Statistics and the Goals of Science

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PSY 2101

Statistics and the Goals of Science

What is(are) Statistics?

- The textbook emphasizes that the term "statistics" has several distinct meanings.
- One use of the term refers to *information designed to convey value on one or more attributes.*
- For example, we talk about "baseball *statistics*" or "unemployment *statistics*" or NCAA football player "graduation rate *statistics*."

What is(are) Statistics?

- Another use of the term "statistics" refers to an academic discipline, the *science* of statistics.
- The *science* of statistics is concerned with the study and development of methods and procedures for extracting valid information from numerical data.
- So when you "take a statistics course," you are studying the science of statistics, and while you are doing that, you will, over and over, be examining numerical statistics.

What is(are) Statistics?

Populations vs. Samples

- There is a third (more technical and specific) meaning of the term "statistic."
- Later in the course we will discuss this in quite a bit of detail, but let me cover it briefly now.
- In many situations, we are interested in a large *population*.For example, we might be interested in the population of all North American males.
- We might also be interested in some numerical characteristic of that population.
- Such a characteristic is called a *parameter*. An example of such a population parameter is the average height of North American males at some fixed point in time.

What is(are) Statistics?

Populations vs. Samples

- A parameter usually cannot be measured with perfect accuracy. The population is just too big for that.
- Statistical science tells us how we can *estimate* the parameter with a desired level of accuracy by taking a moderate sized sample, computing a *statistic* from that sample, and applying statistical estimation methods.
- So we might take a random sample of 50 males from the U.S. population, and compute the arithmetic average of their heights. This number is called the *sample mean*, and is a simple example of a *statistic* used to estimate a *parameter*.

What is(are) Statistics?

Populations vs. Samples

- For example, take a political poll. The goal is to estimate a specific parameter — the proportion of people who plan to vote for a particular candidate.
- A political poll takes a sample of voters. When you read about a poll in the paper, you see something like this: "Support for Candidate A is 54.6%. Opinion polls based on this sample size are, in the long run, accurate within 4 percentage points 95% of the time."
- By the end of the course, you'll know precisely what this statement means, and the formula for producing it. In fact, you'll derive the formula yourself.

What is(are) Statistics?

Summing it up

- Let's sum things up: We've seen three distinct uses of the term "statistics."
  1. *Numbers* designed to convey some useful information
  2. The *science* that deals with methods and procedures for optimally processing numerical information
  3. A *quantity*, a *function of a sample*, used to estimate a parameter.

The Role of Statistics in Science, Business, and Technology

- There is an important reason why we study statistical science.
- Every branch of the sciences now fully incorporates statistical methods into its research.
- It is impossible to study medicine, law, economics, psychology, education, or business, without knowing statistics.
- In fact, some of the hottest new areas of statistical science are the foundation for many of our more recent advances in technology.
- Moreover, the world of business has now fully embraced statistics.

The Role of Statistics in Science, Business, and Technology

- Some examples:
  1. Many large corporations now use *data mining* and *business analytics* methods to provide them with a competitive edge in keeping old clients and attracting new ones.
  2. Manufacturing companies use *quality control statistics* to help them maintain a high level of quality in their products and a low level of on-job injuries to their employees.

The Role of Statistics in Science, Business, and Technology

- Anywhere you turn, you'll find statistics playing an important role.
- It's hard to know where to begin.
- We'll start by looking at a very basic role of statistics in scientific experimentation.

Fundamental Goals of Science

What is Science?

- You can find basic discussions of "what science is" sprinkled liberally over the internet.
- An excellent basic summary can be found at `http://www.livescience.com/20896-science-scientific-method.html`.
- The definition given there is

> *Science is a systematic and logical approach to discovering how things in the universe work.*

- The "systematic" approach they refer to is often referred to simply as "the scientific method."

Fundamental Goals of Science

- Science has several fundamental goals, and these 4 are often the first ones mentioned.
  1. Description
  2. Prediction
  3. Control
  4. Understanding
- Although these goals seem pretty basic, we'll discover that some people, not just laypersons but scientists too, can sometimes confuse these goals.
- So let's analyze them a bit.

Fundamental Goals of Science

Description

- A science often begins with an effort to describe the phenomena it is trying to deal with.
- Take biology as a primary example. Biology is a pre-eminent "life science." The name, biology, quite literally means "The science (or study) of life." The term biology is derived from the Greek word, bios, "life" and the suffix -logia, "study of."
- A substantial amount of the effort expended by early biologists was "taxonomic," that is, biologists studied life forms and tried to characterize them into groups based on various characteristics that they viewed as similar.
- The act of describing sometimes brings special insights, as we shall see in the case of statistical science.

Fundamental Goals of Science

Prediction

- One sign of a maturing science is the ability to predict phenomena in advance.
- Prediction, in advance, need not be precise. It can be probabilistic. That is, based on some information, a scientist might predict that the likelihood of a related event is high (or low), without saying that the event definitely will (or will not) occur.
- Over time, the relative frequency of occurrence of events can be compared with the predicted likelihood, in order to assess the accuracy of predictions.
- Can you think of examples of predicted likelihood in various branches of science?

Fundamental Goals of Science

Prediction vs. Explanation

- As a science advances, it often develops its own specialized terminology to describe its phenomena.
- Sometimes the sophistication of the terminology is mistaken for profundity.
- Consider an example from clinical psychology, the science of behavior disorders and their treatment.
- In the 20th century, Sigmund Freud, the founder of *psychoanalysis*, was a pre-eminent clinical psychologist. Indeed, 50 years ago no course in introductory psychology would fail to devote a week's lectures to Freud's ideas.

Fundamental Goals of Science

Prediction vs. Explanation

- Freud's ideas were complex and controversial, especially because they emphasized, during a rather repressed era, the importance of sexuality and unconscious motivation in human behavior.
- Through psychoanalytic techniques, an individual might get in touch with unconscious conflicts and repressed motivations that are the source of unhappiness.
- A key Freudian idea is that people might become *fixated* at a relatively infantile stage of development because of conflicts generated when they were too young to remember the events consciously.
- So, for example, an individual with an obsessive need for neatness might be described as "fixated at the anal stage," and an "anal-retentive personality," possibly because the individual's mother over-reacted during toilet training.

Fundamental Goals of Science

Prediction vs. Explanation

- Being a psychology major in those days could be a lot of fun.
- You could "analyze" your friends, and hypothesize various fixations and sub-conscious motivations in high-sounding Freudian terms.
- In fact, psychoanalysis is terrific at *explaining* observed behavior in terms of complex theoretical ideas.

Fundamental Goals of Science

Prediction vs. Explanation

- An example:

  Paul (to roomate): Good grief, Sigmund, can't you ever pick your stuff up? This room is a disgraceful mess!

  Sigmund: Paul, have you ever wondered what childhood events led you to become such an anal retentive?

  Paul: There you go again, with your Freudian crap. Give it a break.

