Understanding the Scientific Method

Lesson 1

Dec, 15 2023

What is the Scientific Method?

The scientific method is a **systematic** and **logical approach** used by scientists to **investigate** and **understand** natural phenomena.

It provides a **structured framework** for conducting **experiments**, making **observations**, and drawing **conclusions based on evidence**.

What is the Scientific Method?

The scientific method is important because it fosters a **rigorous** and **reliable** approach to **understanding** the world around us.

Its emphasis on evidence, objectivity, and **reproducibility** ensures that scientific knowledge is **built on a solid foundation** and **continually refined** through ongoing research and discovery.

What is the Scientific Method?

The scientific method is playing a crucial role in advancing our understanding of the natural world

1. **Objectivity**: the scientific method promotes objectivity. It encourages researchers to base their conclusions on tangible evidence rather than personal beliefs or biases
2. **Testable Hypotheses**: The scientific method requires hypotheses to be testable through experimentation. This characteristic ensures that scientific inquiries are grounded in empirical evidence and can be verified or falsified based on the outcomes of experiments.
3. **Reproducibility**: Reproducibility is a cornerstone of the scientific method, as it enables independent verification of findings and enhances the reliability of scientific knowledge

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4. **Problem Solving**: The scientific method provides a structured framework for approaching complex issues by breaking them down into manageable components
5. **Communication and Peer Review**: This process ensures that research is subject to scrutiny by other experts, and maintaining high standards of quality in scientific inquiry.
6. **Technology and Innovation**: The scientific method contributes to the development of new technologies and practical applications that benefit society.
7. **Predictive Power**: Successful scientific theories allow scientists to make predictions about future observations.

Steps of the Scientific Method

Observation

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Question

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- Hypothesis

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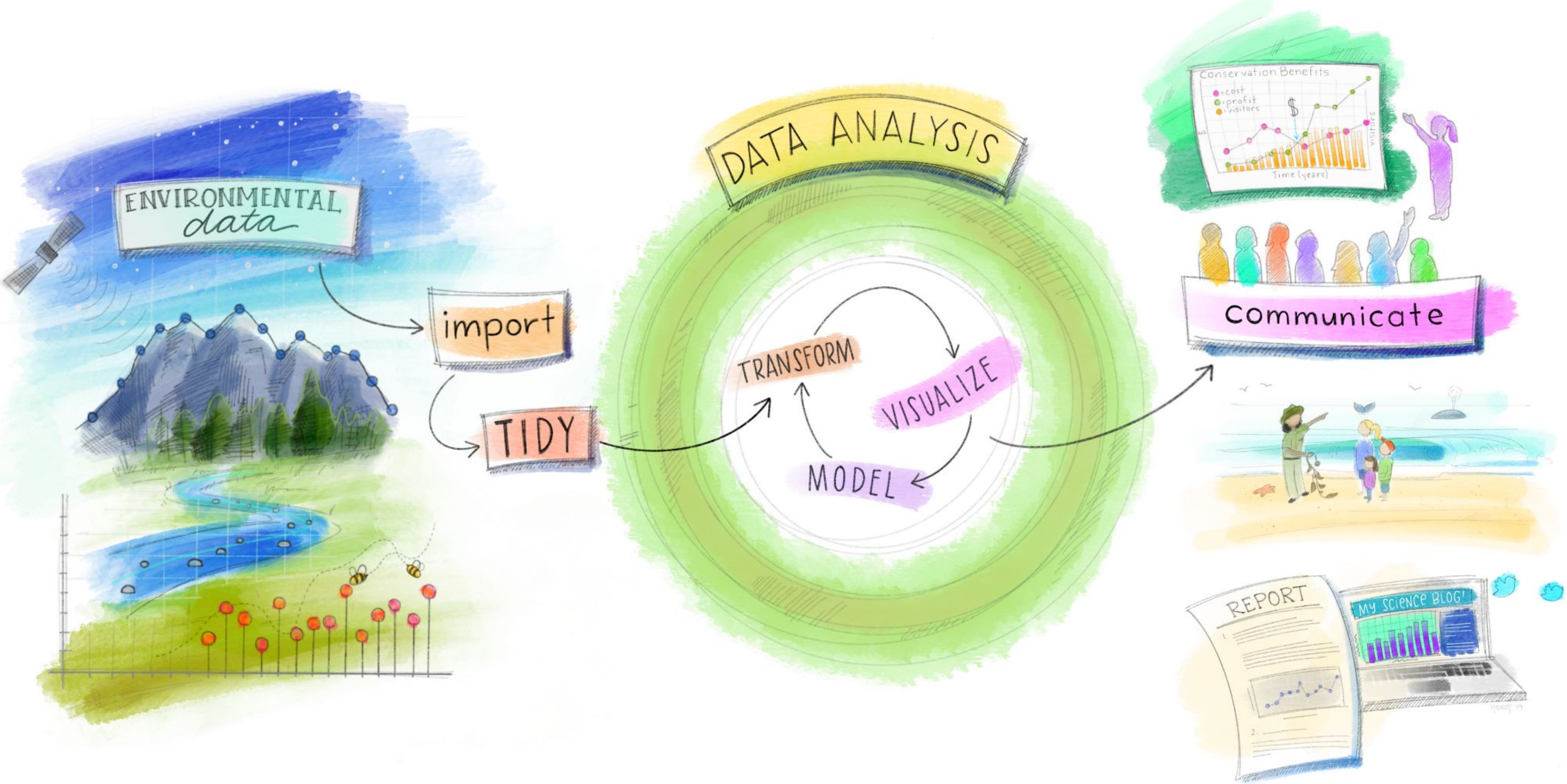
ENVIRONMENTAL data
import
TIDY
DATA ANALYSIS
TRANSFORM
VISUALIZE
MODEL
Conservation Benefits
cost
profit
visitors
Time (years)
communicate
REPORT
My Science Blog!

