Scientific Method and Experimental Design in Preservation and Conservation Research

Chandra L. Reedy
University of Delaware

GOALS

1. Review the most crucial aspects of experimental design;
2. Experimental design NOT statistical analysis;
3. Refresh and renew research design knowledge from past science courses
4. Look at how to incorporate experimental design concepts into daily work in multiple ways
5. Improve ability to evaluate professional literature

ORGANIZATION

I. Scientific Method

- Platt's analysis of progress in scientific research
- Thinking: Fermi and Pasteur
- Steps in the research cycle
- Multiple hypotheses and creativity

ORGANIZATION

Advantages of formal experimental designs

II. Basic Concepts of Experimental Design

Object Protocols
Selection methods; Real or facsimile; Replicates

Measurement Protocols
Variable types; Repeated readings; Repeated measurements; Avoidance of bias through randomization and blinding

Treatment Protocols
Selection of test factors; Controls; Randomization

ORGANIZATION

III. Multiple Object Designs

- Design check sheet
- Research design flow charts
- Case studies

IV. Single Object Studies; Design Variations

- Designing single object studies
- Case studies
- Screening experiments
- Treatment trials

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Part I: Scientific Method

Platt (1964)

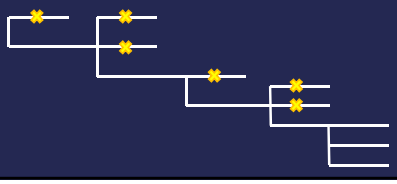
- Some fields of science make faster progress than others. Why?
- *Strong Inference:* The scientific method of hypothesis testing is regularly, explicitly, and systematically applied in the progressive fields; alternative hypotheses, crucial experiments to rule out one or more, then develop sequential ones to refine possibilities that remain
- Formal versus sloppy method

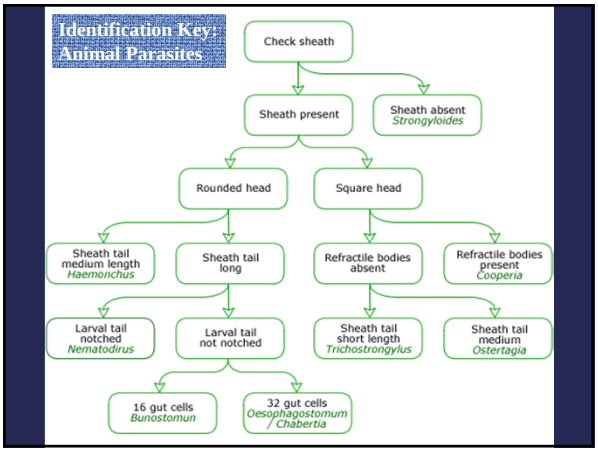
Fermi's Notebook Method

- Devote ½ hour daily to analytical thinking on your research topic
- Write out a logical tree of alternative hypotheses, implications, rationales, possible tests, and sub-hypotheses
- An expansion of the use of the permanent bound notebook for laboratory work

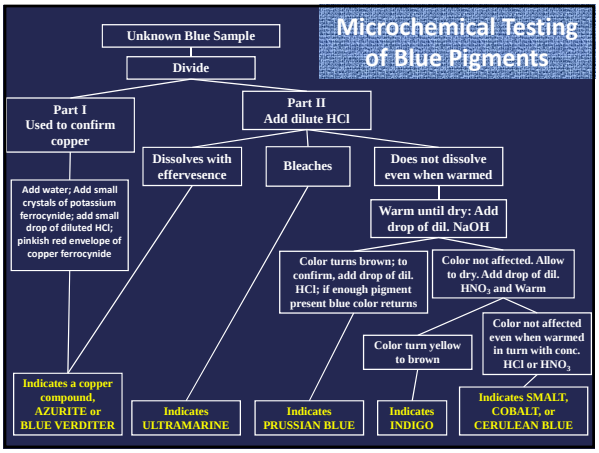
THE LOGICAL TREE

- Produced by devising alternative hypotheses and sub-hypotheses for testing
- Leads to progress in major research programs





Microchemical Testing of Blue Pigments

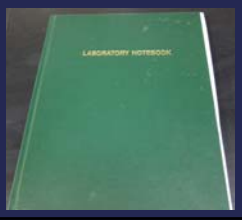


EXAMPLE: PASTEUR

- Importance of spending time <u>thinking</u> daily
- A few thoughtful experiments > many unclear ones

EXAMPLE: PASTEUR

- Thinking clearly can outweigh vast encyclopedic knowledge. Pasteur solved a major biological problem every 2-3 years while others who had spent their lives on those problems were unsuccessful
- Surveys, taxonomies, and observational studies with no explicit hypotheses to test: A substitute for thinking



Writing down observations, hypotheses, implications, possible designs of of experiments and tests, and brainstorming ideas that come from just sitting and thinking about the problem

Not just a laboratory notebook for record of actual experiments and data

SCIENTIFIC METHOD

- Observe
- Specify
- Hypothesize
- Infer
- Design
- Explain
- Experiment
- Analyze
- Publish
- Build

OBSERVE

- Record the initial observation that stimulated your project

SPECIFY

- Choose a research question or problem that is explicit, clear, and answerable (within the period of time that you have available to you)

Clinical Questions

- What phenomena are present?
- What processes are occurring?
- What results do various treatments have?
- Results may provide impetus to conduct further research
- Need as first stage in new scientific research program

Clinical Questions

- Does colorant C fade over time?
- If so, how fast?
- What factors affect the fading of C (light exposure, temperature, humidity, air pollution)?
- Which of 3 proposed controlled environmental parameters most inhibit the fading of C?

