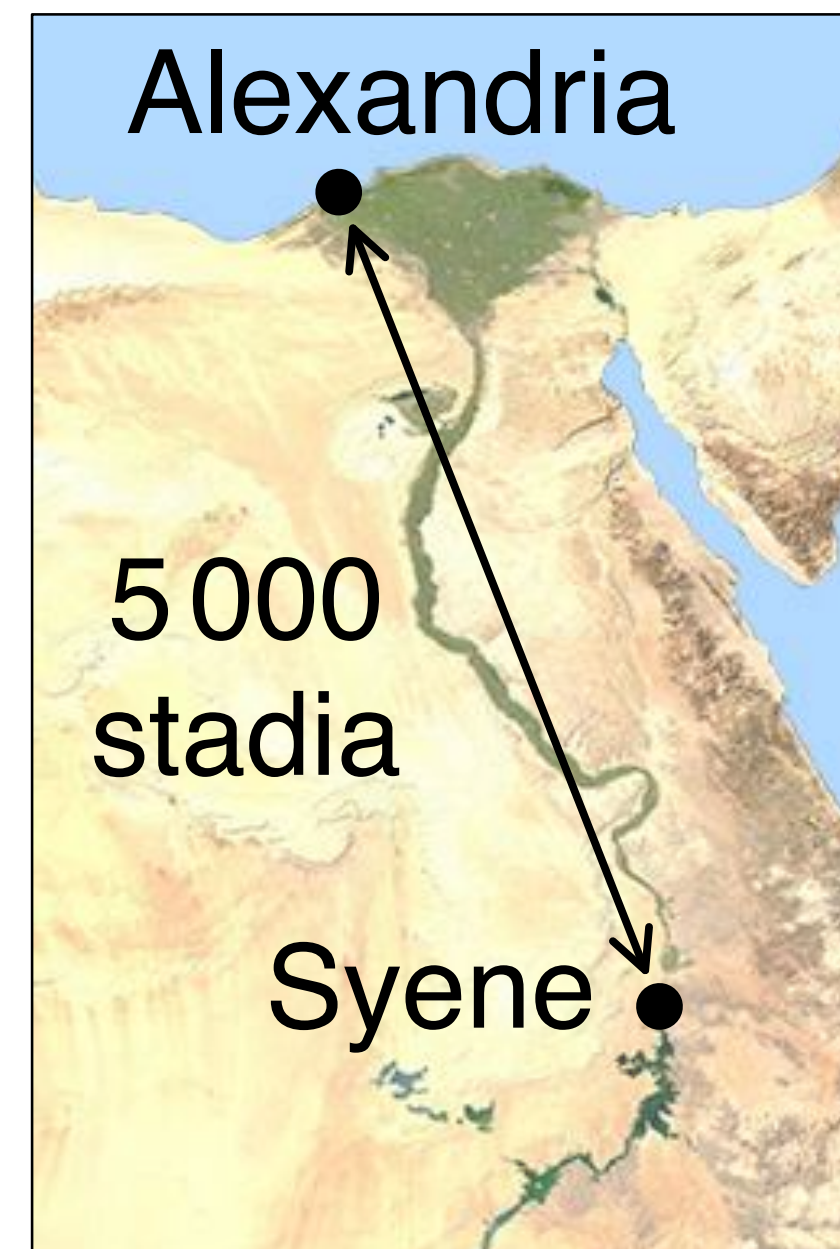
Pole's
shadow

Pole at
Alexandria

Parallel
sun rays

Well at
Syene
(Aswan)