  Sigmund: You hostility is barely repressed.

Fundamental Goals of Science

Prediction vs. Explanation

- The psychoanalytic method focused on long discussions between therapist and client, during which the therapist helped explain unconscious motivations that the client might not be aware of initially.
- Ultimately, people became more aware of the deficiencies of psychoanalysis, with its emphasis on explanation.
- Consider the following example.

Fundamental Goals of Science

Prediction vs. Explanation

Example (Coffee with Professor Demento)

Imagine you are a student in a first year psychology class taught by Professor Demento, who is actually a severely disturbed individual. During the first lecture in the course, you fail to laugh at one of Professor Demento's jokes. He notices this, and obsesses about it. Finally, a week later, he decides to take action. He invites you to join him at the student coffee hour to talk about your career aspirations. While you are momentarily distracted, he drops a gigantic tablet of LSD (a drug that induces hallucinations) into your coffee. You drink it, and a few minutes later have what appears to be a psychotic episode. You're carted off to a mental hospital, where you come to your senses a week later. You find yourself talking to a clinical psychologist. The psychologist looks at you with deeply sympathetic eyes and asks, "Tell me, looking back on the events of your life, can you think of what might have caused your nervous breakdown?"

Fundamental Goals of Science

Prediction vs. Explanation

Example (Coffee with Professor Demento (ctd))

The point is, many people (especially young college students) are operating under many stresses, financial, physical, and personal. For example, you might be a football player who just got cut from the squad and redshirted. Your parents might have just announced their plans to divorce. A long-term relationship might have just ended. The point is, many people in this situation might well be able to hypothesize, in rich detail, factors that might have "caused their nervous breakdown." With the help of the clinical psychologist, they might embed their hypotheses in a rich theoretical framework spiced up with fancy theoretical terminology. And, of course, they'd be completely wrong! It was Professor Demento all the time!

Fundamental Goals of Science

Prediction vs. Explanation

Example (Coffee with Professor Demento (ctd))

This example dramatizes the difference between prediction and explanation as criteria for a valid science. The ability to concoct an explanation for a psychotic episode is quite different from the ability to predict (even probabilistically) a psychotic episode.

Fundamental Goals of Science

Control

- The dream of many a scientist is to be able to control nature.
- For example, it is one thing to be able to describe meteorological phenomena and predict them (at least probabilitically).
- It is another thing entirely to be able to control the weather. But people have been trying.

Fundamental Goals of Science

Control

Example

In 1983 I was a visiting professor of statistics at the University of South Africa. When I arrived there in August, scarcely a drop of rain had fallen anywhere in the country for several months.

Many of the country's top statistical scientists were working on questions related to weather and rainfall. For example:

Based on cloud patterns and meteorological data, where is the best place to construct a major reservoir?

Do the data suggest that cloud seeding can be cost effective as a means of increasing rain? If so, which cloud seeding methods are best, and how can meteorological information best be used to guide them?

Fundamental Goals of Science

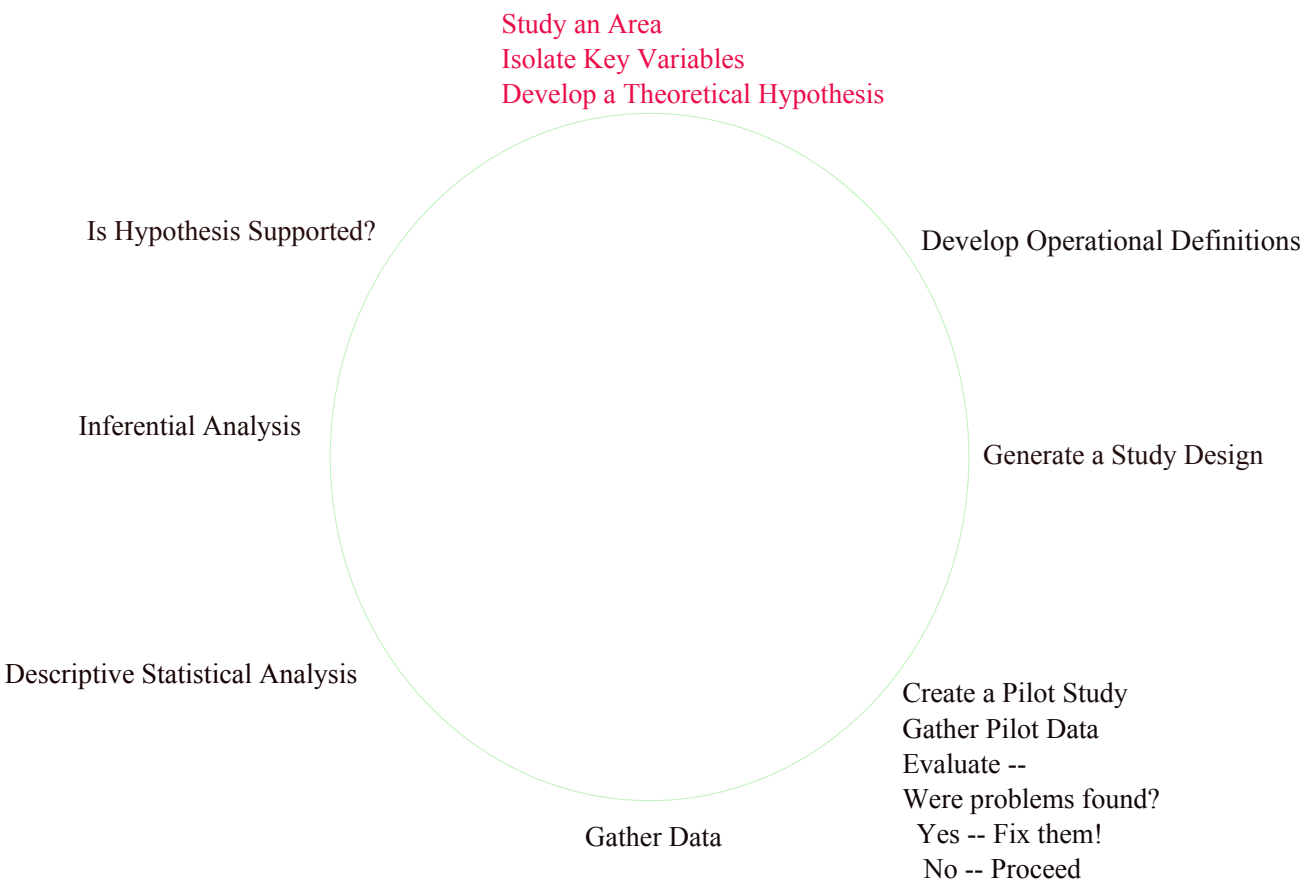
Understanding

- The idea that "understanding" is an ultimate goal of science is complex and controversial.
- True "understanding" can be elusive, and it may not be possible to know if and when one has achieved it.
- For example, Newtonian physics did a superb job of predicting and explaining countless observed phenomena, but was ultimately proven incomplete and, in a sense, "wrong."
- Consequently, it is probably best to view any level of "understanding" of the world as temporary. Such an understanding needs to be reviewed periodically and subjected to new tests that might reveal its deficiencies.
- This process of *testing* our ideas in a controlled and systematic way is the foundation of what we call "the scientific method."