1

Observation

The initial stage where researchers **gather information** about a natural phenomenon or identify a problem that warrants investigation.

Observations are made through careful and systematic **scrutiny of the world**, and they can be derived from various sources, including direct **sensory experiences**, **literature reviews**, or the findings of **previous studies**

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Question

The question step in the scientific method involves formulating a **clear and focused inquiry** based on the observations made during the initial stage.

This step is crucial for **guiding the subsequent research and experimentation**

The questions generated should be **clear, specific, and precise**.

Ambiguous or vague questions may lead to unclear hypotheses and make it challenging to design effective experiments

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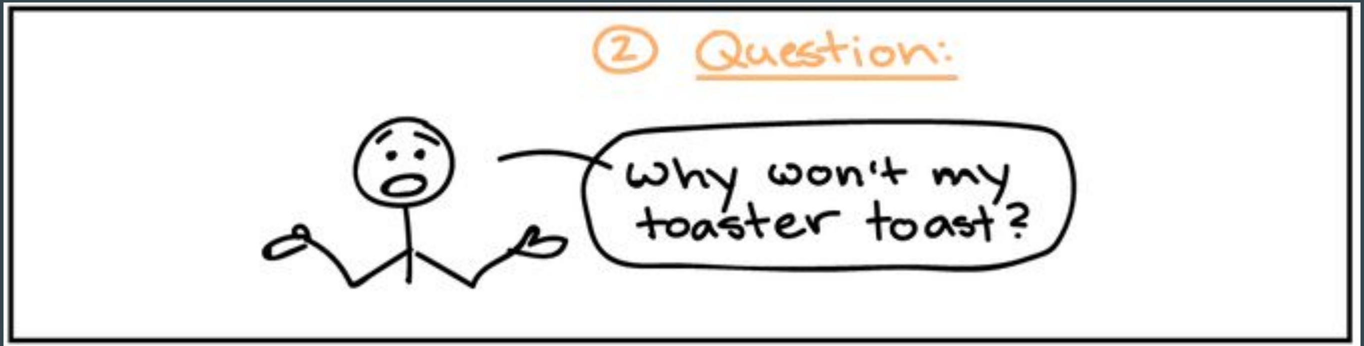

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Hypothesis

The hypothesis step involves formulating a **testable and falsifiable statement** that proposes a potential answer to the research question.

A hypothesis is essentially a **prediction** about the relationship between **variables** and serves as a **guide for designing experiments**

3

Hypothesis

Here are key aspects of the hypothesis step

Expressing Cause and Effect: changing one variable will influence another in a specific way. [spurious correlation]

Falsifiability: A good hypothesis is falsifiable, meaning that it can be proven false based on evidence. If a hypothesis cannot be proven false, it may lack scientific validity.

Alternative Hypotheses: In some cases, researchers may also formulate alternative hypotheses. The scientific method aims to compare these alternative hypotheses through experimentation

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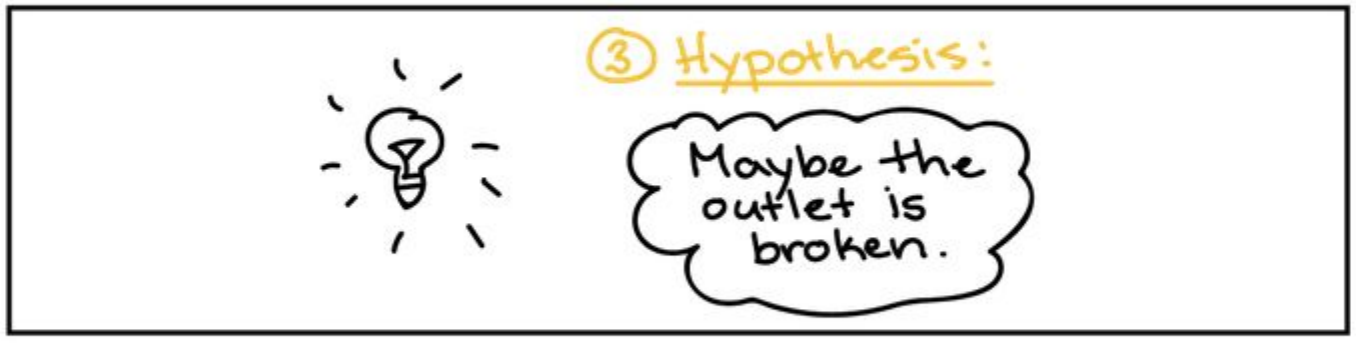