39,060 to 40,320 km
true value: 40,075 km
error: -2.4 to 0.8%



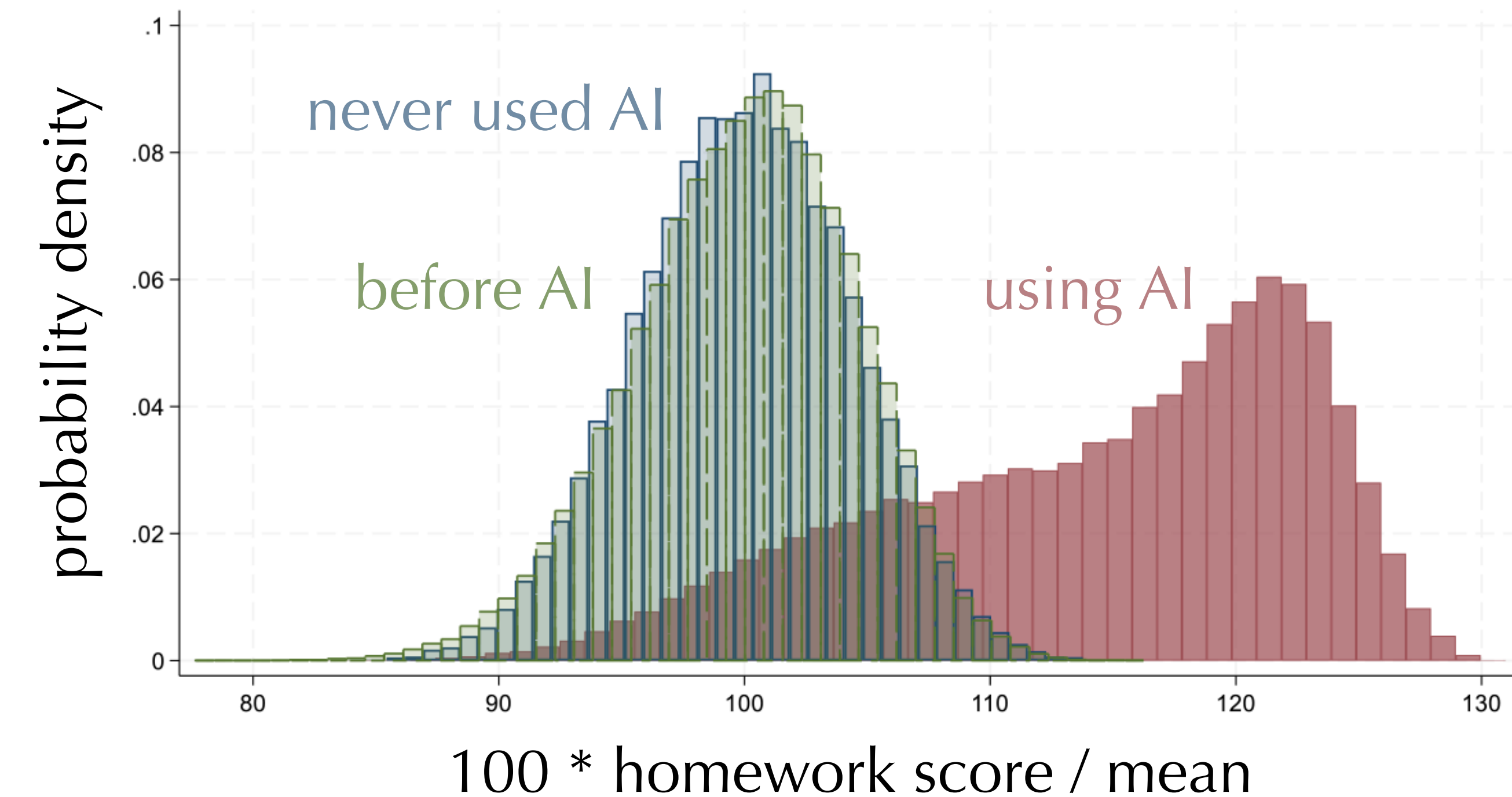
<https://en.wikipedia.org/wiki/Eratosthenes>