The Scientific Method

- Scientists have made tremendous progress in the last 3 centuries by employing a systematic approach to the development of knowledge.
- This approach is loosely referred to as "the scientific method" in many textbooks.
- Let's review fundamental aspects of this approach.

The Scientific Method

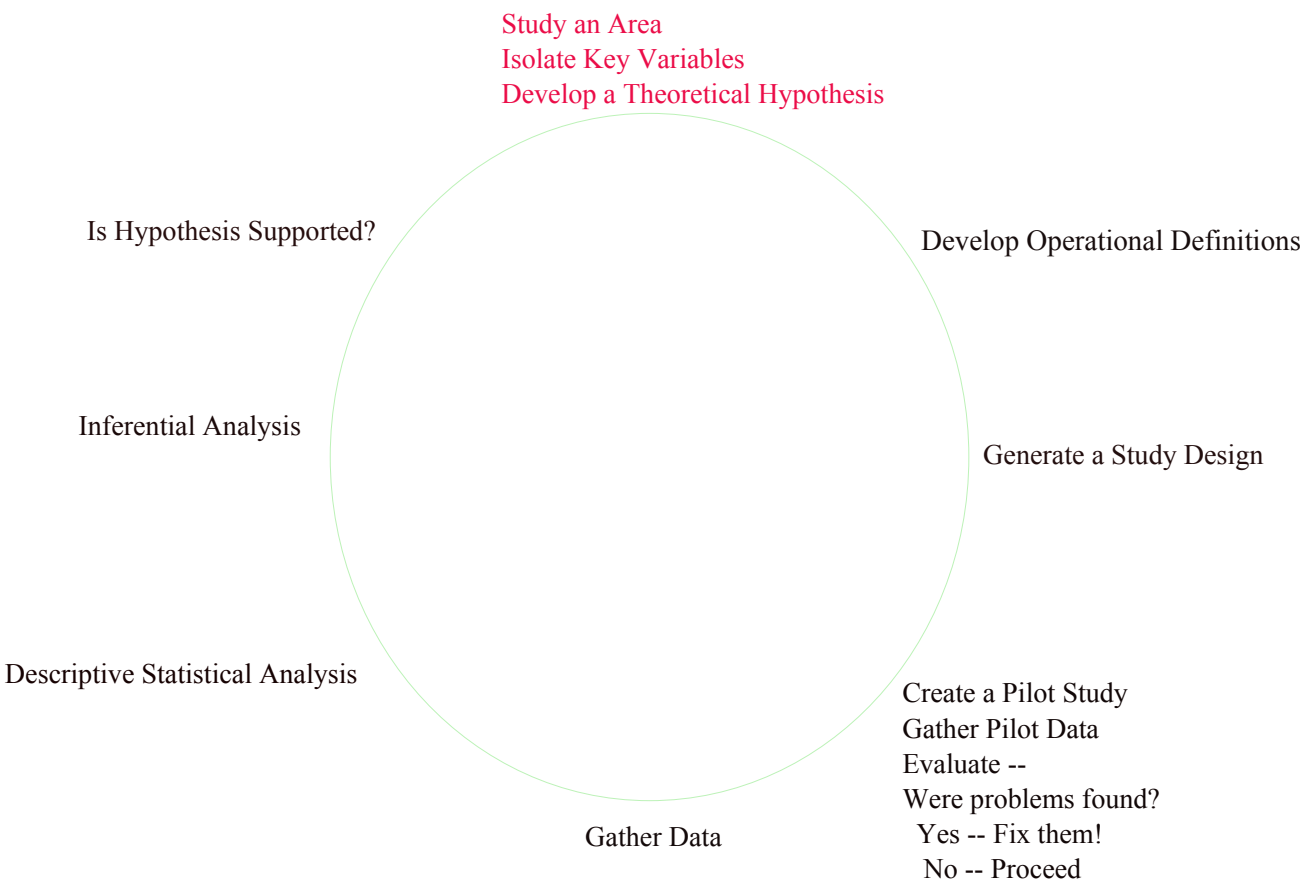


The Scientific Method

Hypothesis Formation

- In this stage, the scientist picks an area of inquiry and studies what work has gone before.
- A critical analysis of previous work in the field can raise important theoretical insights into new possible avenues for research.
- The scientist develops an hypothesis about the relationship between scientific variables.
- Independent (or "exogenous") variables are viewed as affecting dependent (or "endogenous") variables.
- A simple kind of hypothesis is that "variable X affects variable Y."
- What are some examples of such a simple, two-variable hypothesis?

The Scientific Method



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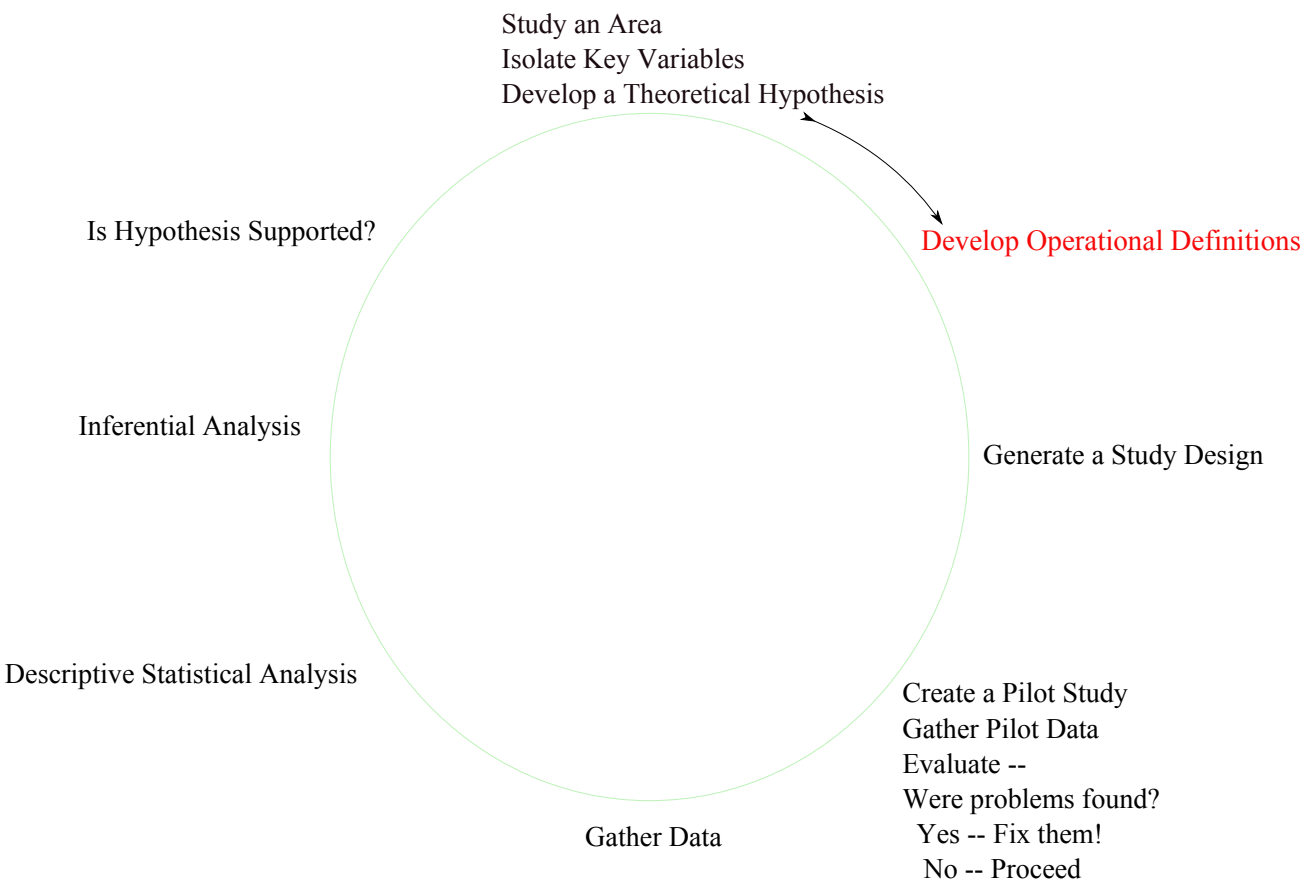


