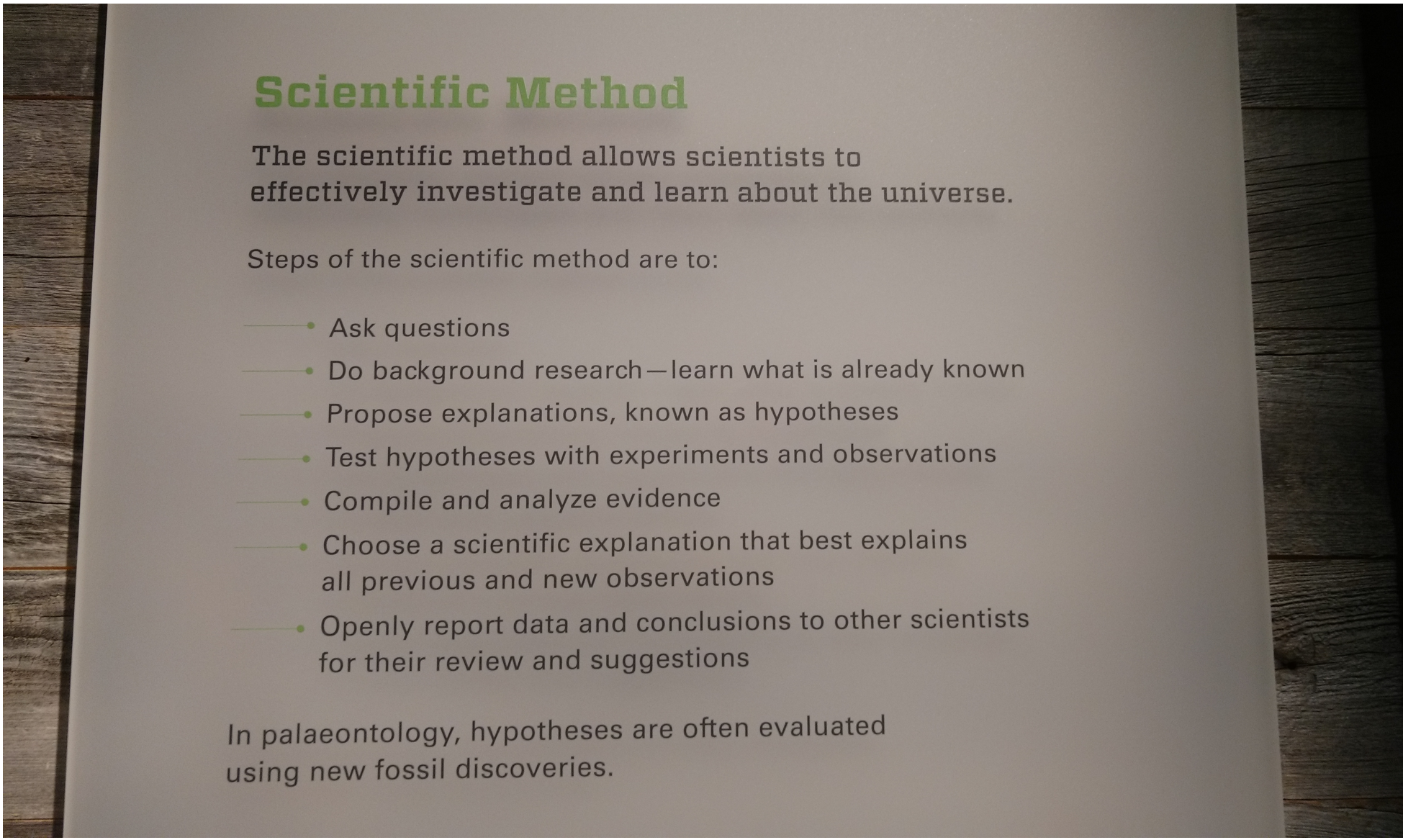
## The Scientific Method

- systematic approach to scientific research that supports all natural and social sciences
- develops systematically from the beginning (a research question) to the end (a published manuscript/presentation)

# At The Royal Tyrell Museum





# At The Royal Tyrell Museum



The scientific method allows scientists to effectively investigate and learn about the universe.