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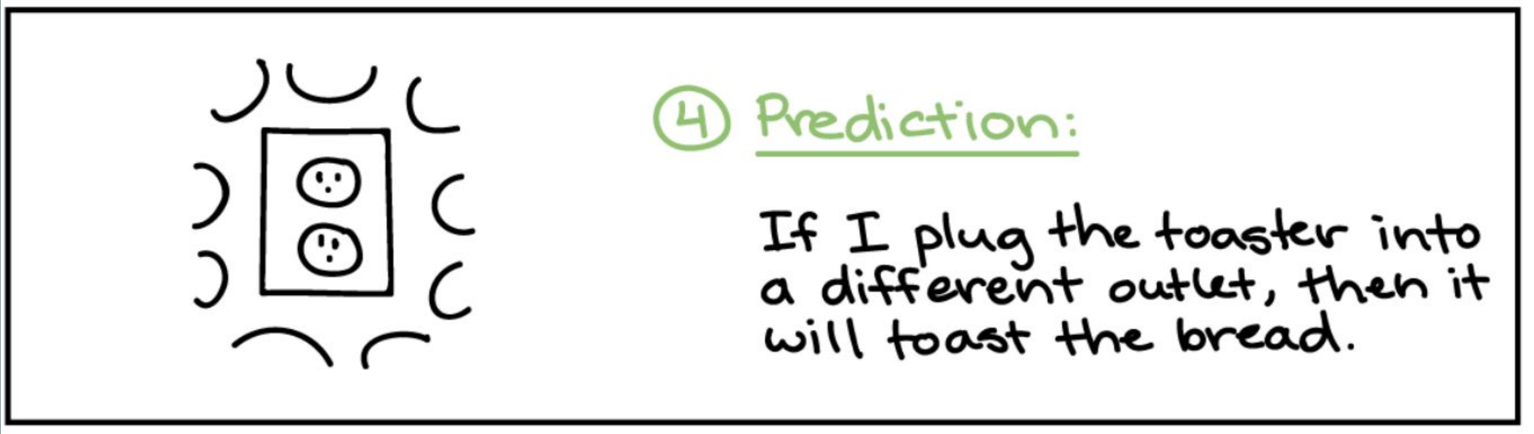
Experiment

The Experiment step is a critical component of the scientific method, as it involves **planning** and **organizing** the actual procedure you will follow to test your hypothesis



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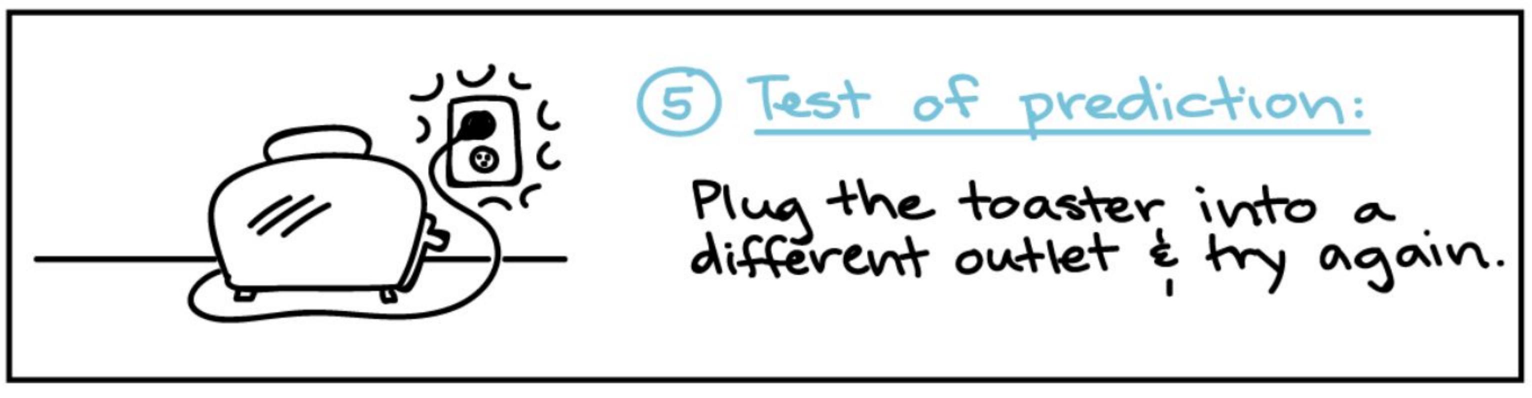

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Data collection

Data can be broadly categorized into two types:

	Qualitative Data	**Quantitative Data**
Nature	descriptive and deals with qualities or characteristics that cannot be easily measured or counted	numerical and deals with quantities that can be measured and counted
Form	consists of non-numeric information, such as observations, descriptions, or categorical data.	It consists of numerical values, often obtained through measurements or counts.
Examples		
Analysis	analyzed through methods such as thematic analysis, content analysis	Quantitative data is analyzed using statistical methods

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Examples	Color of a flower (red, blue, etc.) Texture of a material (smooth, rough, etc.)	Height of a plant (measured in centimeters) Temperature of a substance (measured in degrees Celsius)
Analysis	analyzed through methods such as thematic analysis, content analysis	Quantitative data is analyzed using statistical methods

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Data collection

Precision and **accuracy** are two important concepts in scientific measurements

	Precision	Accuracy
Definition	Refers to the **degree of reproducibility** of measurements. It indicates how closely individual measurements or values agree with each other.	Refers to the **closeness of a measurement** to the true value. It assesses how well the measurements reflect the actual quantity being measured.
Characteristics	Precise measurements show **little variation when repeated**. Precision is associated with **consistency** and reliability.	Accurate measurements are **close to the target value**. Accuracy is associated with **correctness** and lack of systematic errors.
Examples	If you weigh a substance multiple times [...], your measurements are precise.	If you weigh a substance [...], your measurement is accurate.

