

IPM component 3



Term 1, week 5

On replicability and falsifiability

The need for replicability, verifiability, and falsifiability

Falsifiable statements

1) "Water above 0°C is liquid"

- This statement can be verified. It is open to being falsified or not, as follows:
 - Measure the temperature of water at different pressures (say at sea level, then on Everest)

The need for replicability, verifiability, and falsifiability



Falsifiable statements

1) "Water above 0°C is liquid"

- This statement can be verified. It is open to being falsified or not, as follows:
 - Measure the temperature of an iceberg and the water below it.

The need for replicability, verifiability, and falsifiability

Falsifiable statements

1) "Water above 0°C is liquid"

- This statement can be verified. It is open to being falsified or not, as follows:
 - Water contracts between 0°C and 4°C and can therefore become solid. This is why ice (a solid) floats on water (a liquid).

The need for replicability, verifiability, and falsifiability



Replicable statements

1) "Water above 0°C is liquid"

- This statement is also replicable in the sense that we can repeat the experiment:
 - Take measurements from 100 different icebergs in 100 different locations in the north Atlantic ocean.

The need for replicability, verifiability, and falsifiability

Falsifiable statements

2) "Water boils at 100°C"

- This statement can be verified. It is open to be confirmed or not, i.e. falsified, as follows:
 - Boil water at different pressures (say at sea level, then on Everest)

The need for replicability, verifiability, and falsifiability

Falsifiable statements

2) "Water boils at 100°C"

- This statement can be verified. It is open to be confirmed or not, i.e. falsified, as follows:
 - The higher your altitude the lower the boiling point of water. On Everest the boiling point of water is $\sim 72^{\circ}\text{C}$.

The need for replicability, verifiability, and falsifiability



Replicable statements

2) "Water boils at 100°C"

- This statement is also replicable in the sense that we can repeat the experiment:
 - 100 experiments at the same altitude/pressure;
 - The same experiment at 100 different altitudes/pressures.

Replicability and repeatability



- There is a distinction between replicability and repeatability.
- As an example consider the experiment of determining the boiling point of water:
 - *Equipment:* Kettle, mercury thermometer, tap water
 - *Environment:* experiment performed at home
 - *Procedure/Protocol:* “Procedures 1”

Replicability and repeatability



- There is a distinction between replicability and repeatability.
 - *Repeating an experiment:*
 - use exactly the same equipment,
 - set up the equipment in exactly the same way,
 - Perform the experiment in exactly the same physical conditions and environment

Replicability and repeatability



- There is a distinction between replicability and repeatability.
 - *Repeating an experiment:*
 - *Equipment:* Kettle, mercury thermometer, tap water
 - *Environment:* experiment performed at home
 - *Procedure/Protocol:* "Procedures 1"

Replicability and repeatability



- There is a distinction between replicability and repeatability.
 - *Replicating an experiment: Version 1*
 - *Equipment:* Pan, mercury thermometer, tap water;
 - *Environment:* experiment performed in a clean room;
 - *Procedure/Protocol:* “Procedures 2”