The Scientific Method

Operationalization

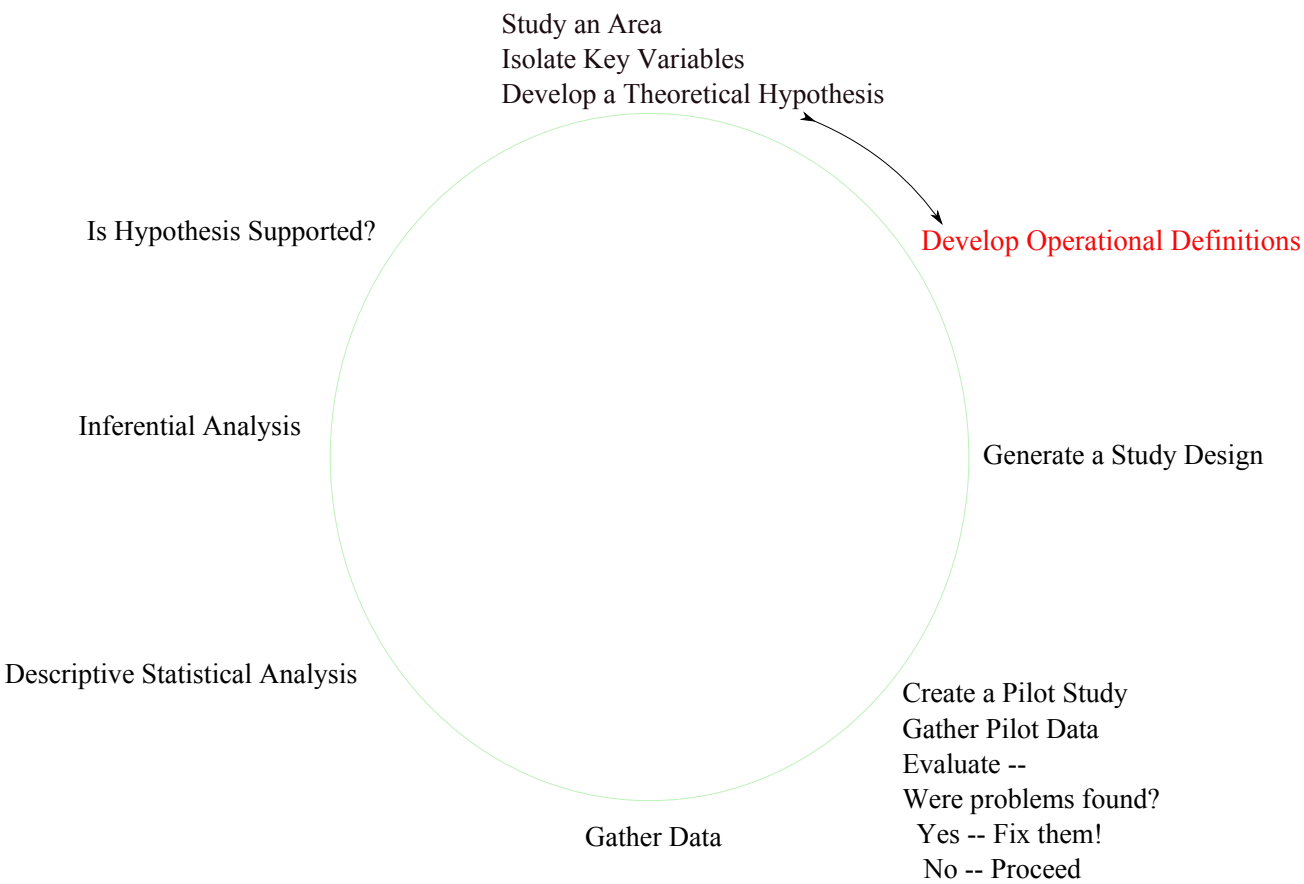
- When the scientist starts to plan a study, one of the first steps is *operationalization* of the key variables in the study.
- For example, suppose you were studying the impact of "intelligence" on income in a large organization.
- You would have to develop *operational definitions* for each of those variables.
- For example you might operationalize intelligence as the IQ score achieved by each employee on a well-known standardized IQ test.

The Scientific Method

Operationalization

- Operationalization involves tradeoffs between generality, simplicity, and replicability.
- A simple, well-defined measure makes a study easier to do, and easier to replicate.
- However, if the measure is too simple, it may fail to capture important aspects of the construct being measured.
- Many people are not convinced that IQ scores adequately measure intelligence, for example. But they are effective at predicting performance within large organizations, and it seems they do correlate with what is commonly thought of as intelligence.

