MRC | Biostatistics Unit

UNIVERSITY OF CAMBRIDGE

Certain and uncertain discoveries

Statistical thinking at the heart of science

Dr Simon R. White
Department of Psychiatry and MRC Biostatistics Unit
University of Cambridge
2019/Mar/21

Certain and uncertain discoveries

MRC Biostatistics Unit
UNIVERSITY OF CAMBRIDGE

Certain and uncertain discoveries

Statistical thinking at the heart of science

Dr Simon R. White
Department of Psychiatry and MRC Biostatistics Unit
University of Cambridge
2019/Mar/21

We'll begin without controversy, but move on to ever more uncertainty. Throughout, we'll be thinking about how the key scientific question has some uncertainty.

Uncertainty is not a bad thing, we all live with uncertainty – will it rain today, there is no prediction that is always right. But that doesn't matter that much, but sometimes it can.

π

Certain and uncertain discoveries

π

2019-03-21

π

What is π?

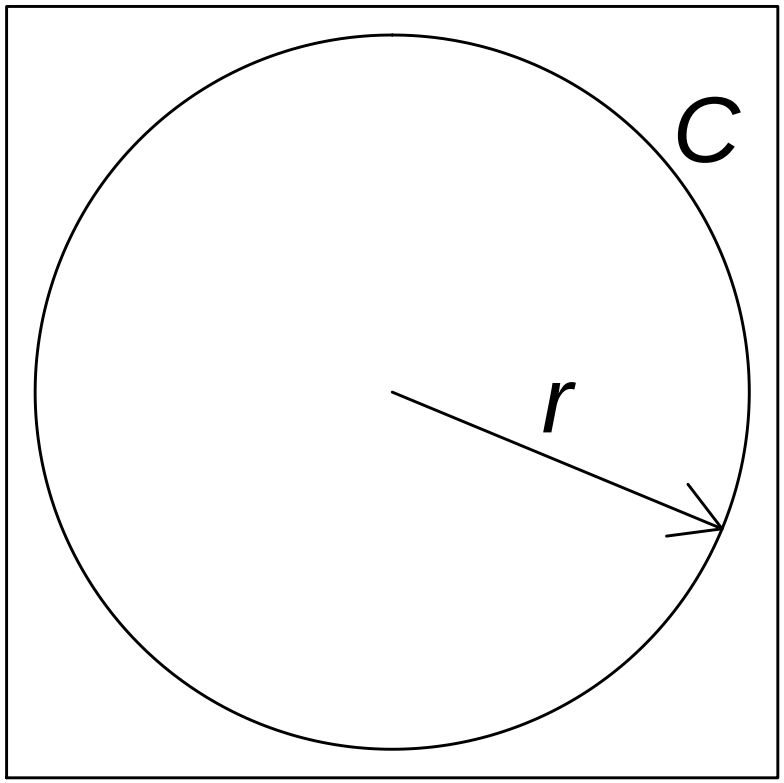
$$\pi = \frac{c}{2r}$$

$$\pi = \frac{c}{2r}$$

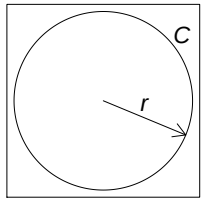
One of the oldest problems in geometry, dating back thousands of years with really important uses: building and construction, navigation, physics and mathematics.

What is π?