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Examples	If you weigh a substance multiple times and consistently get nearly the same result each time, your measurements are precise.	If you weigh a substance, and your measurement is close to the true weight, your measurement is accurate.

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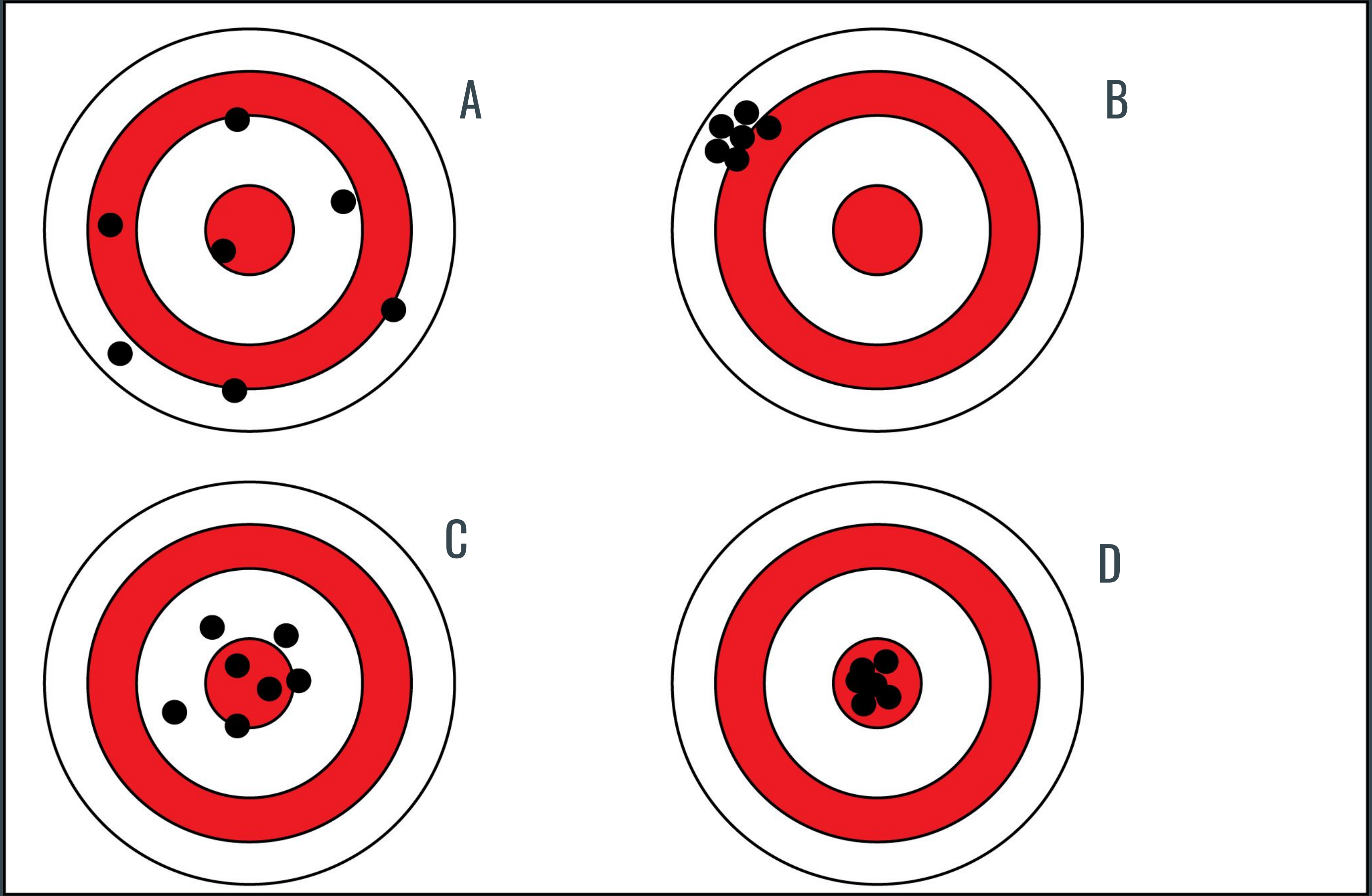