The Scientific Method



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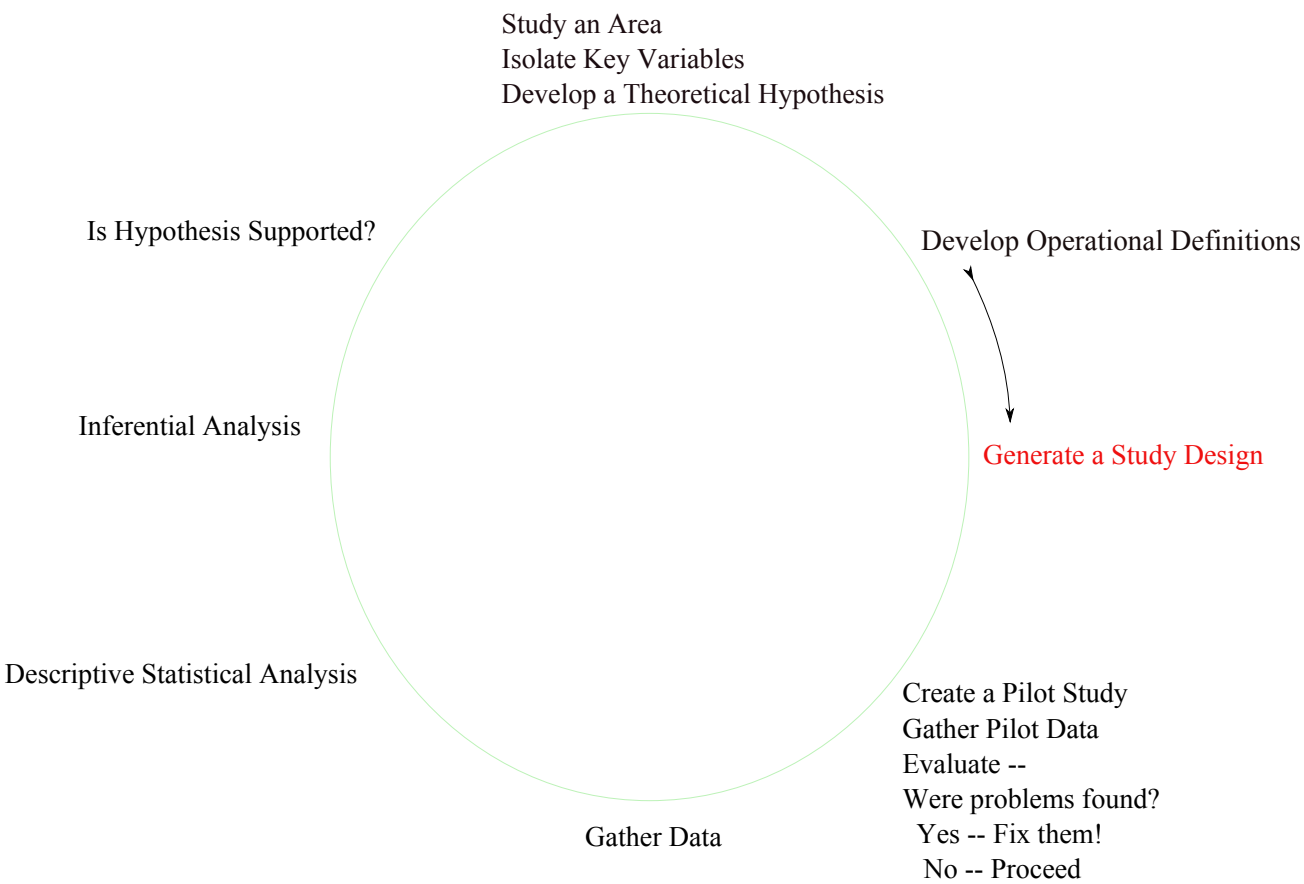


The Scientific Method

Choosing a Design

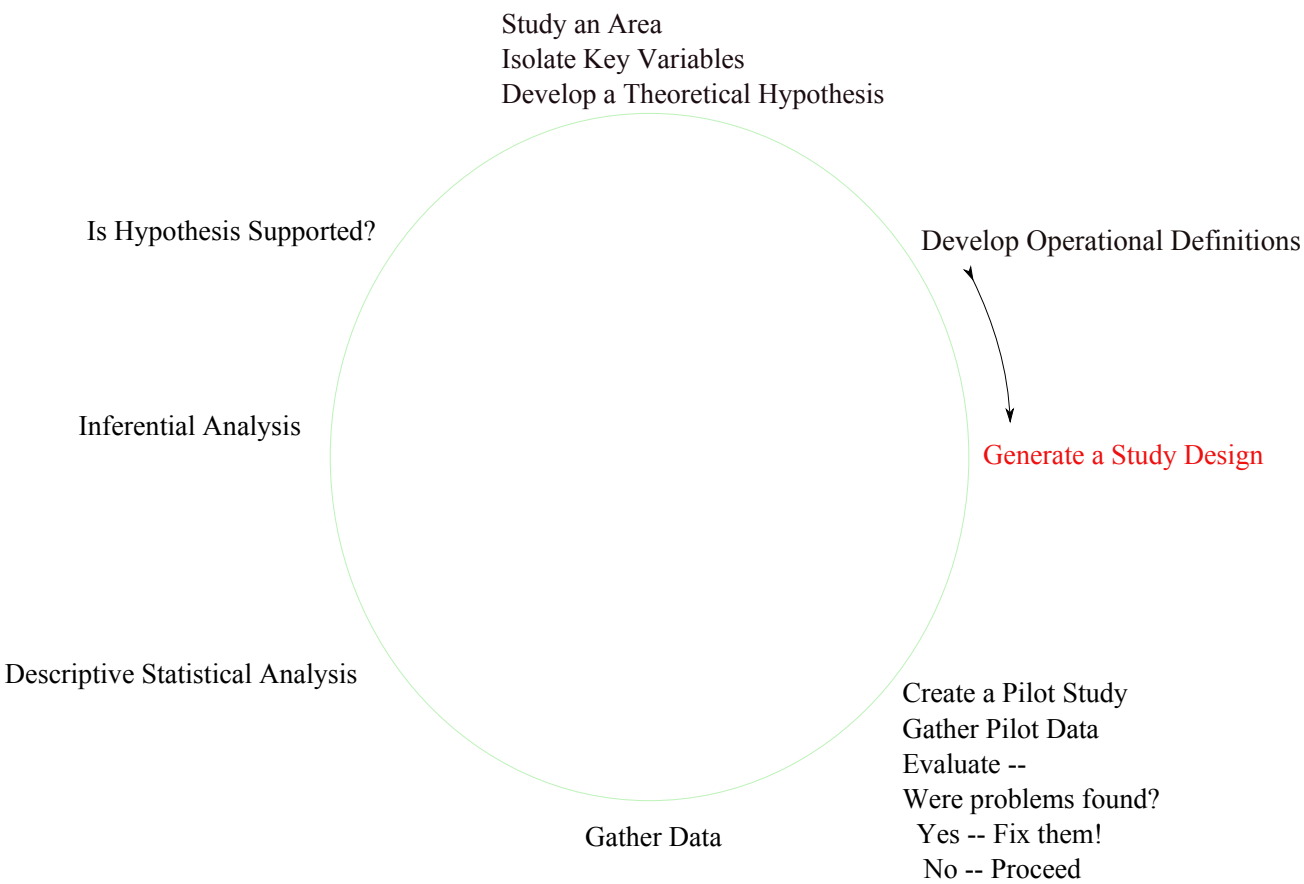
- One basic design choice is between *manipulative* ("Experimental") research and *non-manipulative* ("Observational," "Correlational," or "Quasi-Experimental") research.
- In manipulative experimentation, the experimenter manipulates the independent variable X and observes its effect on the dependent variable Y while trying to hold other variables constant.
- In non-manipulative research, the experimenter observes X and Y, and but does not directly manipulate either.

