MSc Graduate Program
Electrical Power Engineering
Clean Energy and Energy Conservation Engineering

Lecture 2:
Scientific Research and Research Methods

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Lecture Outline

- **What is Scientific Research?**
- **Fundamental Principles of Scientific Research?**
- **Common Conceptions/Misconceptions About Scientific Research**
- **Basic Elements of the Scientific Methods**
- **Scientific Method of Research:** Four Steps:
- **Understanding of Methodology and Methods**

What is Scientific Research?

Scientific research is the systematic investigation of **scientific** theories and hypotheses.

Scientific Research:

- **A process of rigorous reasoning based on interactions among theories methods, and findings;**
- **Builds on understanding derived from the objective testing of models or theories;**
- **Accumulation of scientific knowledge is laborious, plodding, circuitous, and indirect;**
- **Scientific knowledge is developed and improved through critique contested findings, replication, and convergence;**
- **Scientific knowledge is developed through sustained efforts;**
- **Scientific inquiry must be guided by fundamental principles.**

Fundamental Principles

1. Ask significant questions that can be answered empirically.

- ✓ "The formulation of a problem is often more essential than it's solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old questions from a new angle, requires creative imagination and marks real advance in science" (Einstein & Infeld, 1938);

- ✓ The research questions must be asked in a way that allows for empirical investigation.

Fundamental Principles

II. Link research to relevant theory.

- ✓ **Scientific research can be guided by a conceptual framework model, or theory that generates questions to be asked or answers to the questions posed;**
- ✓ **Theory drives the research question, the use of methods, and the interpretation of results.**

Fundamental Principles

III. Select and apply research designs and methods that permit direct investigation of the question.

- ✓ **The trustworthiness of any research study is predicated initially on several major elements:**
  - o **The suitability of the proposed research design or methodology to address the specific questions posed by the study;**
  - o **The scientific rigor by which the methodology is applied;**
- ✓ **The trustworthiness of any research study is predicated initially on several major elements (cont'd):**
  - o **The link between question and methodology must be clear and justified;**
  - o **Detailed description of the method, measures, data collection procedures, data analyses, and subjects must be available to permit replication.**

Fundamental Principles

IV. Provide a coherent and explicit chain of reasoning that can be replicated.

- **What assumptions underlying the inferences were made? Were they clearly stated and justified?**
- **How was evidence judged to be relevant?**
- **How were alternative, competing hypotheses, and explanations identified, considered, and accounted for (accepted or discarded)?**

Fundamental Principles

V. Replicate and generalize across studies.

- **Internal Validity: The observations made are consistent an generalize from one observer to another, from one task to a parallel task from one measurement occasion to anther occasion.**
  - **Statistical methods – e.g. correlation;**
  - **Non-statistical methods – e.g. triangulation, comparative analysis.**
- **External Validity: The extent to which the treatment conditions and participant population reflect the "world" to which generalization is desired.**

Fundamental Principles

VI. Report research publicly to encourage professional scrutiny, critique and replication.

- **Criticism** is essential to scientific progress;
- The extent to which new findings can be reviewed contested, and accepted or rejected by scientific peers depends upon accurate, comprehensive, and accessible records of:
  - **Data**
  - **Methods**
  - **Inferential reasoning**