Scientific Questions

- Why are observed phenomena present?
- Why do certain processes occur?
- Why do various treatments produce the results observed?
- Builds on knowledge from answered clinical questions
- Answer allows you to predict outcome for conditions not yet tested

Scientific Questions

- Why does colorant C fade over time?
- If ozone accelerates the fading of C, what is the mechanism of that effect?
- Knowing that mechanism, can we predict what other factor(s) might also cause C to fade?
- Can we predict what will happen in the environment of building X?

Examples

Clinical:

Rank several colorants by degree of fading in a similar environment

Scientific:

Explain the ranking, identify underlying relationships so can predict fading on untested colorants

Other Questions

- How much variability do we see in results?
- Is the observed phenomena (such as fading) great enough to be worth additional attention?

HYPOTHESIZE

- Construct alternative hypotheses by writing down several possible answers to your research question or several possible explanations of your initial observation

Multiple Working Hypotheses (Chamberlin 1965)

- A problem often has multiple explanations or facets. A single hypothesis may be too limiting. Example: What is the origin of the Great Lakes basin?
- Prevents over-attachment to one hypothesis
- Encourages creativity

Clinical Example

- Observation: Some adhesives used in conservation of paper type P discolor
- Question: Which of 3 adhesives will discolor the least on paper type P?

Clinical Example

- Hypotheses:

(1) There is no significant difference in discoloration over time for these adhesives on paper P

(2) The 3 adhesives are significantly different enough to be ranked from better to worse

Conservation Example: Scientific (H. Alten, 1988)

- Observations

1. At a wet archaeological site in England there is wide variation in amount of visible deterioration for different wet glass fragments
2. Air-drying the glass often causes loss of translucency, visual emphasis of defects, or cracking and fragmentation

- Research Questions

For both observations, what is the cause?

Alten's Multiple Hypotheses

1. Waterlogged glass is damaged by air-drying
2. Damage by air-drying is more severe in the more corroded samples
3. The physical removal of water causes damage to the glass
4. The refractive index of the water merely masks damage already present
5. Initially-different glass compositions causes differing glass corrosion

EXPLAIN

- If the relationship of hypotheses, implications, tests, and design is not crystal clear, give a rationale to explain the relationship

INFER

- What are the implications of your hypothesis? If a hypothesis is true, what should happen or be observable? Write down some concrete predictions
- Hypotheses and their implications should be explicit. Write them down even if they seem obvious

Clear and Explicit

- Hypotheses and their implications should be explicit. Write them down even if they seem obvious.

Example (Scientific)

- Observation: Some adhesives used in the conservation of paper type P discolor
- Question: What factors determine how much an adhesive will discolor on P?
- Hypothesis 1: Adhesives with certain chemical bonds susceptible to hydration will react with water, causing discoloration.

Example (continued)

- Implication: Color measurement of some adhesives subjected to varying humidity will show greater discoloration after exposure to high humidity
- Rationale: Excess moisture allows hydration reactions to occur

Example (continued)

- Hypothesis 2: Adhesives containing the impurity phenol formaldehyde will discolor over time
- Rationale: Phenol formaldehyde is a highly reactive impurity that can be introduced during adhesive synthesis or processing

Example (continued)

- Implication: Color measurements made before and after artificial aging on adhesives with and without the impurity will show greater discoloration on ones with the impurity

DESIGN

- Devise tests to support or eliminate one or more of the hypotheses. Think of experiments that can test your predictions. Try to eliminate hypotheses.

Simplify

- What is the simplest experiment that can exclude one of your alternatives?
- A simple, short, elegant experiment that clearly excludes one of your possibilities is intellectually and financially preferable to a long and complicated one that produces the same result.

EXPERIMENT

- Select objects, measure variables and apply treatments according to the design
- Observe what happens

ANALYZE

Analyze and interpret the test results

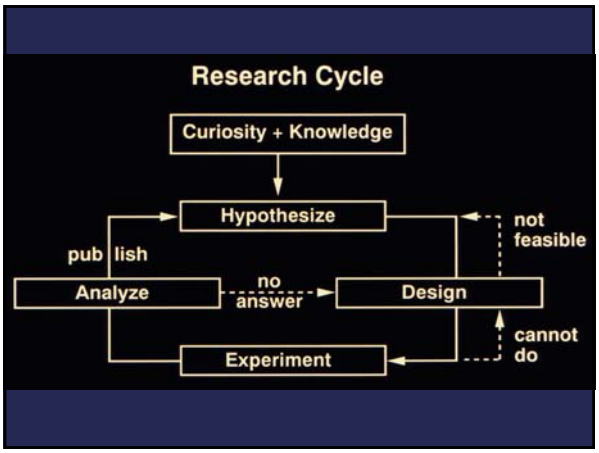
- Do statistical analysis if appropriate
- Compare actual results to expectations for each hypothesis

PUBLISH

- When possible, make results public for discussion and use by others

BUILD ON RESULTS

- Construct sub-hypotheses or sequential hypotheses to refine the possibilities that remain
- Repeat remaining procedures
- Refine the research question if appropriate



RESEARCH IS RARELY LINEAR

- If something can go wrong, it probably will
- No matter how much time you spent thinking, planning, and doing literature reviews, it is likely that something will emerge mid-experiment that you failed to consider!

MULTIPLE HYPOTHESES

- Encourage creativity
- Encourage consideration of complex causes of a problem
- May lead to more sophisticated solutions
- Think of as many potential answers to a question as possible rather than stopping with one or a few