The Scientific Method

Choosing a Design

- One of the best known manipulative designs is the two-group, Experimental-Control group design.
- Both groups are treated exactly the same, except the Experimental group receives the variable of interest.

The Scientific Method



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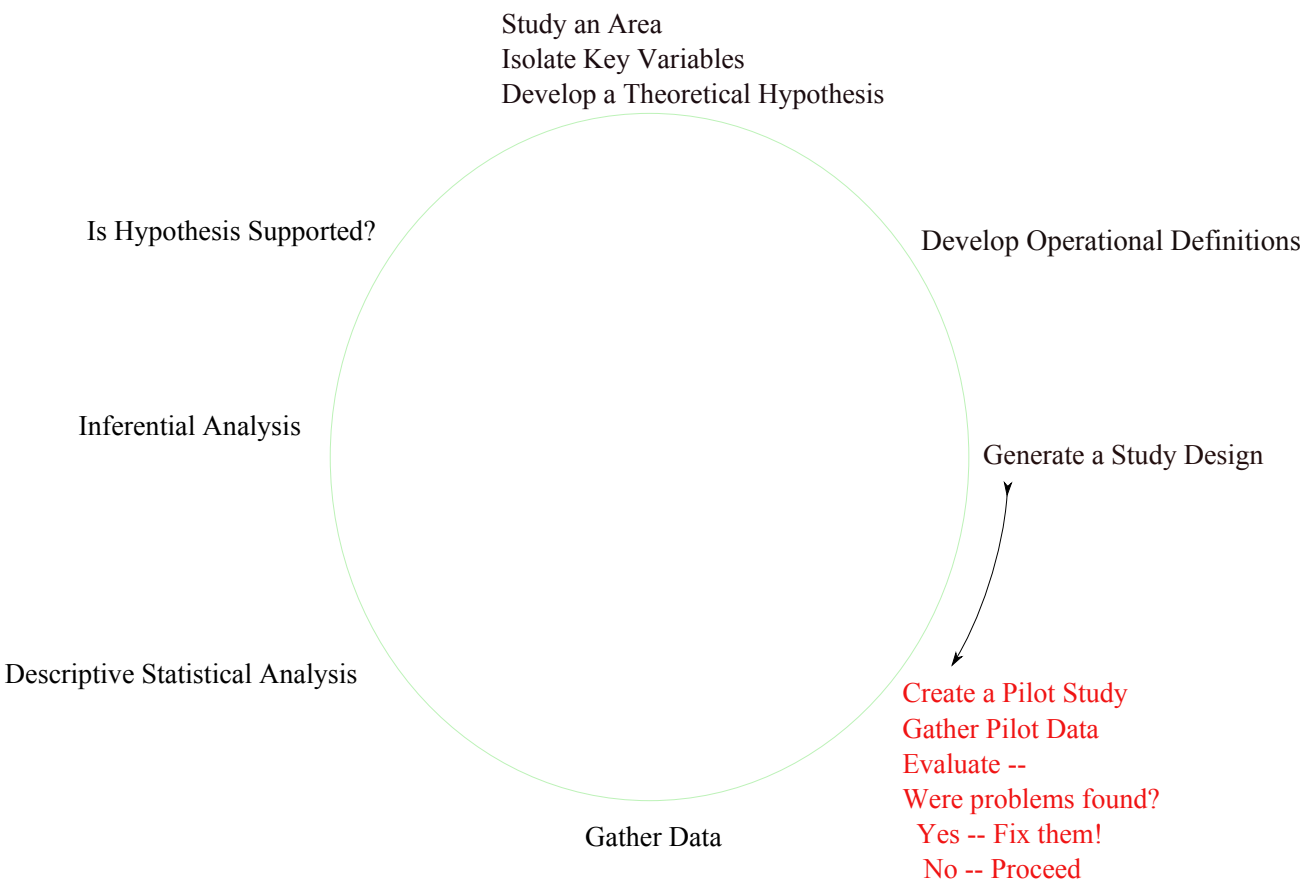


The Scientific Method

Pilot Studies

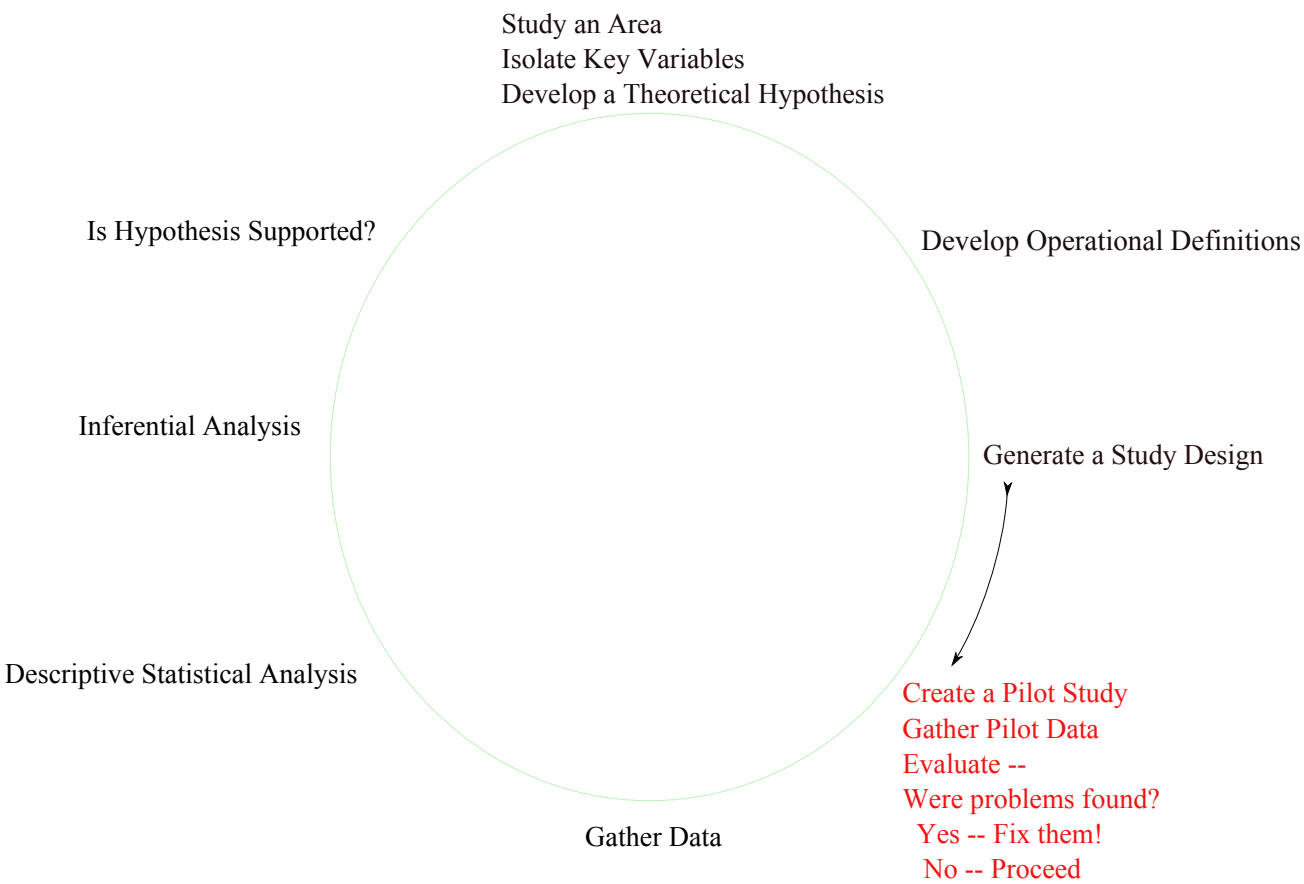
- Of course, many details have to be worked out before an experiment can get fully underway.
- A "pilot study" is often run on a small group of participants, in order to detect any obvious errors in the experimental setup.
- Problems often emerge during the pilot study stage. For example, instructions may be clear to the experimenters, but ambiguous to the participants. Or, the lighting in the room may turn out to be inadequate.