Common Conceptions/Misconceptions About Scientific Research

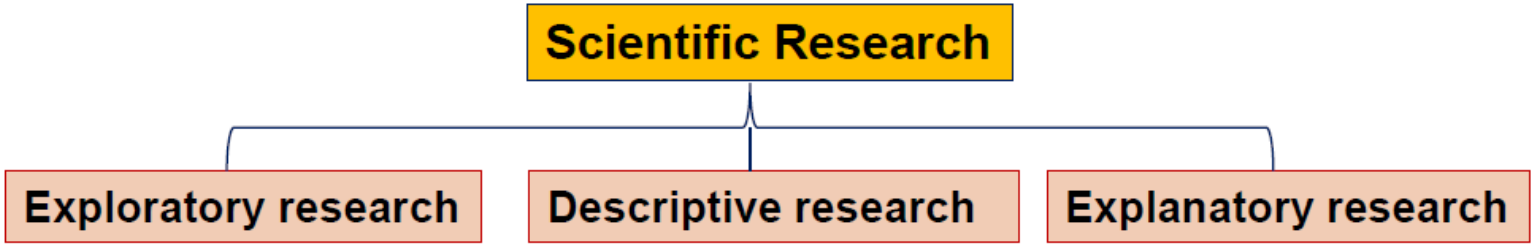
- ✓ **Experimental research is more "scientific" than descriptive or qualitative research…**
- ✓ **A study is deemed to be "scientific" when:**
  - o **There are a clear set of testable questions underlying the design;**
  - o **The methods are appropriate to answer the questions and falsify competing hypotheses and answers;**
  - o **The study is explicitly linked to theory and previous research;**
  - o **The data are analyzed systematically and with the appropriate tools;**
  - o **The data are made available for review and criticism.**
- ✓ **Research in education is fundamentally different than in the "hard" sciences.**

Basic Elements of the Scientific Methods

Scientific method refers to a standardized set of techniques for building scientific knowledge, such as how to make valid observations, how to interpret results, and how to generalize those results.

1. Replicability	**Replicate or repeat a scientific study and obtain similar, if not identical, results.**
2. Precision	Theoretical concepts that are to be defined so that others can use those definitions to measure those concepts and test that theory
3. Falsifiability	Theories that cannot be tested or falsified are not scientific theories and any such knowledge is not scientific knowledge.
4. Parsimony	When there are multiple explanations of a phenomenon, scientists must always accept the simplest or logically most economical explanation.

Types of Scientific Research

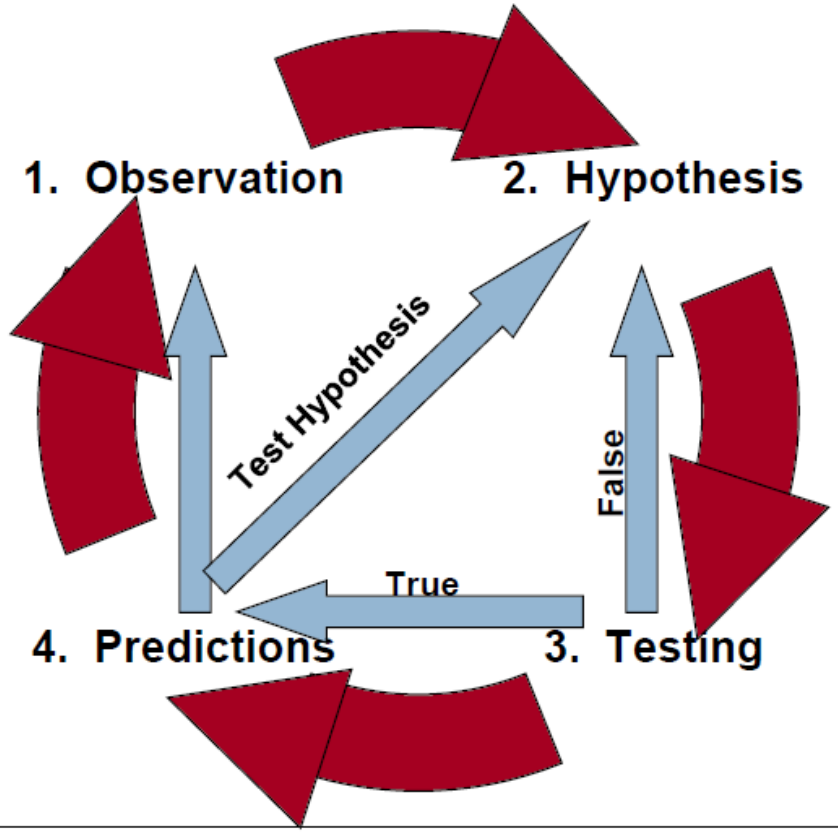


Research
1. **Quantitative Research**
2. **Qualitative Research**

Quantitative research is generally associated with the positivist/post-positivist paradigm. It usually involves collecting and converting data into numerical form so that statistical calculations can be made and conclusions drawn.