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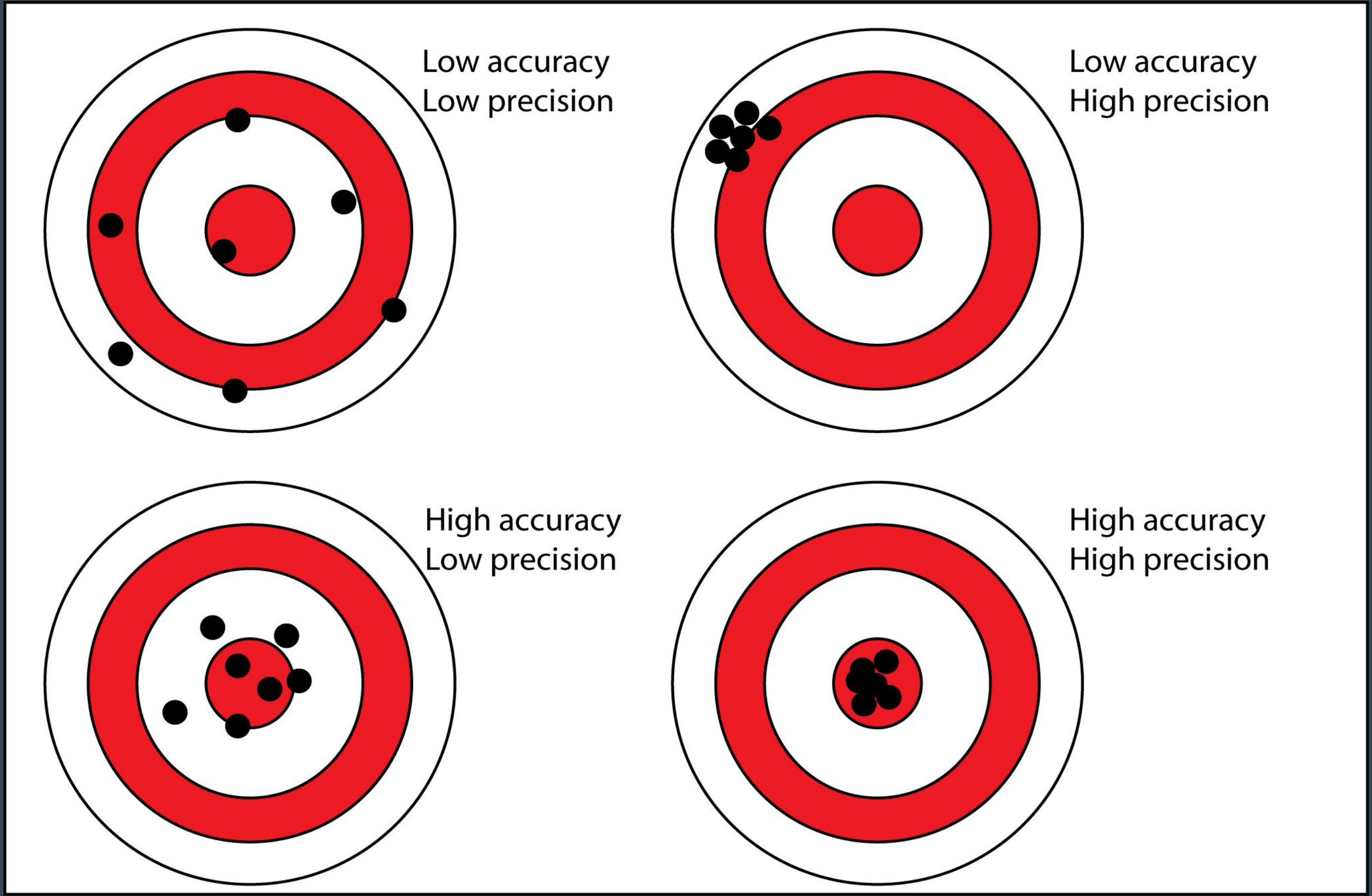

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Data collection

Variables:

- Clearly define the **independent variable** (the variable you are changing) and the **dependent variable** (the variable you are measuring).

Plant Growth

Independent Variable: Amount of sunlight
Dependent Variable: Height of plants

Drug Dosage

Independent Variable: Dosage of a drug
Dependent Variable: Heart rate

Exam Scores

Independent Variable: ???
Dependent Variable: Exam scores

5

Data collection

The **control group** in an experiment serves several important purposes

Baseline Comparison: It helps to assess the normal state of the subjects under study without the influence of the experimental treatment.

Minimizing Confounding Variables: Confounding variables are external factors that could affect the outcome of an experiment. The control group allows to control for these variables by keeping all conditions the same except for the manipulated variable in the experimental group.

Establishing Cause and Effect: By comparing the outcomes of the control group and the experimental group, researchers can infer causation.

Providing a Standard for Comparison: The control group serves as a standard to which the experimental group can be compared. This comparison is essential for drawing meaningful conclusions about the impact of the independent variable.

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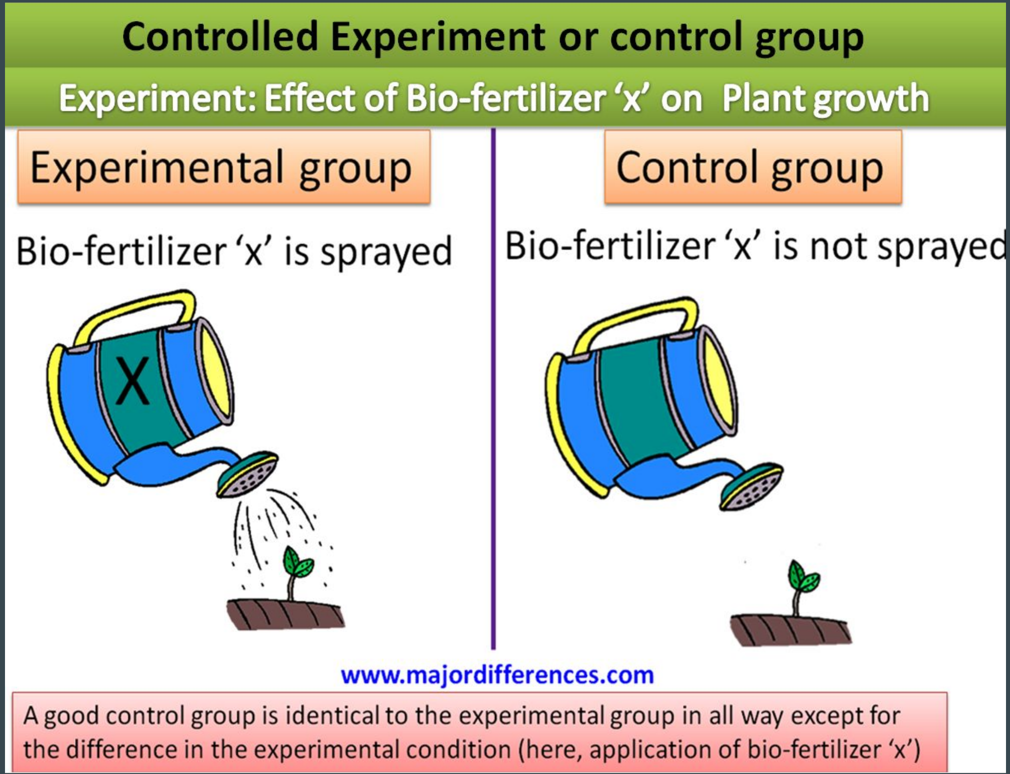