$$\pi = \frac{c}{2r}$$

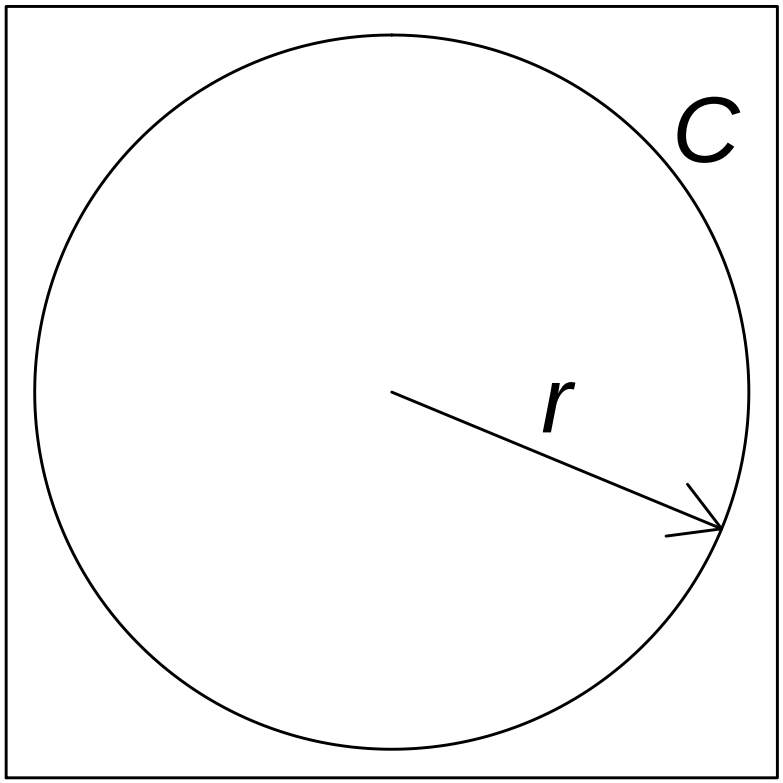


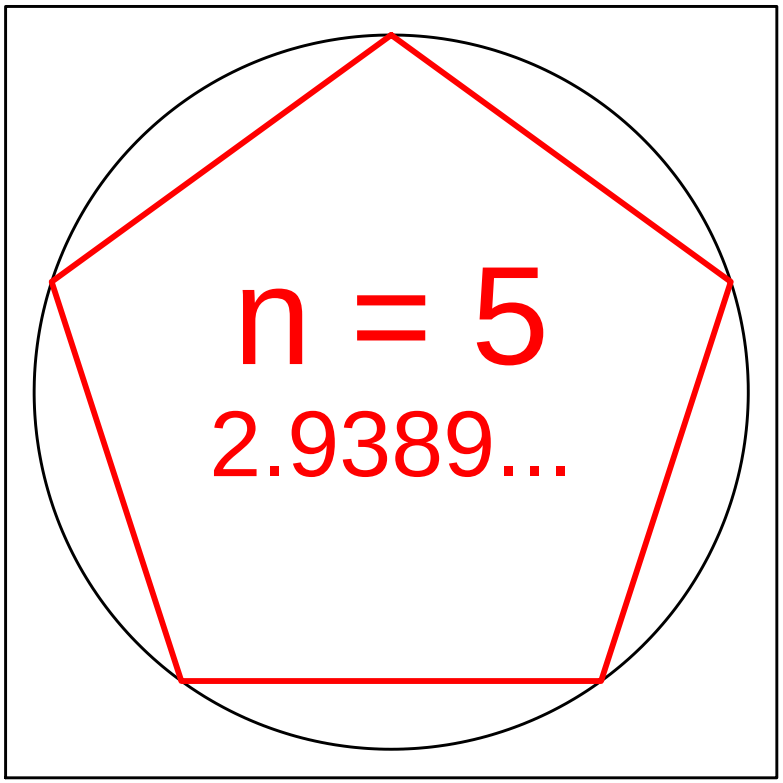
$$\pi = \frac{c}{2r}$$

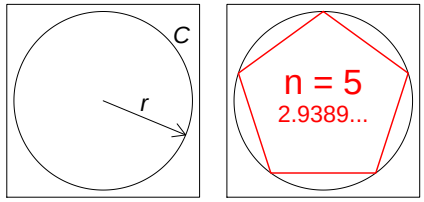


But how do we calculate π?

What is π?