Laser Interferometer Gravitational Wave Observatory

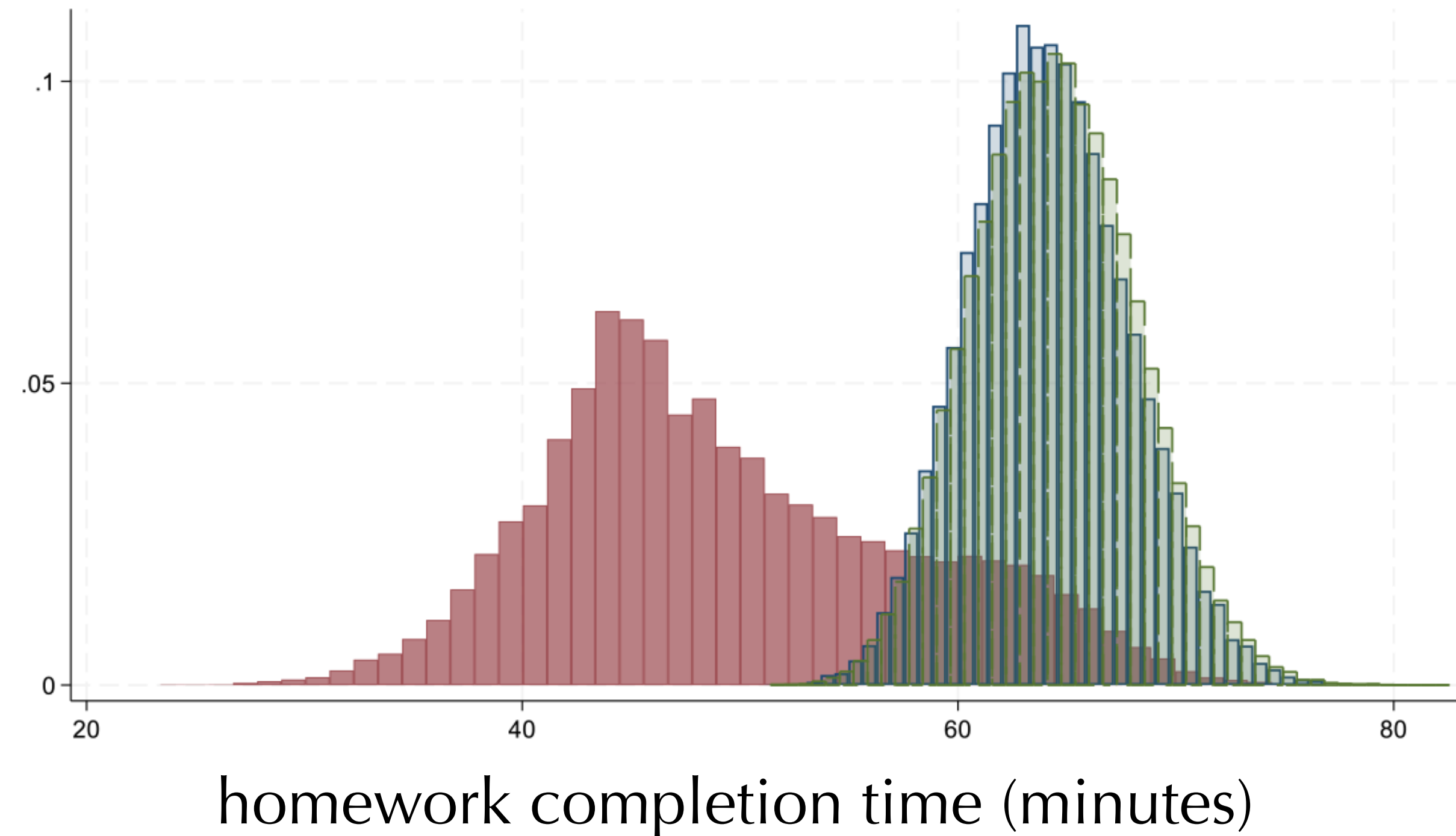
- Two detectors: Hanford, WA and Livingston, LA
- 4 km long, effective laser beam length 1200 km
- Measures displacements 10,000 times smaller than atomic nucleus
 - Nucleus $\sim 1 \text{ fm} = 10^{-15} \text{ m}$
 - Sensitivity about $10^{-15} \text{ m} / 10,000 / 4 \text{ km} = 2.5 \times 10^{-24}$!
- First detection of gravitational waves (3 black hole mergers, 2015-2016)
- 2017 Nobel prize to Rainer Weiss, Kip Thorne, and Barry Barish