Replicability and repeatability

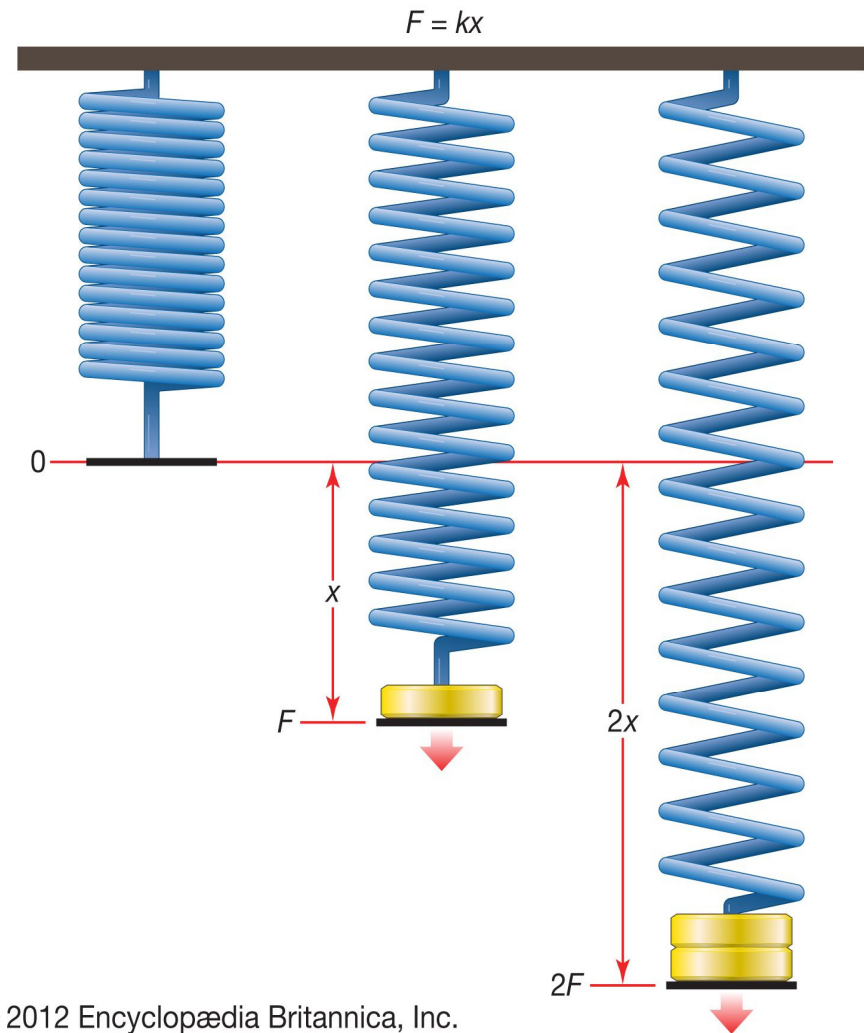


- There is a distinction between replicability and repeatability.
 - *Replicating an experiment: Version 2*
 - *Equipment:* beaker, thermocouple, distilled water;
 - *Environment:* experiment performed in space;
 - *Procedure/Protocol:* “Procedures 3”

Replicability and repeatability

Exercise:

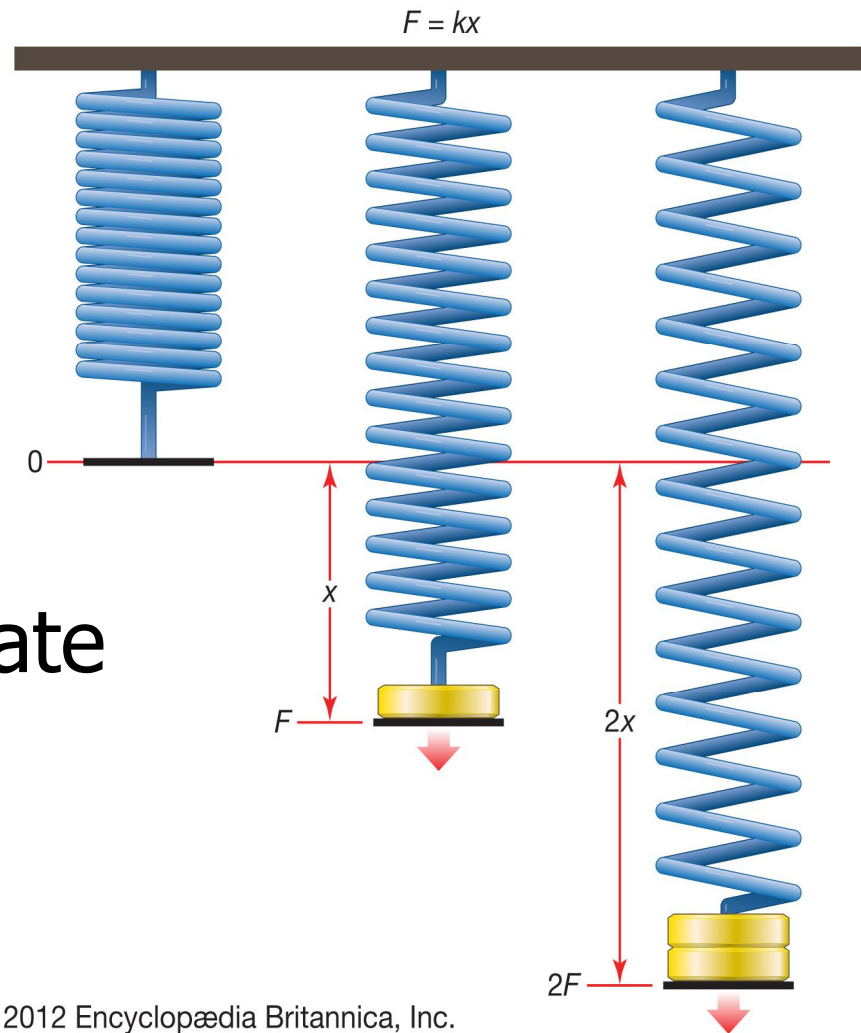
Consider the experiment of verifying Hook's law of elasticity.