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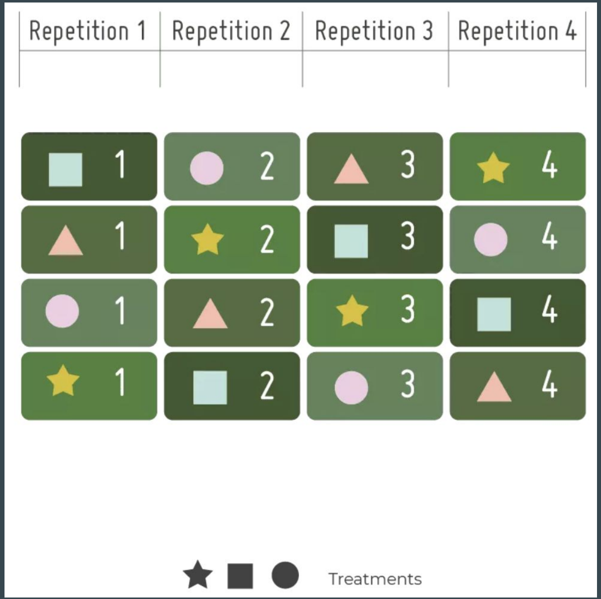
Data collection

Randomization and Replication:

- If applicable, consider whether randomization of subjects or replication of trials is necessary.
- Randomization helps eliminate bias, and replication helps ensure the reliability of your results.



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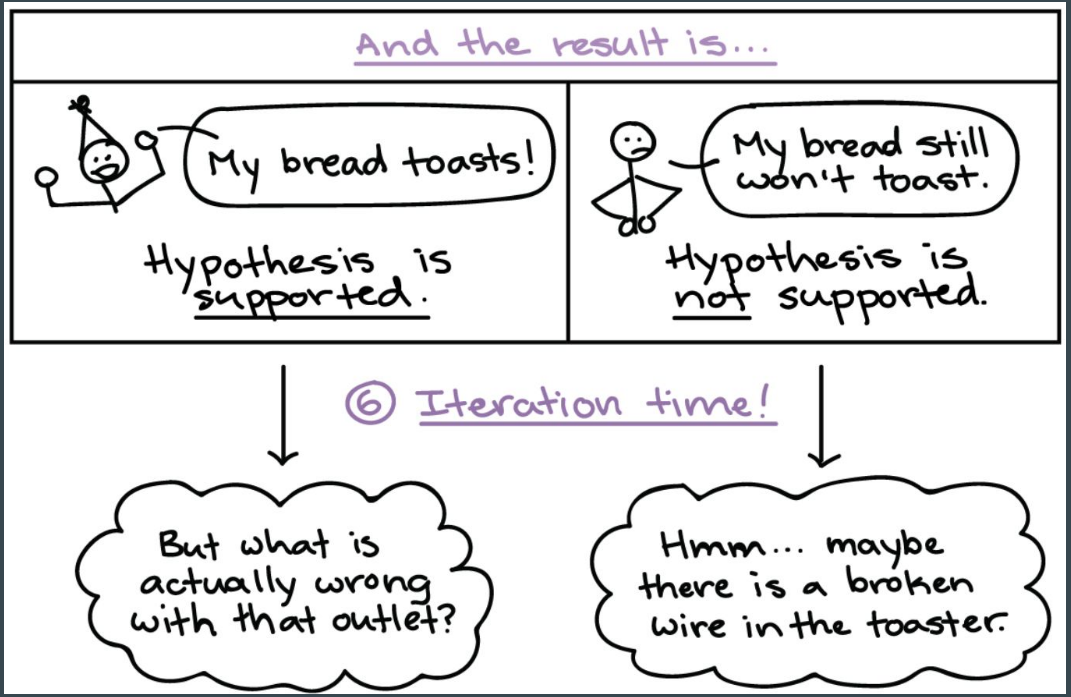
Data analysis

The analysis step involves **examining the data** collected during the experiment to **draw conclusions** about the hypothesis.



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Organizing Data (data cleaning)

Raw data collected during the experiment needs to be **organized** systematically. This may involve arranging data in tables, graphs, charts, or other visual representations.

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Descriptive Statistics

Descriptive statistics are used to **summarize and describe** the features of a dataset. Common measures include the **mean** (average), **median** (middle value), and **standard deviation** (measure of variability).

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Graphical Representations

Creating graphs or charts is a common way to **visually represent data**.