Qualitative research is the approach usually associated with the social constructivist paradigm which emphasizes the socially constructed nature of reality. It is about recording, analyzing and attempting to uncover the deeper meaning and significance of human behavior and experience, including contradictory beliefs, behaviors and emotions. Researchers are interested in gaining a rich and complex understanding of people's experience and not in obtaining information which can be generalized to other larger groups.

Scientific Method of Research: Four Steps



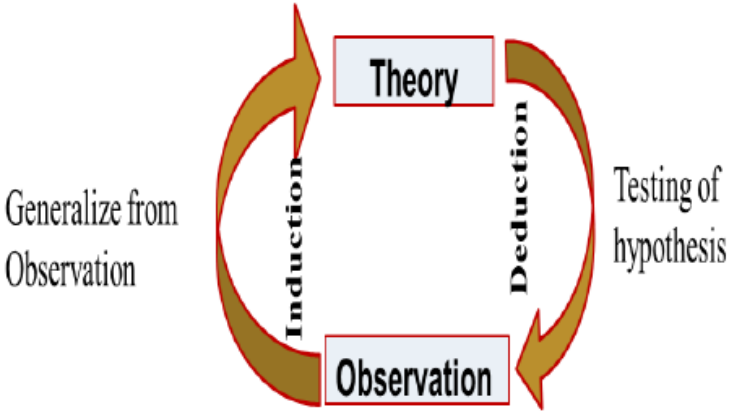


Figure: The cycle of Scientific Research

- If the experiments prove the **hypothesis** to be true, it becomes a **theory** or **law** of nature. If the experiments prove the hypothesis to be false, the hypothesis must be rejected or modified. The scientific method used properly should give us **predictive power** (to understand phenomena which have not been tested).

1. Observation

An act of recognizing and noting a fact or occurrence often involving measurement with instruments

- ***Experiments*** performed in the laboratory.
- ***Experiments*** gained from knowledge of the literature.

Keys to Implementation in your Research:

Sorting Observations (from Literature Searches):

Useful	Not Useful (Yet!)
Contains unanswered questions which you think you have means of addressing	Proclaims research has explained everything (does not contain unanswered questions)

Formulate Hypothesis!

Note Results (in report format- optional) for future use in confirming/denying your hypothesis (once your hypothesis is found)!

2. Hypothesis

Tentative assumption made in order to draw out and test its logical or empirical consequences

Keys to Implementation in your Research:

- ✓ Good Hypothesis can be TESTED with Experiment or Calculation.
- ✓ This requires A LOT of thought and reading--- leap from observation to hypothesis. It is worth the effort because after thinking this through, you are ready to go into the laboratory (which is the FUN part of research)!

Suggestions (no one can tell you HOW to do this, you have to develop this skill):
1. Couple archival journal reading with **your in-class theory**.
2. Couple archival journal reading with your **'common sense'** or intuition about the way things should be in the system that you are studying.
3. Follow a **logical reasoning** about what you are reading with scientific and/or mathematical basis (use drawings and diagrams to help your understanding).
4. **Write up your thoughts** and opinions either in report format (or in a way which you can follow within one notebook).

2. Hypothesis

Hypothesis---- Shape and guide a research study in terms of:

- ✓ Identification of study sample size
- ✓ What issues should be involved in data collection
- ✓ The proper analysis of the data
- ✓ Data interpretation

Traditionally…..