Replicability and repeatability

Exercise:

- 1) How would you repeat the experiment?
- 2) How would you replicate the experiment?



Replicability and repeatability



- Replicability and repeatability of experiments acts to support verifiability or falsifiability.
- See notes for five questions about replicability.

Commentary



On falsifiability

- A statement or theory is scientific only if it can be falsified.
- This means that such a statement/theory has to be worded in a certain way.

Commentary



On falsifiability: Examples

- 1) “The extension of a spring is proportional to the weight attached to the spring”
 - The wording is such that we can confirm or deny this statement;
 - The wording is, in fact, categorical: “this is so”, “this does that”. I.e.
 - Extension is proportional to weight.

Commentary



On falsifiability: Examples

- 1) “The extension of a spring is proportional to the weight attached to the spring”
 - Key aspects can be tested directly: test extensibility and proportionality against different springs and weights.

Commentary



On falsifiability: Examples

- 2) “Solids are denser than liquids, and so always fall to the bottom of any container”
- The wording is such that we can confirm or deny this statement;
 - The wording is, in fact, categorical: “this is so”, “this does that”. I.e.
 - Solids are denser than liquids,
 - Solids fall to the bottom of containers.

Commentary



On falsifiability: Examples

- 2) “Solids are denser than liquids, and so always fall to the bottom of any container”
- Key aspects can be tested directly: test different solids and different liquids (of different viscosities).
 - Boats are denser than water but float;
 - Solid water (ice) floats on liquid water.

Commentary



On falsifiability: Example

- 3) Einstein's theory of relativity predicted that light bends around massive objects (such as stars, black holes, etc.)
- 4) Einstein's theory of relativity predicted the universe had to be expanding.

Commentary



On falsifiability: Question

- Consider an experiment which produces data which confirms the theory,
 - Is one experiment enough to confirm the theory as correct? How does your answer explain examples 3 and 4 above?
 - Are two experiments enough to confirm the theory as correct?

Commentary



On falsifiability: Question

- Consider an experiment which produces data which confirms the theory,
 - If the experiment cannot be repeated or replicated does this mean the theory is incorrect?

Commentary



On repeating and replicating

- In science replicability is not the same as repeatability.
- Repeating an experiments means
 - doing exactly the same thing in exactly the same way with the same equipment over exactly the same time period and environment.

Commentary



On repeating and replicating

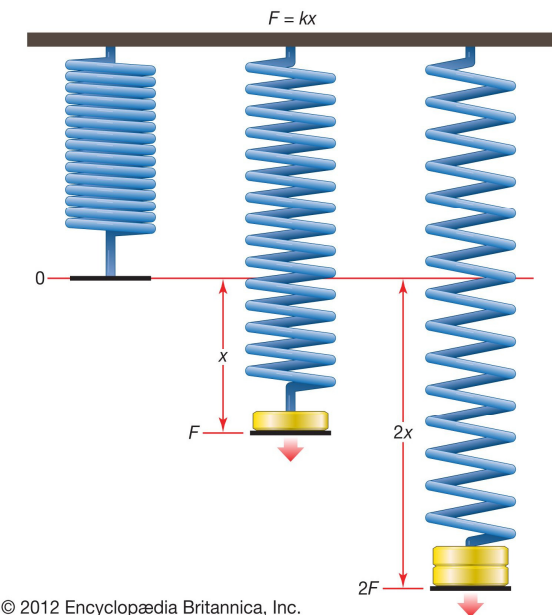
- In science replicability is not the same as repeatability.
- Replicating an experiments means
 - Using different equipment, and/or environment and/or procedures to try to obtain the same results.