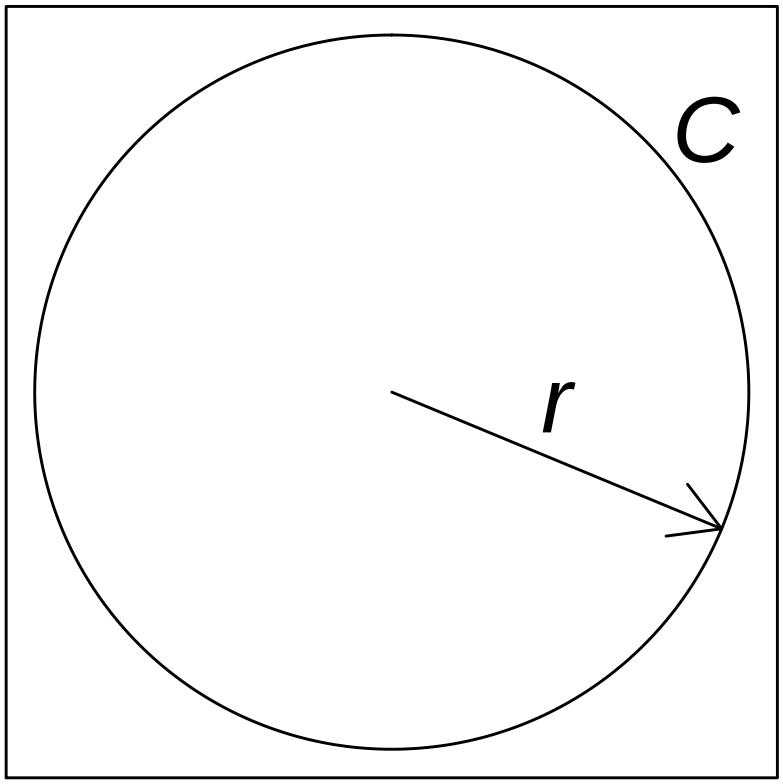


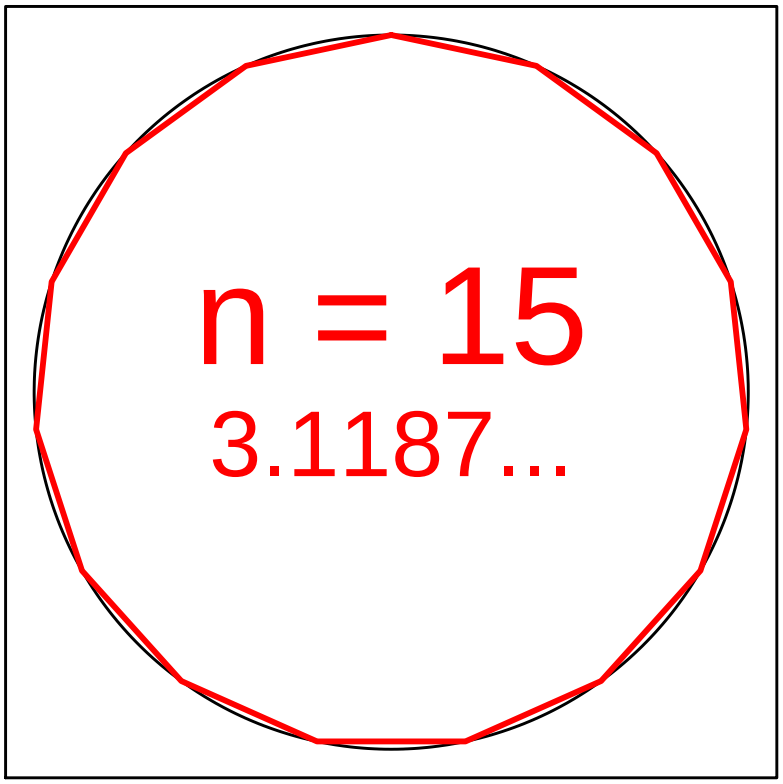


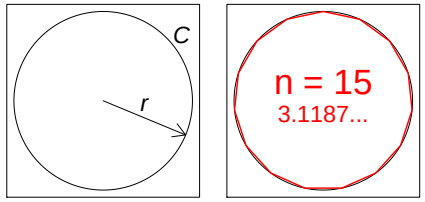


The polygon approximation was developed thousands of years ago, before modern mathematics it was the most reliable way.

What is π?