H_0: "Null" hypothesis (assumed)
H_1: "Alternative" hypothesis

H_0: There is **no association** between the exposure and disease of interest

H_1: There **is** an association between the exposure and disease of interest (beyond what might be expected from random error alone)

3. Experimental Testing

To apply a test as a means of analysis or diagnosis

Keys to Implementation in your Research:

- ✓ Good TESTS will **prove or disprove** your hypothesis.
- ✓ Experimental Tests can be performed within the realm of computing. (e.g. Coventor model with calculations and predictions can serve as experiment and model).
- ✓ Consider all alternatives. Experiment may not disprove all (but may disprove only parts) of your hypothesis. That is still alright to perform. Carefully note which aspects of your hypothesis this experiment will test.
- ✓ Consider the availability of instrumentation to perform your tests.

4. Predictions

To declare or indicate in advance; *especially* : foretell on the basis of observation, experience, or scientific reason

Keys to Implementation in your Research:

- ✓ Good Predictions can also be tested against your hypothesis.
- ✓ Consider going back to the basics (textbook theory) to development of a mathematical model/construct which will help to make predictions about more systems than you can reasonably test.

Suggestions:
• You may begin thinking about predictions as soon as you have a hypothesis, however, if your hypothesis is proven false, your prediction will also fail! • Use *mathematical model* to test your prediction.

Mathematical Models: Empirical vs. Deterministic

Empirical	Deterministic
Based on experimental observation	Based on first *principles approach*! (e.g. Density Functional Theory, Molecular Dynamics)

Keys to Implementation in your Research:

- ✓ All thesis experiments should have empirical models (at least).
- ✓ If do not have a mathematical model--- only data, then we need to find an equation for which we can perform least squares fitting your data.
- ✓ Our suggestion: If you run into an interesting hypothesis which can be tested via deterministic models (first principles approach), meet with modeling to discuss the hypothesis and modeling.

Understanding of Methodology and Methods

Methodology?

Methodology is defined as:

- ✓ "the analysis of the principles of methods, rules, and postulates employed by a discipline";
- ✓ "the systematic study of methods that are, can be, or have been applied within a discipline"; or
- ✓ "a particular procedure or set of procedures."

- ➢ a collection of theories, concepts or ideas
- ➢ comparative study of different approaches
- ➢ critique of the individual methods

Methodology refers to more than a simple set of methods; it refers to the rationale and the philosophical assumptions that underlie a particular study.

Understanding of Methodology and Methods

Method?

Method - a (systematic?) codified series of steps taken to complete a certain task or to reach a certain objective.

The "scientific method" attempts to minimize the influence of the researchers' bias on the outcome of an experiment.

- *The researcher may have a preference for one outcome or another, and it is important that this preference not bias the results or their interpretation.*
- *Sometimes "common sense" and "logic" tempt us into believing that no test is needed.*
- *Another common mistake is to ignore or rule out data which do not support the hypothesis.*

Basic Consideration!

But there is no single, universal formal "scientific method". There are several variants and each researcher needs to tune the process to the nature of the problem and his / her working methods.

Methodological choice: Scientist vs Engineer

A scientist sees a phenomenon and asks "why?" and proceeds to research the answer to the question.

An engineer sees a practical problem and wants to know "how" to solve it and "how" to implement that solution, or "how" to do it better if a solution exists.

The basic is that a scientist builds in order to learn, but an engineer learns in order to build.

Quantitative vs Qualitative Methods

Scientific Rigor in Quantitative Method

Data collected through quantitative methods are often believed to yield more objective and accurate information because they were collected using standardized methods, can be replicated, and, unlike qualitative data, can be analyzed using sophisticated statistical techniques.

Scientific Rigor in Qualitative Method

Qualitative researchers feel that there is no objective social reality, and all knowledge is "constructed" by observers who are the product of traditions, beliefs, and the social and political environments within which they operate.

Quantitative vs Qualitative Methods

Four issues can affect the choice of method:

1. **Credibility of findings**
2. **Staff skills**
3. **Costs**
4. **Time constraints**

Applications of Methods

- **Quantitative Methods**
- **Qualitative Methods**
- **Mixed Methods**

Thank You All...