For example, scatter plots, bar graphs, histograms, or line graphs can help illustrate **trends and patterns** in the data.

example

7

Conclusion

The conclusion step involves **synthesizing the results** of the analysis to make a final determination regarding the hypothesis

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Comparison with Hypothesis: The primary focus is on comparing the results with the initial hypothesis. Researchers assess whether the <u>data supports or contradicts the predicted outcome stated in the hypothesis</u>.

Validity of Results: Scientists evaluate the validity of the results. They consider factors such as the <u>reliability of the data</u>, the rigor of the experimental design, and the presence of any confounding variables that might have influenced the outcomes.

Statistical Significance: If statistical analyses were performed, researchers assess the significance of the results. They consider whether any <u>observed differences are statistically significant</u>, indicating that the differences are unlikely to be due to random chance.

Alternative Explanations: Scientists consider alternative explanations for the results. They assess whether <u>other factors or variables might account for the observed outcomes</u> and discuss these possibilities.

7

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Generalization: Researchers discuss the generalizability of their findings. They consider whether the results are specific to the conditions of the experiment or if they can be applied more broadly to other situations or populations.

Implications: The conclusion step includes a discussion of the broader implications of the results. Scientists consider how their findings contribute to the understanding of the topic and whether they have practical applications or suggest avenues for further research.

Communication of Findings: Scientists prepare to communicate their findings to the scientific community and, potentially, the public. This often involves writing a research paper, creating presentations, or submitting the results to a scientific journal. Before publication, research papers undergo peer review.

Example Experiment: penicillin

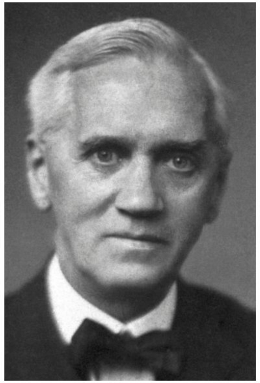
Photo from the Nobel Foundation archive.

Sir Alexander Fleming
The Nobel Prize in Physiology or Medicine 1945

Born: 6 August 1881, Lochfield, Scotland

Died: 11 March 1955, London, United Kingdom

Affiliation at the time of the award: London University, London, United Kingdom

Prize motivation: “for the discovery of penicillin and its curative effect in various infectious diseases”

Prize share: 1/3


Photo from the Nobel Foundation archive.

Ernst Boris Chain
The Nobel Prize in Physiology or Medicine 1945

Born: 19 June 1906, Berlin, Germany

Died: 12 August 1979, Mulrany, Ireland

Affiliation at the time of the award: University of Oxford, Oxford, United Kingdom

Prize motivation: “for the discovery of penicillin and its curative effect in various infectious diseases”

Prize share: 1/3


Photo from the Nobel Foundation archive.

Sir Howard Walter Florey
The Nobel Prize in Physiology or Medicine 1945

Born: 24 September 1898, Adelaide, Australia

Died: 21 February 1968, Oxford, United Kingdom

Affiliation at the time of the award: University of Oxford, Oxford, United Kingdom

Prize motivation: “for the discovery of penicillin and its curative effect in various infectious diseases”

Prize share: 1/3

Example Experiment: penicillin

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Example Experiment: penicillin

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In September 1928, Fleming was working at St. Mary's Hospital in London. He was studying Staphylococcus bacteria and left some petri dishes containing the bacteria on his workbench while he went on vacation.

Example Experiment: penicillin

- Observation
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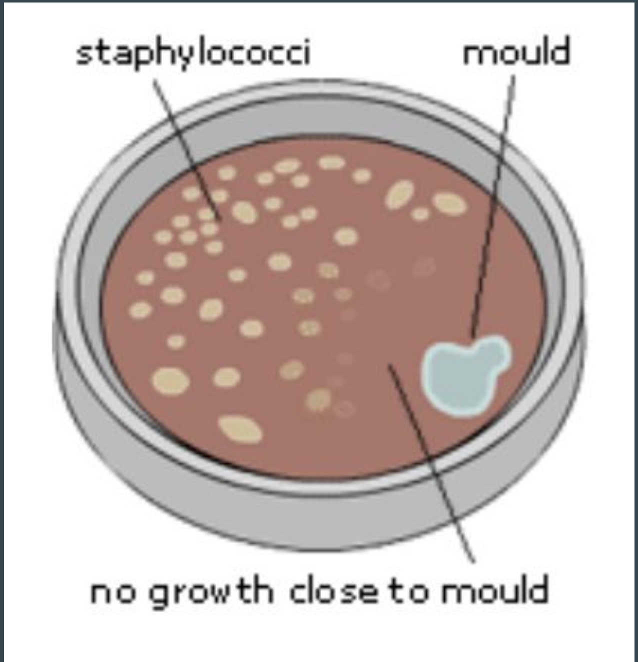
Upon returning, Fleming observed that one of the petri dishes had mold growing on it. He noticed a clear area around the mold where the bacteria seemed to be killed.



Example Experiment: penicillin

- Observation
- Question
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- Experiment
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- Conclusion

Fleming hypothesized that the mold, later identified as a strain of Penicillium, released a substance that inhibited the growth of bacteria.