Commentary

On repeating and replicating

Initial experiment: Hook's law.

- To study the stretchiness of a spring under weight.
 - Use a metal spring;
 - Measure the unstretched length;
 - Use 1kg and 2kg weights;
 - Measure the stretched lengths using these weights;



Commentary



On repeating and replicating

Repeating Hook's law experiment

- Use the same spring;
- Use the same weights;
- Extend the spring as much as before;
- Use the same procedure for doing the experiment.

Commentary



On repeating and replicating

Replicating Hook's law experiment

- Use springs of different stiffness;
- Use springs of different materials (different metals, or even plastic),
- Use a spring of the same metal but different thickness;

Commentary



On repeating and replicating

Replicating Hook's law experiment

- Use different weights;
- Extend the spring much further: extend to destruction;
- Use a different procedure for doing the experiment.

Commentary



On repeating and replicating

- In the real world some repeated or replicated experiments will not give the exact same results for a theory known to be correct.
- Experiment: Measure the height or weight of 1000 people.

Commentary



On repeating and replicating

- Repeating the experiment:
Use the same 1000 people, the same measuring device, etc.
- Results: May be different to the results of the original experiment. Why?

Commentary



On repeating and replicating

- Replicating the experiment:
Use a different group of 1000 people, a different measuring device, etc.
- Results: Will be different to the results of the original experiment. Why?

Commentary



On repeating and replicating

- But we accept the average height and weight of a 1000 people to be in a range of values, say
 - $1.5\text{m} \leq \text{height} \leq 2\text{m}$
 - $50\text{kg} \leq \text{weight} \leq 80\text{kg}$

Commentary



On repeating and replicating

- So, scientists accept a certain degree of deviation between results of experiments repeated or replicated by other people.
- They look for results which agrees to within an acceptable level of accuracy.

Commentary



On scientific theory

- A theory is scientific if
 - it can make predictions,
 - It is testable,
 - the tests confirm or deny the predictions made by the theory,
 - repeating or replicating the tests continues to confirm or deny the theory.

Commentary



On scientific theory

- “If you want to know the time look at two different watches or ask two different people, instead of looking at your watch twice”
- So, results from an experiment which replicates another experiment will be more confirming of a theory than repetition of the same original experiment.

Commentary



Replicability and falsifiability in statistics

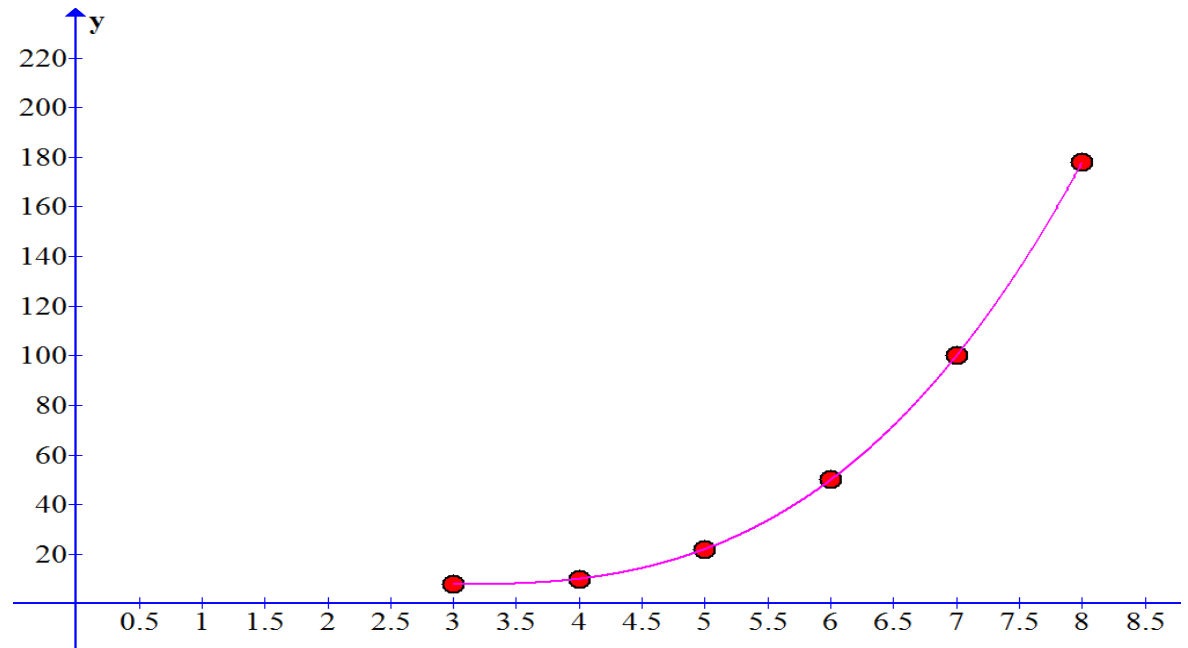
- Statistics deals with probabilities and trends.
- It does not deal in exact relationships between variables.
- This means that statistics does not provide true answers.