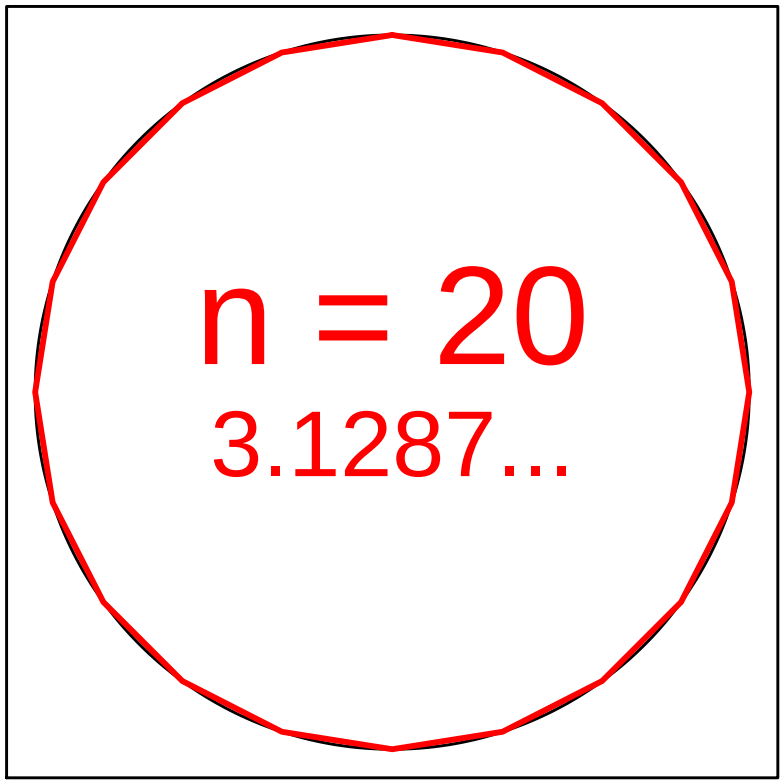




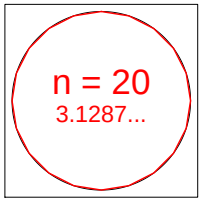
The approximation improves the more sides we include. Remember, at the time the method of calculating the perimeter of the polygon was very, very time consuming.

What is π?

$$\pi = 3.142857\ldots$$



$\pi = 3.142857\ldots$



Compare to the “modern” value of π.

But it’s not actually the real value, this is still an approximate answer (unlikely anyone in the audience will notice the incorrect value, but someone might) - but it is actually reasonably good.

What is π?

$$\pi \approx \frac{22}{7}$$
$$= 3.142857\ldots$$

$$\pi = 3.141592\ldots$$

$\pi \approx \frac{22}{7}$
$= 3.142857\ldots$

$\pi = 3.141592\ldots$

Archimedes upper bound of 22/7, derived in 250BC using 96-sided polygon. Quite an old approximation.

So in summary, π is a mathematical constant with a fixed true value, but it took centuries to obtain a reliable method to calculate it.

In the 14^{th}–16^{th} Century various Indian mathematicians develop infinite series; these ideas were derived again in the 16^{th}–17^{th} Century in Europe.

Until then, only approximations were available. We now know π to millions of decimal places, but we will never know it exactly (it is impossible to right it down exactly, it is a transcendental irrational number).

Standard gravity

Standard gravity

Gravity

“scientific theory”

An explanation of an aspect of the natural world that can be repeatedly tested and verified in accordance with the scientific method, using accepted protocols of observation, measurement, and evaluation of results.

“theory” in common language

In everyday speech, theory can imply an explanation that represents an unsubstantiated and speculative guess.

“laws” in science

Describe or predict a range of natural phenomena.

"scientific theory"
An explanation of an aspect of the natural world that can be repeatedly tested and verified in accordance with the scientific method, using accepted protocols of observation, measurement, and evaluation of results.

"theory" in common language
In everyday speech, theory can imply an explanation that represents an unsubstantiated and speculative guess.

"laws" in science
Describe or predict a range of natural phenomena.

`https://en.wikipedia.org/wiki/Scientific_theory`

Part of the "science denial" movement is based on mis-representation, this has been particularly true when discussing the Theory of Evolution and to some extent the Theory of Gravity (people who believe the earth is flat).

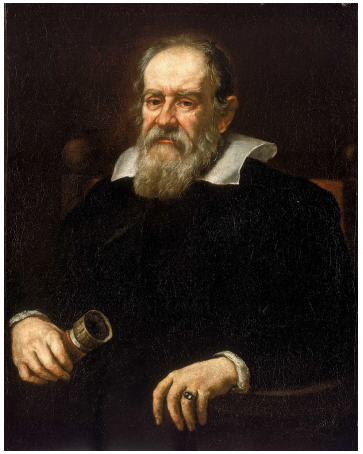
Language and definitions are important, as a statistician I wwould say that definitions and being precise are fundamental, but sometimes these details can confuse discussions/debate.