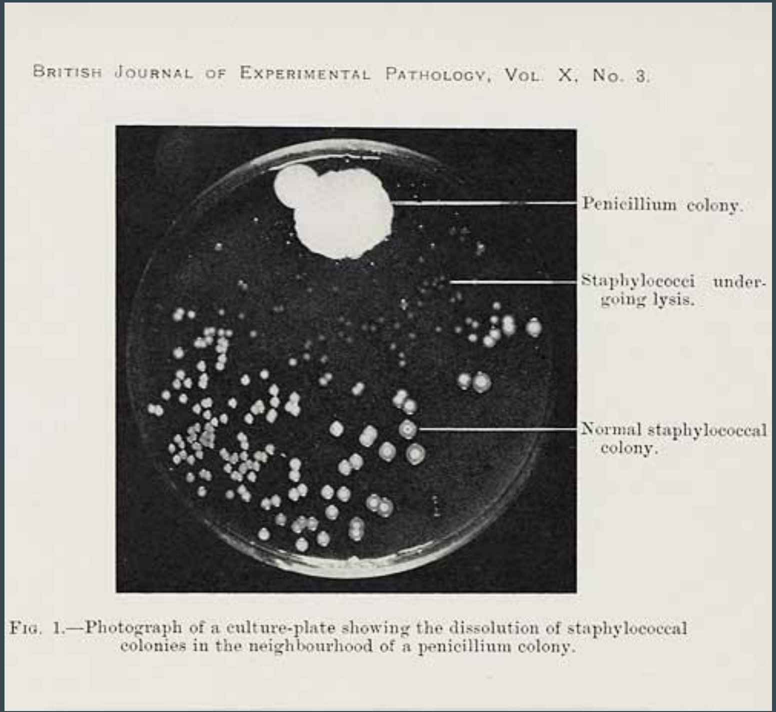


FIG. 1.—Photograph of a culture-plate showing the dissolution of staphylococcal colonies in the neighbourhood of a penicillium colony.

Example Experiment: penicillin

- Observation
- Question
- Hypothesis
- **Experiment**
- Data Collection
- Analysis
- Conclusion

To test his hypothesis, Fleming conducted a series of experiments. He isolated the mold and began extracting its secretions. He then tested these secretions against various bacteria, including Staphylococcus.

Example Experiment: penicillin

Observation

Question

Hypothesis

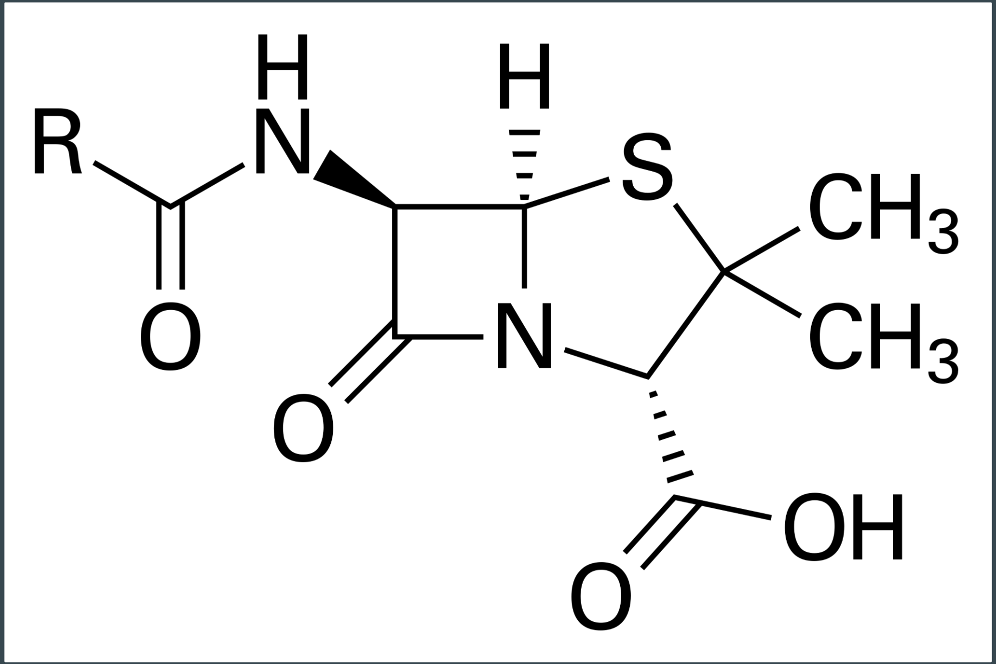
Experiment

Data Collection

Analysis

Conclusion

Fleming found that the substance produced by the mold effectively killed a wide range of bacteria but <u>was not toxic to human cells</u>. This substance was later named **penicillin**.



Example Experiment: penicillin

- Observation
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- **Analysis**
- Conclusion

Fleming analyzed the implications of his discovery. He recognized the potential of penicillin as an antibiotic, a substance that **could be used to treat bacterial infections**

Example Experiment: penicillin

- Observation
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- Analysis
- **Conclusion**

It's estimated that to date, penicillin has saved

>200 millions LIVES

Example Experiment: penicillin

Observation

Question

Hypothesis

Experiment

Data Collection

Analysis

Conclusion

Development

The full realization of penicillin's potential came in the 1940s when scientists Howard **Florey** and Ernst Boris **Chain**, along with their team, successfully isolated and produced penicillin in large quantities.

This marked the beginning of the era of **antibiotics** in medicine.

Hypothesis

Different Types of Soil Affect Seed Germination

Hypothesis

Different Types of Soil Affect Seed Germination

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Formative assessment

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