Commentary

Replicability and falsifiability in statistics

- *Example: Exact relationship*

x	y
3	8
4	10
5	22
6	50
7	100
8	178



Commentary



Replicability and falsifiability in statistics

- *Example: Exact relationship*

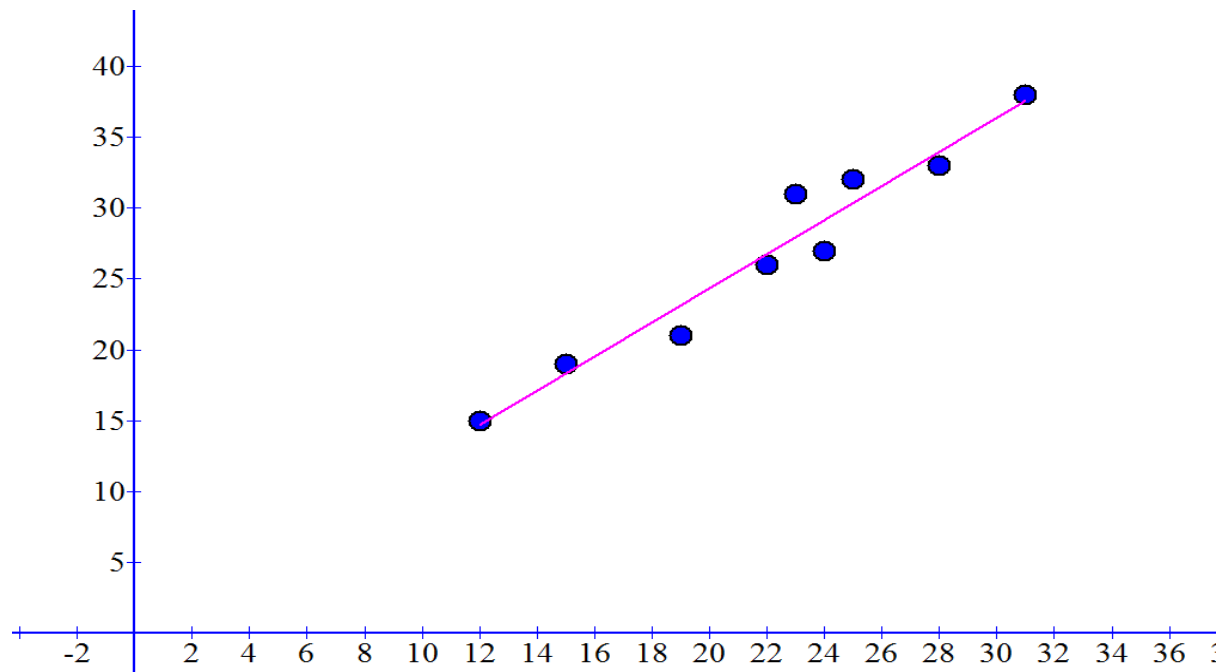
Any value I choose between $x=3$ and $x=8$ will give me a true answer to y .

Commentary

Replicability and falsifiability in statistics

- *Example: Approximate relationship*

x	y
12	15
22	26
19	21
15	19
31	38
25	32
28	33
24	27
23	31



Commentary



Replicability and falsifiability in statistics

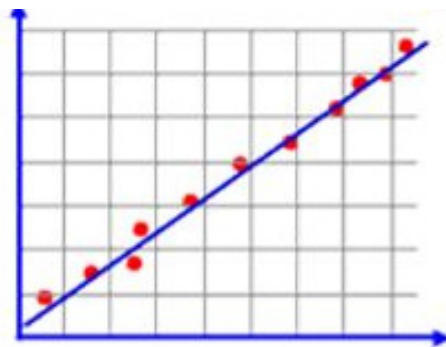
- *Example: Approximate relationship*

Any value I choose between $x=12$ and $x=23$ will **not** give me a true answer to y .