Steps of the scientific method are to:

- Ask questions
- Do background research – learn what is already known
- Propose explanations, known as hypotheses
- Test hypotheses with experiments and observations
- Compile and analyze evidence
- Choose a scientific explanation that best explains all previous and new observations
- Openly report data an conclusions to other scientists for their review and suggestions

## The Scientific Process

- Planning and Preparation
- Data Collection
- Analyzing, Interpreting and Presenting Data
- Scientific Writing and Research Presentations (sharing with peers)

# What is Science?

- "The intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment." (Oxford Living Dictionary)
- "a : knowledge or a system of knowledge covering general truths or the operation of general laws especially as obtained and tested through scientific method
  b : such knowledge or such a system of knowledge concerned with the physical world and its phenomena : natural science " (Merriam-Webster online dictionary)

## more on "Science"

- "science" – from the Latin word *scientia* for knowledge
- allows discovering the nature of the Universe
- is a method of investigation by which knowledge is acquired or inferred
- develops *models* for predicting the ways in the Universe
- is self correcting through testing the accuracy of knowledge and predictions

## What is then "Technology"?

- the application of scientific knowledge in the production of tools, machines, materials, techniques, etc. that we use to make our life or work easier and more successful

## Scientific Theory

- *model* that is developed to explain some phenomenon and is used as the basis for making predictions

## Hypothesis versus Theory

- hypothesis – a prediction or proposed explanation which is usually specific
- theory – a set of hypotheses that combine together to produce a theory

## Proof of Scientific Theories

- science **does not prove** theories (or hypotheses) to be correct
- experimental results consistent with predictions made by the theory **provide evidence to support** the theory

- statistical analysis can determine the likelihood of an error (Type I Error and P-value)

# Proof of Scientific Theories – examples

- theory with little support: four cups of coffee per day increase life expectancy of humans (December 2017)
- theory well supported by a large amount of evidence and data: theory of evolution (Darwin (1809–1882))
- a theory is accepted as scientific knowledge (law) when it has been verified by rigorous scientific studies (e.g. $E = mc^2$)
- a theory remains a theory until it has been repeatedly proven or tested experimentally

- Also, if you want proof beyond all doubt become a mathematician

## Scientific Law

- description of a phenomenon that has never been observed to be wrong
- a law is not considered absolutely correct
- often derived from an experimental study
- Isaac Newton's (1643–1727) law of universal gravitation was assumed to be correct for several centuries until Einstein proved its flaws and presented a new theory about gravitation, the theory of general relativity

# Disciplines of Science

- Natural sciences (biophysical sciences)
  - Physical sciences (physics, chemistry, geology, earth and atmospheric sciences)
  - Biological or Life sciences
  - Mathematics and logic – are these natural sciences?
- Social sciences
  - Sociology, Anthropology, Political Science, Psychology, Education, Economics

Note: The humanities (history, religion, philosophy, languages, fine arts, etc.) are not part of science, because knowledge of these cannot be scientifically proven or tested

## The Scientific Process

- "A process is a series of actions or steps taken in order to achieve a particular end" (Oxford Dictionary)
- The *scientific process* synonymous with scientific method – science in action
- The purpose of the scientific process/scientific research is to discover the unknown and add it to systematized knowledge

## The Scientific Process – definitions

- The principles, processes, and procedures used in the systematic pursuit of objective knowledge
- The **systematic**, **creative** process or methodology of gaining **original knowledge**
- An inquiry into the nature of, the reasons for, and the consequences of any particular set of circumstances, whether these circumstances are experimentally controlled or observed as they occur naturally

## Features of Scientific Research

- *logic*
- *systematic* (in methodology and organization of results)
- *objective* (not based on personal judgment or feelings)
- *rigourous* (thorough, following strict procedures, accurate)
- *consistent* (minimize effect of confounding factors)