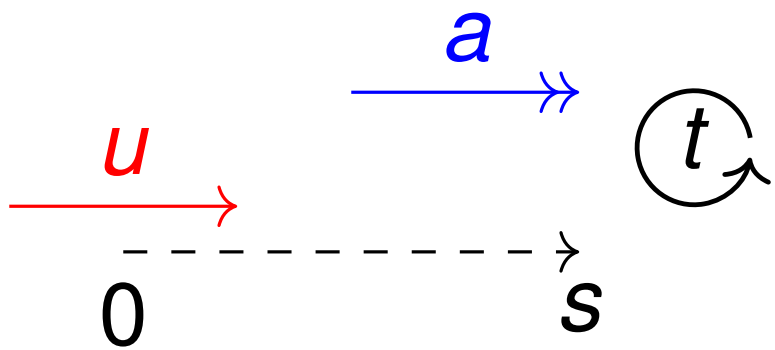
Example scientific theories: Theory of Probability, Theory of Evolution, Plate Tectonics, Attribution Theory.

Example scientific laws: Laws of Probability, Laws of Motion, Laws of Gravity (Special and General Relativity), Laws of Thermodynamics.

How to estimate standard gravity, g

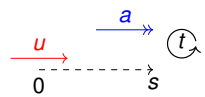
Consider Galileo's famous Leaning Tower of Pisa experiment which shows that objects fall at the same rate regardless of their mass.
Using the equations/laws of motion (developed over many centuries) we can conduct an experiment to determine standard gravity.





$$s = ut + \frac{1}{2}at^2$$

Consider Galileo's famous Leaning Tower of Pisa experiment which shows that objects fall at the same rate regardless of their mass.
Using the equations/laws of motion (developed over many centuries) we can conduct an experiment to determine standard gravity.

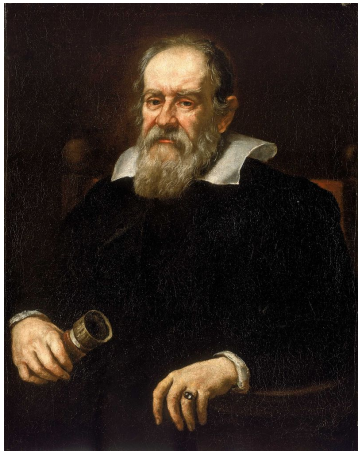


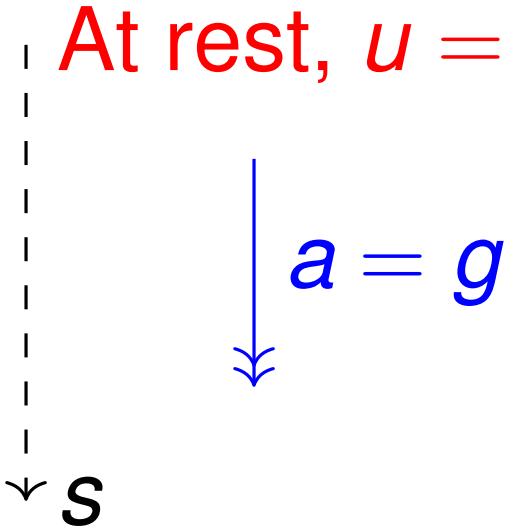
$$s = ut + \frac{1}{2}at^2$$

The equations of motion, also known as the SUVAT equationsVisual of the equation of motion we will use.

How to estimate standard gravity, g

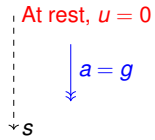
Consider Galileo's famous Leaning Tower of Pisa experiment which shows that objects fall at the same rate regardless of their mass.
Using the equations/laws of motion (developed over many centuries) we can conduct an experiment to determine standard gravity.