Using Artificial Intelligence for Homework

- 26,811 students age 12-18 in China



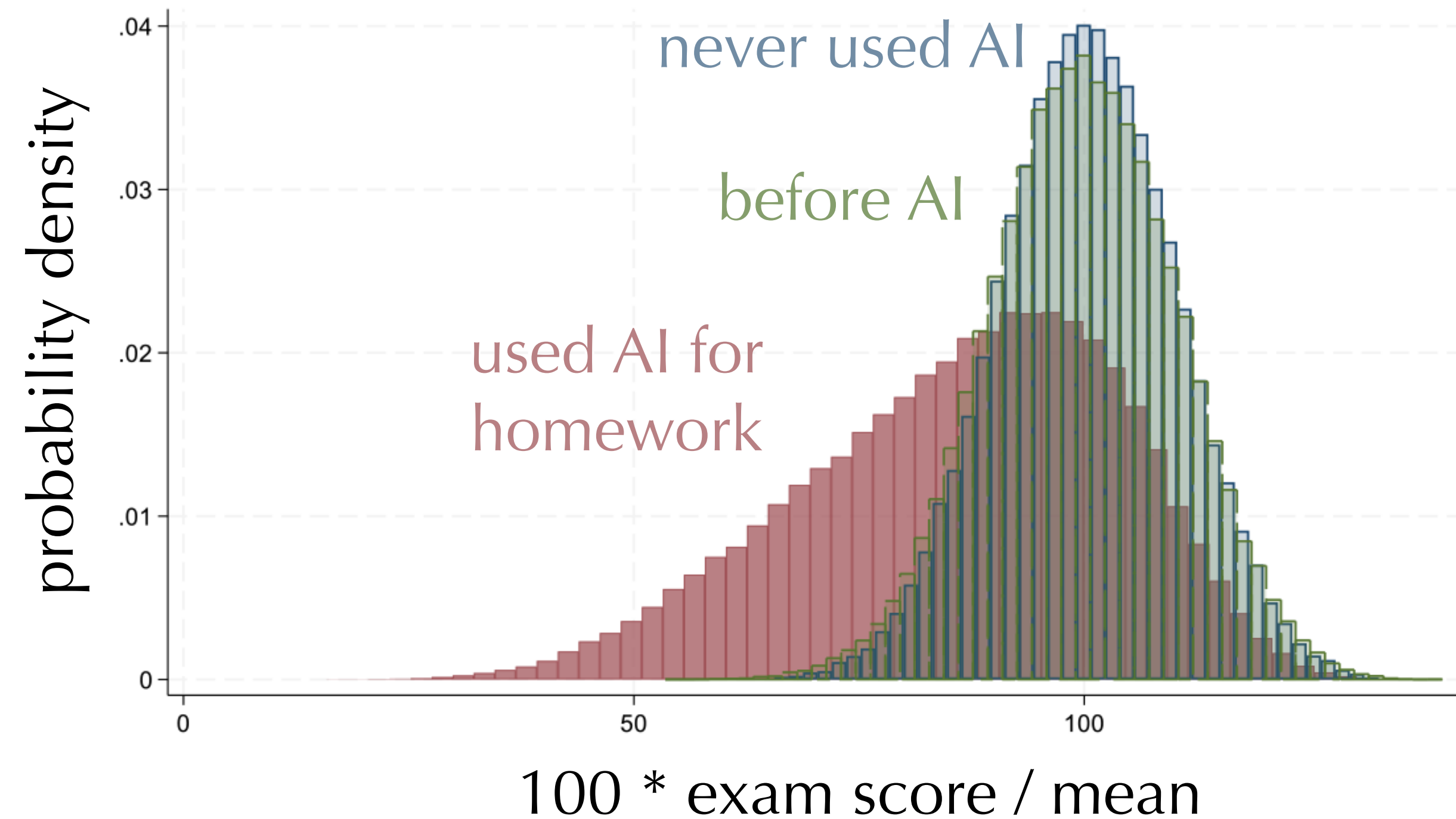
Students using AI
scored higher



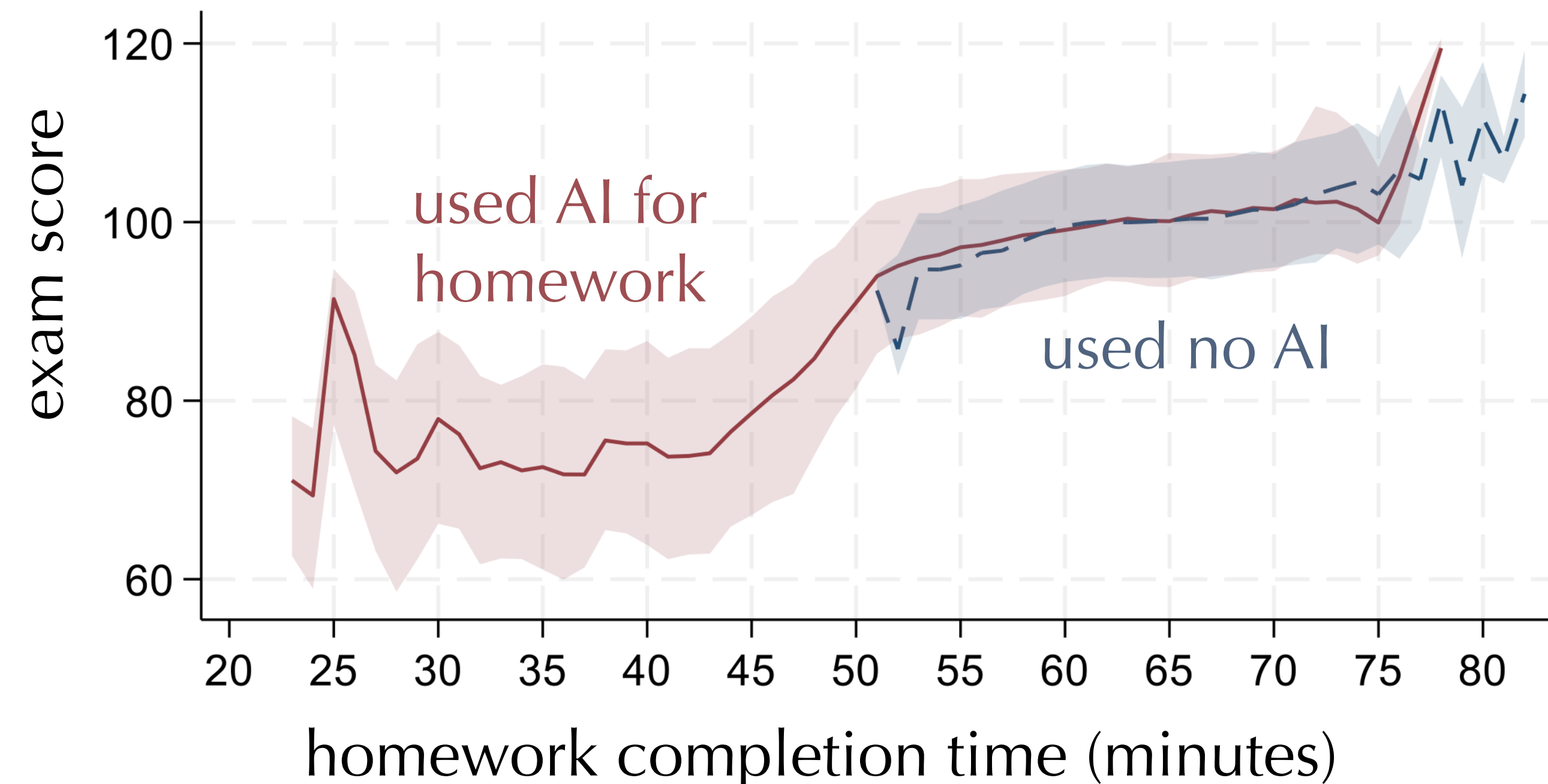
Students using AI
finished quicker

Using Artificial Intelligence for Homework

9



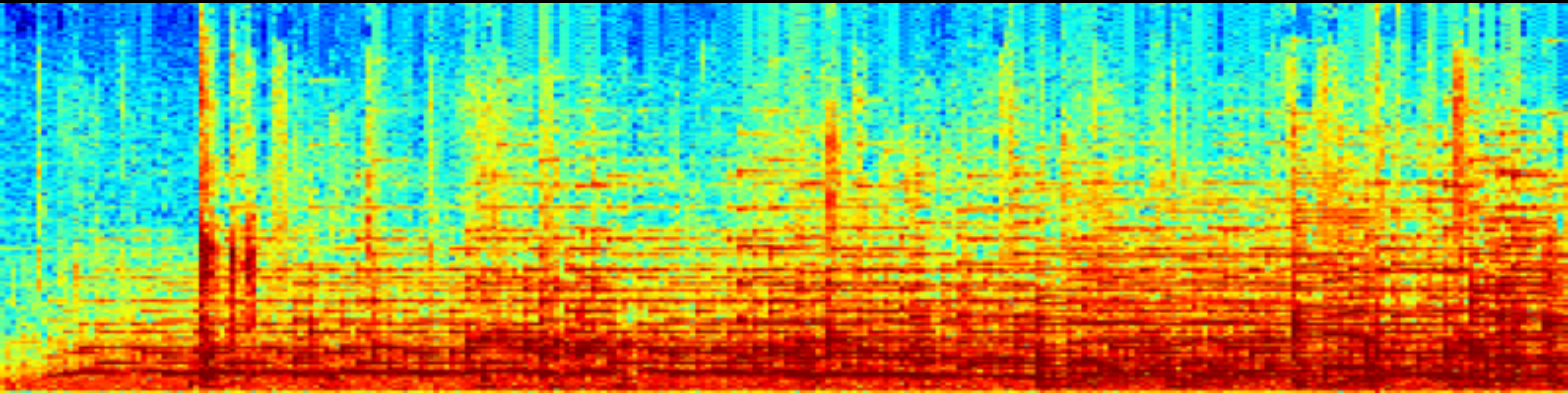
Students using AI on homework
scored lower on exams...



...unless they
spent enough time

Introduction to Measurement

Wheeler & Ganji Chapter 2



measure (v): ascertain the size, amount, or degree of (something) by using an instrument or device marked in standard units or by comparing it with an object of known size

Error

- No measurement is perfect! How good is it? An engineer's goal is to estimate error.
- $\text{error} = \text{measured value} - \text{true value}$
- Every error can be classified as one of two types:
 - **Systematic error** is consistent and repeatable. It signals a shortcoming of the measurement system and can be calibrated away.
 - $\text{systematic error} = \text{average of readings} - \text{true value}$
 - **Random error** is the error that remains after systematic error is eliminated and varies from each reading to the next (not repeatable).
 - $\text{random error} = \text{reading} - \text{average of readings}$

Loading error

- A **loading error** occurs when the measurement process influences its outcome.
- Q: Systematic or random?
- Example: An alcohol thermometer is used to measure two temperatures: that of a cup of coffee and that of a swimming pool. Which outcome is more affected by the measurement process?
- The coffee. The thermometer measures *its own* temperature and must come into thermal equilibrium with the material it's meant to measure. The coffee contains less heat and is therefore affected more strongly.

Dynamic measurements

- Example: Plunge an alcohol thermometer into a swimming pool. To accurately measure the pool's temperature, you'll need to wait. Why?
- The thermometer must come into equilibrium with the pool.
- First law of thermodynamics: rate of heat inflow = rate of change of thermal energy

thermometer surface area thermometer temperature thermometer specific heat

$$hA(T_p - T_t) = mc \frac{dT_t}{dt} \text{ — time}$$

heat transfer coefficient pool temperature thermometer mass characteristic measurement time τ

- Algebra leads to $T_p - T_t = \boxed{\frac{mc}{hA}} \frac{dT_t}{dt}$

- Small τ implies quick response time (desirable) but may compromise robustness

Dynamic measurements