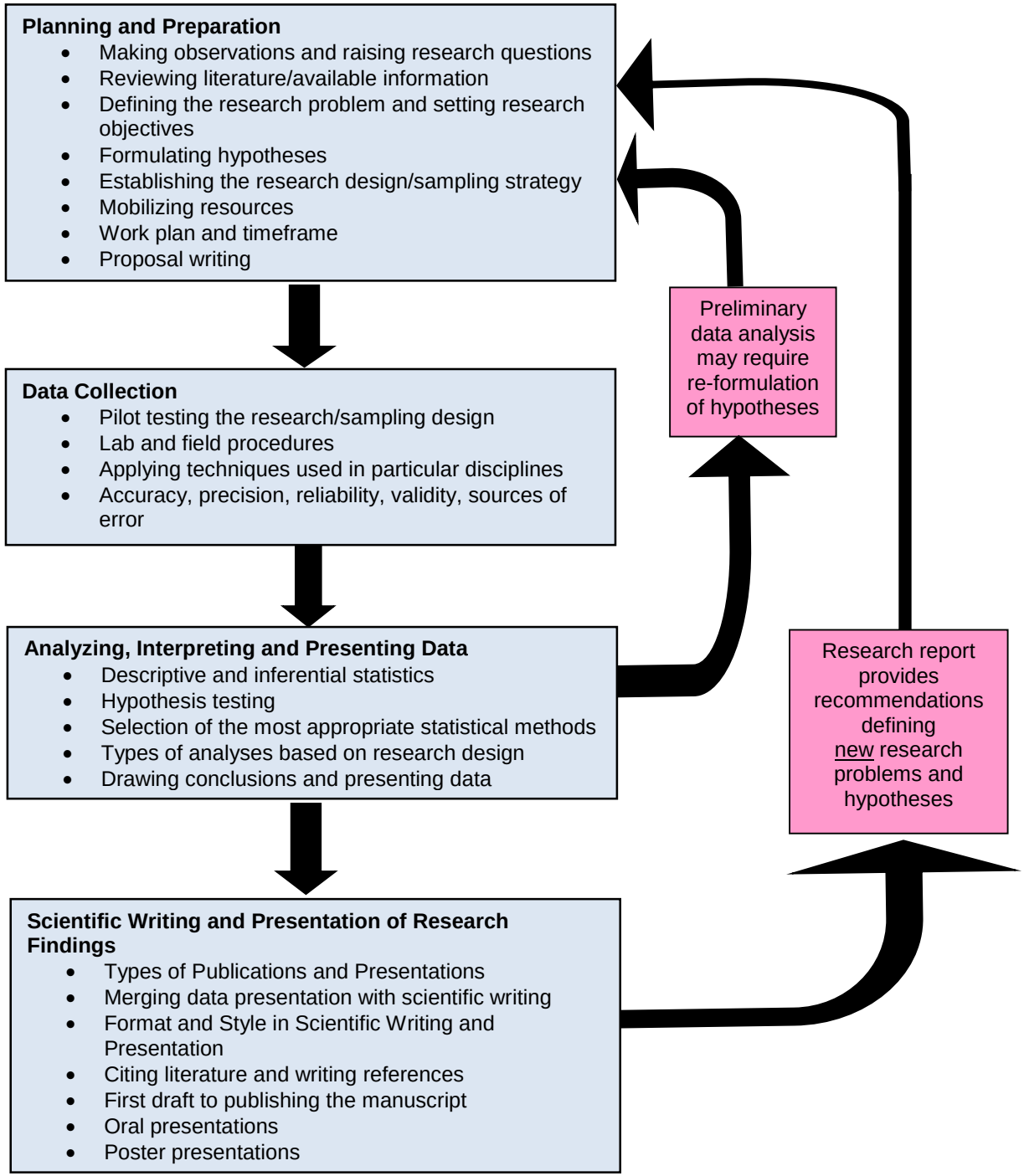
# Features of Scientific Research (contd.)