The Scientific Method

Pilot Studies

- The experimental "paradigm," consisting of the design setup, operational definitions, and specific procedures, may be refined successively through a series of pilot studies.

The Scientific Method



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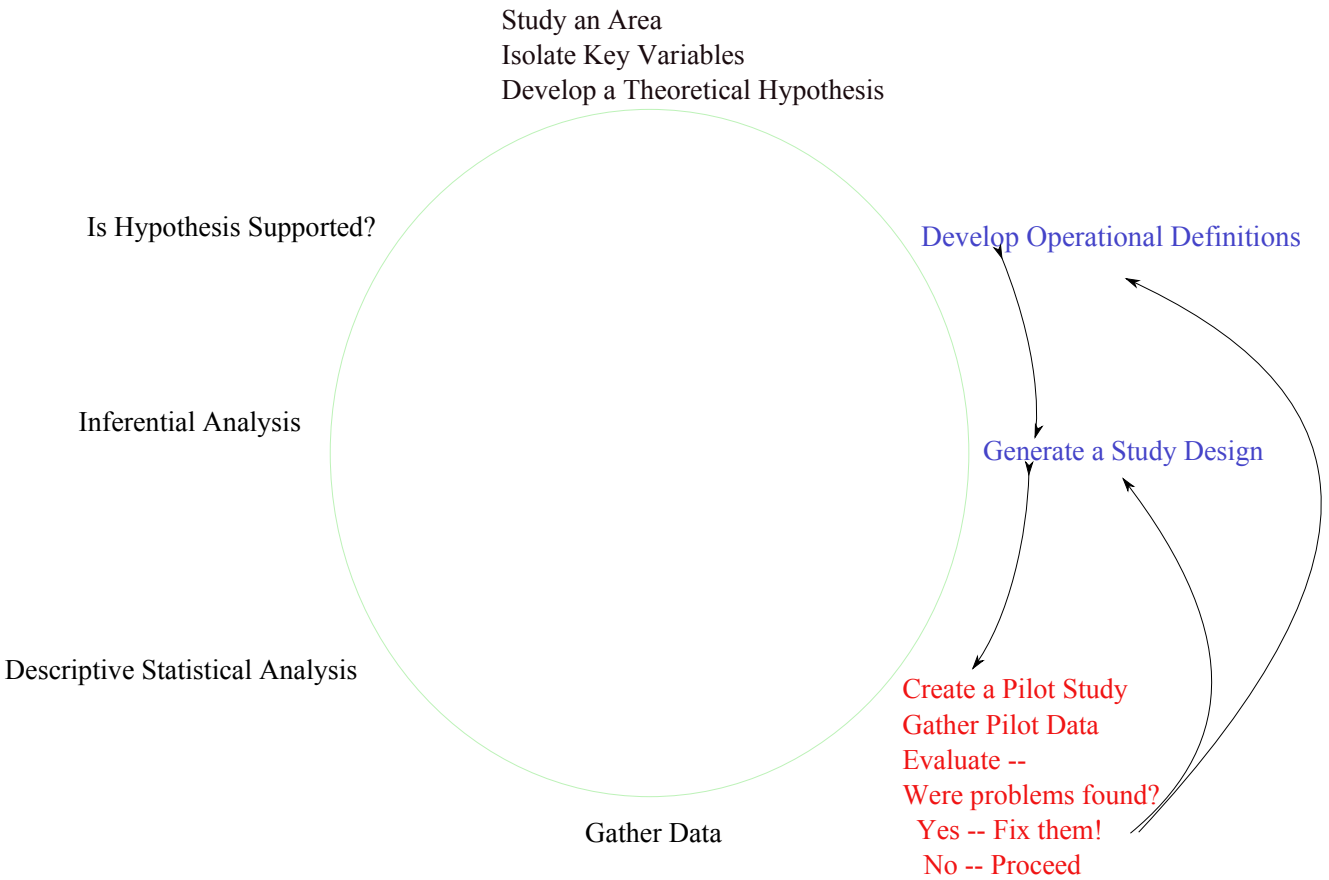
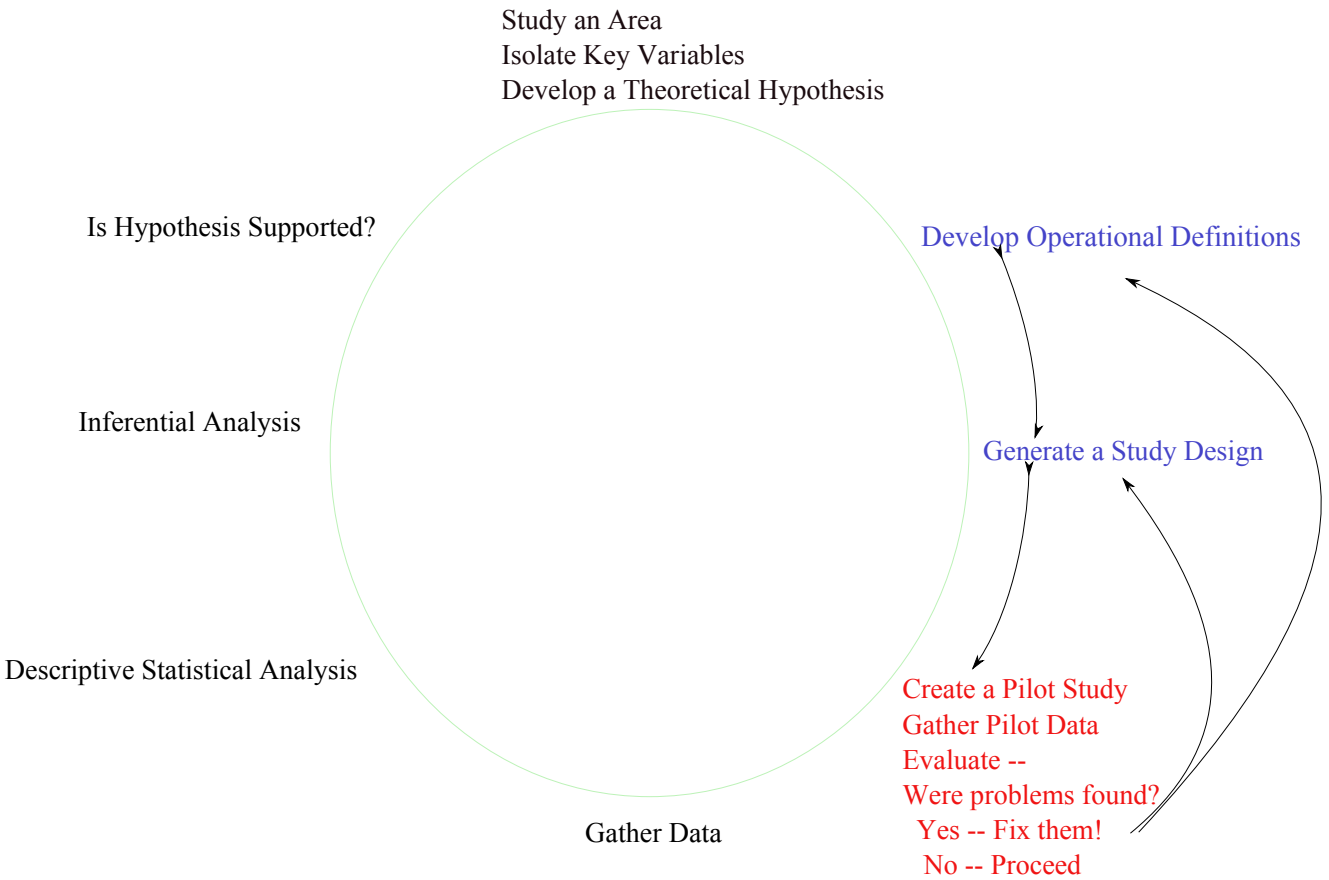