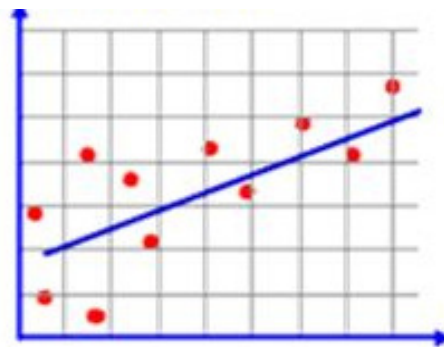
Commentary

Replicability and falsifiability in statistics

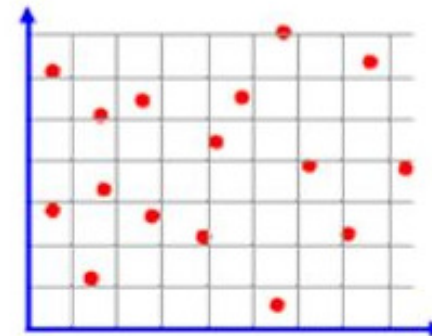
- There are degrees of strength to probabilities and trends, as illustrated below.



Strong positive correlation



Weak positive correlation



No correlation

Commentary

Replicability and falsifiability in statistics

Example

- Record the heights of 100 people:

2.15	1.68	1.67	1.78	2.04	2.13	1.53	1.65	1.49	1.90
1.97	1.90	1.82	2.06	1.71	1.39	1.68	1.91	1.82	2.16
1.83	1.57	1.60	1.38	1.88	1.89	1.33	1.60	1.58	1.19
–	–	–	–	–	–	–	–	–	–
1.92	1.68	1.98	1.73	1.88	1.80	1.90	1.78	1.79	1.87
1.77	1.98	1.87	1.63	2.09	1.49	1.63	2.04	1.74	1.78
1.85	1.58	2.14	1.91	1.80	1.55	2.22	1.82	1.74	1.74

Commentary



Replicability and falsifiability in statistics

Example

- Consider this the population of heights.
- We want to find the average height and spread of the population.
 - Five experimenters each take a sample of 10 people.
 - Their results are recorded below.

Commentary

Replicability and falsifiability in statistics

Example

- Experimenter results:

Sample of 10 people	Mean (m)	Spread (m) (Standard Deviation)
Experimenter 1 (row 1)	1.80	0.242
Experimenter 2 (row 2)	1.84	0.217
Experimenter 3 (row 3)	1.59	0.236
Experimenter 4 (row 4)	1.79	0.169
Experimenter 5 (row 5)	1.83	0.167

Commentary



Replicability and falsifiability in statistics

Example: Questions

- 1) Have the experimenters been able to repeat the experiment?
- 2) Have the experimenters been able to repeat the results?

Commentary



Replicability and falsifiability in statistics

Example: Questions

- 3) Have the experimenters been able to replicate the experiment?
- 4) Have the experimenters been able to replicate the results?

Commentary



Replicability and falsifiability in statistics

Answers to questions

1) Yes and no:

- Yes, because they used the same procedure of taking a sample of 10 people;
- No, because they took different samples.

Commentary



Replicability and falsifiability in statistics

Answers to questions

- 2) No: None of them obtained the same results as any other.
- 3) Yes. Taking samples of 10 people (even if they were different samples) is indeed replicating the experiment

Commentary



Replicability and falsifiability in statistics

Answers to questions

4) Yes.

- In terms of statistics the answer is Yes, even though their results are all different.
- There is natural variation between samples of a population. Statistics take account of this variation when deciding what is a significant difference or not.

Commentary



Replicability and falsifiability in statistics

- Statistical results are valid only for large scale data not individual cases.
- Statistics is then about obtaining consistent results within an error margin deemed acceptable.

Commentary



Replicability and falsifiability in statistics

- There is no such thing as truth in statistics, only probabilities, trends, degrees of significance or confidence.

Replicability, verifiability, and falsifiability



The end