- *falsifiable*
- *precise* and *reliable*
- *based on empirical evidence*
- *probabilistic*
- *repeatable*, *reproducible* and *replicable*

  repeatable – given data and statistical tools the same results can be recreated
  reproducible – given a description of a study it can be conducted again producing consistent results

  replicable – given a description of the aims of a study a new study can be conducted leading to consistent conclusions
- *shared*
- *generalizable*

**Flow Chart of the Scientific Process**



# Types of Scientific Reports

- academic research papers submitted to universities or other organizations
- technical reports
- journal papers/articles
- short communications/synopses
- review papers (meta analyses)
- conference proceedings
- books or chapters of books
- book reviews
- consultancy reports
- oral and poster presentations

# Why Science?

- crucial role in the advancement and progress of human civilization
- through science, man rises above nature and can control his environment
- discovers solutions to social problems
- invents new tools and technologies that makes work easier and save time
- facilitates development and economic advances
- provides basis for government policies

## Why Science? (contd.)

- agent of diversification and evolution of society
- leads to evolution of life styles and society in general
- trains the mind in logic and understanding
- new look at the world and every day experiences in life in an objective and analytical way

## A word of caution

- science is neither good nor bad.
- *use and application* of science must be controlled by moral and ethical values
- artificial intelligence (can be used to help, but also to destruct), super virus/weapons (could kill humanity, but help understand the world and prevent such events)),
  manipulate human behaviour to gain unethical advantages to nudge decision towards "better" actions

Society should aim for useful, productive, and positive uses of science and technology

# Organization – some recommendations

- keep detailed records for every step of your activity (conversation notes, emails, R programs)
- keep detailed records of all data, even if the data might not be used in the final report and be sure to have secure backup copies of everything
- record choices made in your activities, this helps when writing final report
- while reading literature and referencing in your report create bibliography. This will save time for searching for the references again when adding the reference section
- keep drafts when writing the report, you might later find it important to include points that you removed from the drafts

# Ethical Treatment and Protection of Subjects

- Applies to social sciences and studies in biology that involve animals
- Human subjects' protection:
  - respect and consideration for those who are the subjects of the study (privacy)
  - Confidentiality: don't disclose confidential communications between people
  - In medical sciences, don't disclose patients' records
- Animal protection:
  - take proper care of animals when using them as subjects of research

## Ethics oversight at MacEwan

- Research Ethics Board (REB)
  - Must examine and approve all studies based on human subjects
  - Contact: research@macewan.ca or Rebecca Mitchell: mitchellr38@macewan.ca
- Animal Research Ethics Board (AREB)
  - Must examine and approve all studies on animals
  - Contact: areb@macewan.ca

## Ethics Tutorial

- TCPS2 CORE tutorial (https://tcps2core.ca/)
- first homework

## Honesty and Integrity

Scientists demonstrate

- *moral integrity* in all aspects of research
- *openness*, share results and are open to different ideas
- *honesty* in recording and analyzing data as well as reporting findings

# Honesty and Integrity (contd.)

Use of *all* evidence collected:

- Data should not be removed from analyses unless they are outliers – criteria for removal must be reported
- It is legitimate to remove outliers from analyses if:
  - the procedure of the experiment was not properly applied when recording that observation
  - there was a recording error
  - the individual measured belonged to a different population or species
- If no reasonable explanation can be found for observing the outlier, the outlier should either be retained or removed with caution. Report!

## Objectivity, Impartiality and Lack of Prejudice

Scientists

- are objective and avoid bias in all aspects of scientific studies
- lack prejudice

## Competence and Carefulness

Scientists

- strive to maintain, promote, and improve competence in their profession
- demonstrate carefulness in all aspects of their research
- are meticulous in recording and analyzing data and in scientific writing

## Socially Responsible

- work towards human progress by conducting meaningful research, by promoting scientific education, and by eliminating any possible harmful consequences of research
- responsible publication: publish for the advancement of science and society
- legality: knowledgeable and obedient to laws and government policies when conducting research

# Respect for Intellectual Property

Scientists

- honour patents, copyrights
- do not use unpublished data or results without permission
- acknowledge source of public data (like data on the Internet)
- do not take credit for the work of others
- fully acknowledge the participation and contributions of others to the research
- avoid plagiarism, that is:
  - presenting someone else's work in their own report without giving credit to the one who did the original work
  - misrepresenting someone else's findings to suite own needs is also considered plagiarism, even if the source is acknowledged

## Scientific misconduct is often identified by:

- Peer reviews
- Scientists repeating the same studies later and reporting different results
- Online search and compare tools can discovers plagiarism

Famous case in recent years: Researcher using the same graph in different contexts, only relabelling the axes.