$$\frac{2}{g}s = t^2$$

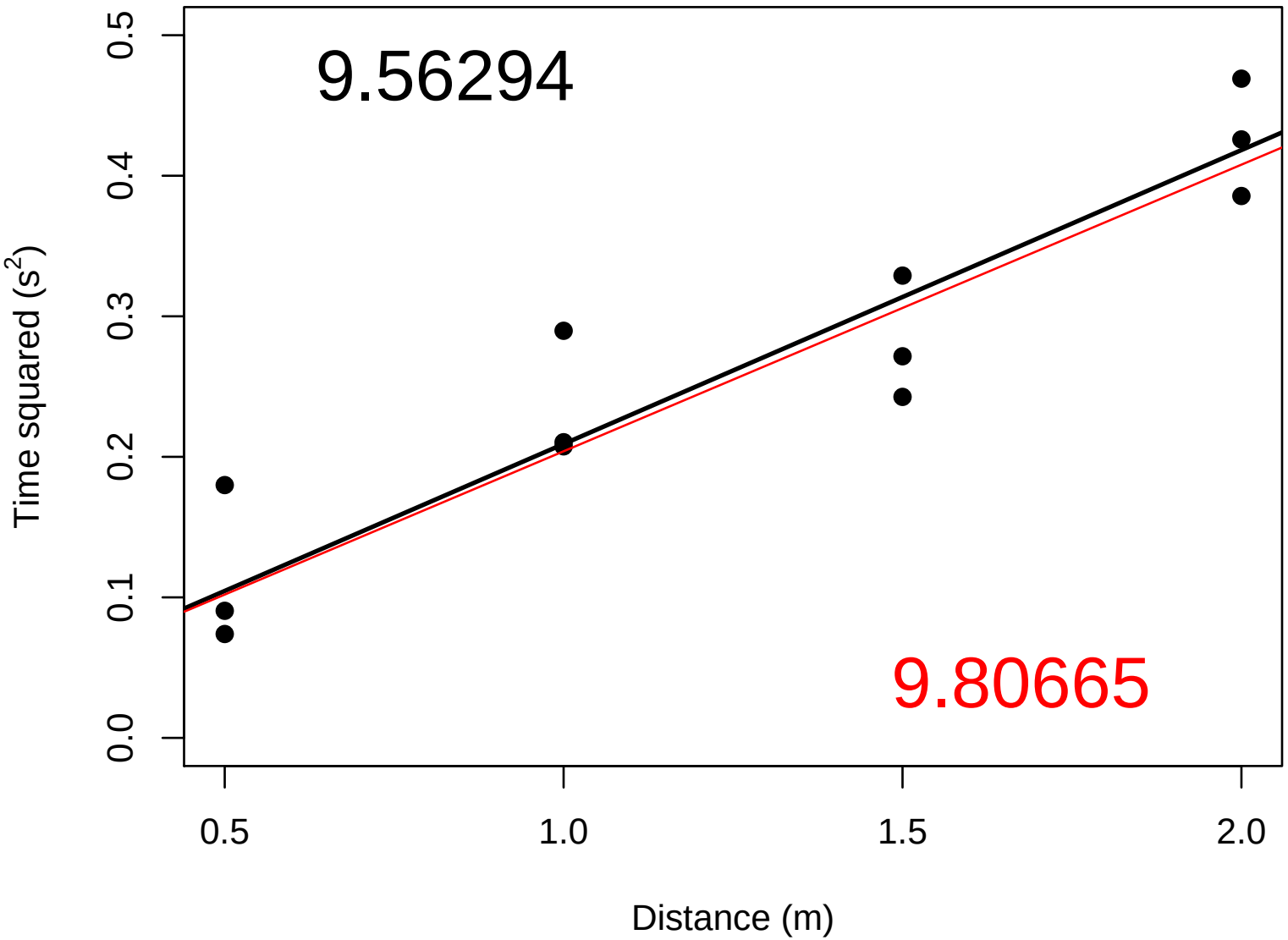
Consider Galileo's famous Leaning Tower of Pisa experiment which shows that objects fall at the same rate regardless of their mass.
Using the equations/laws of motion (developed over many centuries) we can conduct an experiment to determine standard gravity.

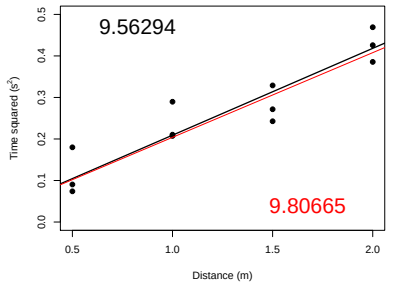


$$\frac{2}{g}s = t^2$$

Redraw to illustrate how we will apply the equation to a falling object, and use this to estimate (standard) gravity.The formula we will use to estimate g.

How to estimate standard gravity, *g*





Plotting the results from an experiment and estimating (standard) gravity.

Now we have meet measurement error within science, the idea that we can only measure aspects of the world to a certain accuracy. We have continually improved our measurement techniques, but there are still limits to what we can achieve.

The internationally accepted value of standard gravity is 9.80665 in a vaccum near the surface of the earth.

However, sometimes it doesn't matter as much as you might think. For example, when using π to navigate through space

Smoking causes lung cancer

Certain and uncertain discoveries
Smoking causes lung cancer

Smoking causes lung cancer

What is the question?

- What do we mean by smoking?
  - People start and stop smoking during their lives.
  - They change how their quantitiy of smoking.
  - Tobacco can be consumed in many ways (cigarette, pipe, even chewed)
- Why lung cancer?
  - Alternative: does smoking reduce your life expectancy?
  - Alternative: does smoking increase risk of all cancers?
- What information/data would we need to answer this question?
- How certain about our answer would we be?

Certain and uncertain discoveries

Smoking causes lung cancer

What is the question?

What is the question?

- What do we mean by smoking?
  - People start and stop smoking during their lives.
  - They change how their quantitiy of smoking.
  - Tobacco can be consumed in many ways (cigarette, pipe, even chewed)
- Why lung cancer?
  - Alternative: does smoking reduce your life expectancy?
  - Alternative: does smoking increase risk of all cancers?
- What information/data would we need to answer this question?
- How certain about our answer would we be?

History of smoking and lung cancer

- In the early 20th Century (i.e. 1900s) some people began to suspect a link between tobacco and ill health.
-

Certain and uncertain discoveries

Smoking causes lung cancer

History of smoking and lung cancer

- In the early 20th Century (i.e. 1900s) some people began to suspect a link between tobacco and ill health.
-

Brain training

Certain and uncertain discoveries
Brain training

Brain training

What is brain training?

Certain and uncertain discoveries

Brain training

What is brain training?

Summary

Summary

Summary: computing π

Of scientific interest for (approximately): 2000 years

As a mathematical constant there is an exact answer.

Might have assumed π was always certain, but it's value was uncertain for centuries.

Of scientific interest for (approximately): 2000 years

As a mathematical constant there is an exact answer.

Might have assumed π was always certain, but it's value was uncertain for centuries.

Summary: estimating standard gravity constant

Of scientific interest for (approximately): 400 years

We first met the idea of measurement error.

We can define a clear experiment using the Laws of Motion.

The constant is well defined (ish).

Standard gravity is certain (but it varies).

Certain and uncertain discoveries

Summary

Summary: estimating standard gravity constant

Summary: estimating standard gravity constant

Of scientific interest for (approximately): 400 years

We first met the idea of measurement error.

- We can define a clear experiment using the Laws of Motion.
- The constant is well defined (ish).

Standard gravity is certain (but it varies).

Summary: smoking(/tobacco) links to lung cancer

Of scientific interest for (approximately): 100 years

A simple question becomes complex when you try to answer it:

The negative outcome, developing lung cancer, is well defined.

The (negative) exposure, smoking, has some ambiguity.

We have never proved beyond doubt that smoking causes lung cancer in humans – completely unethical.

Certain and uncertain discoveries

Summary

Summary: smoking(/tobacco) links to lung cancer

Summary: smoking(/tobacco) links to lung cancer

Of scientific interest for (approximately): 100 years

A simple question becomes complex when you try to answer it:

- The negative outcome, developing lung cancer, is well defined.
- The (negative) exposure, smoking, has some ambiguity.

We have never proved beyond doubt that smoking causes lung cancer in humans – completely unethical.

Summary: brain training protects against developing dementia

Of scientific interest for (approximately): 25 years

A simple question becomes complex when you try to answer it:

The negative outcome, dementia, is not well defined.

The outcome in some studies is not even dementia.

The activity, brain training, is not well defined.

Highly uncertain what benefit (for dementia) there is in brain training, but evidence of benefit in broader cognitive health.

Certain and uncertain discoveries

Summary

Summary: brain training protects against developing dementia

Summary: brain training protects against developing dementia

Of scientific interest for (approximately): 25 years

A simple question becomes complex when you try to answer it:

- The negative outcome, dementia, is not well defined.
  - The outcome in some studies is not even dementia.
- The activity, brain training, is not well defined.

Highly uncertain what benefit (for dementia) there is in brain training, but evidence of benefit in broader cognitive health.

Thank you

@SimonWhite83

Certain and uncertain discoveries
Summary

Thank you

@SimonWhite83