The Scientific Method

Data Gathering

- Once the paradigm has been refined to a point where there are no longer any obvious problems, the experimenters will perform *sample size analysis* in order to assess how many participants they should use in order to optimize the likelihood of making correct inferences.
- At that point, subjects are recruited (if they haven't been already) and the experiment commences.
- Weeks (or months) later, the experimenters have lists of numbers representing the performance of the subjects in the experiment. At that point, statistical analysis commences.

The Scientific Method



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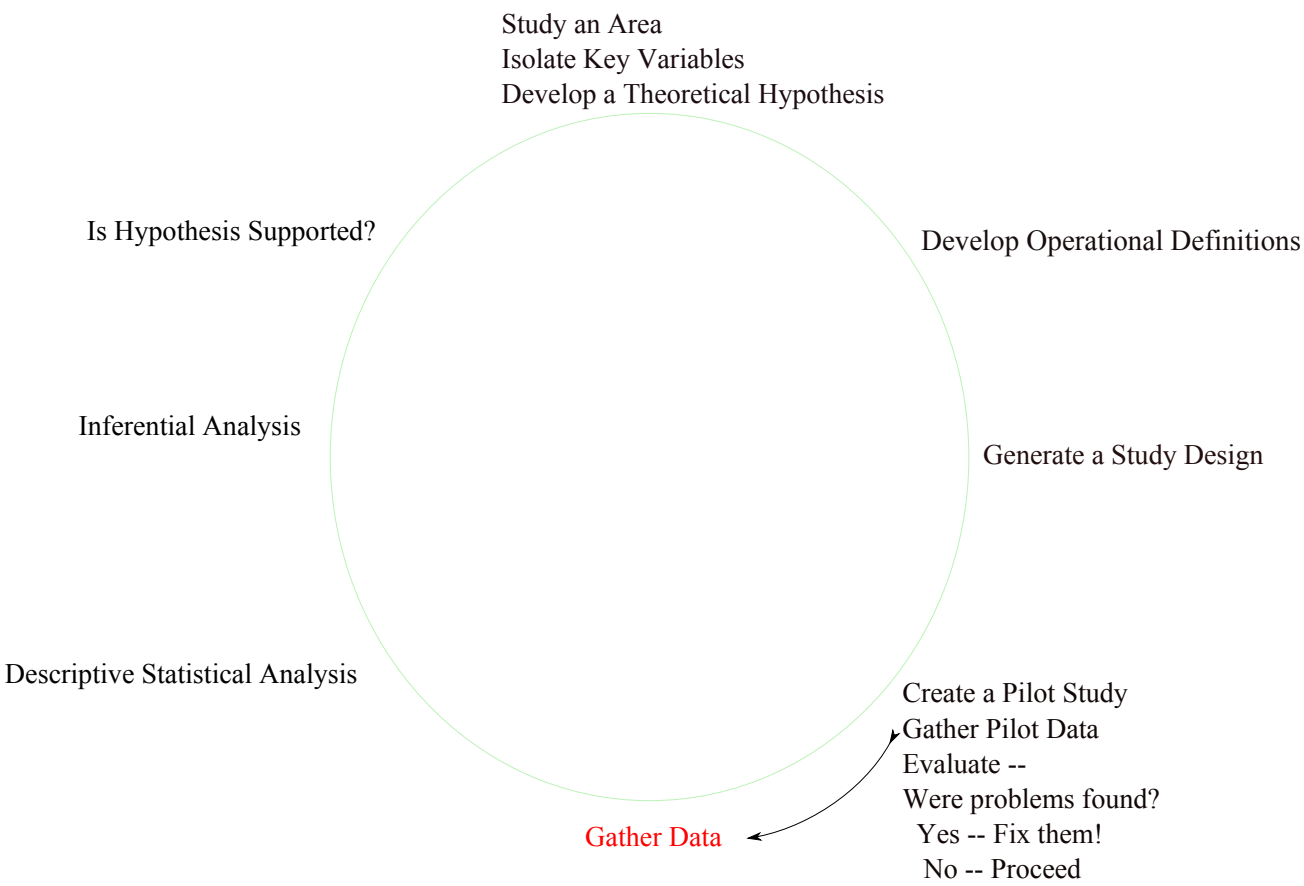
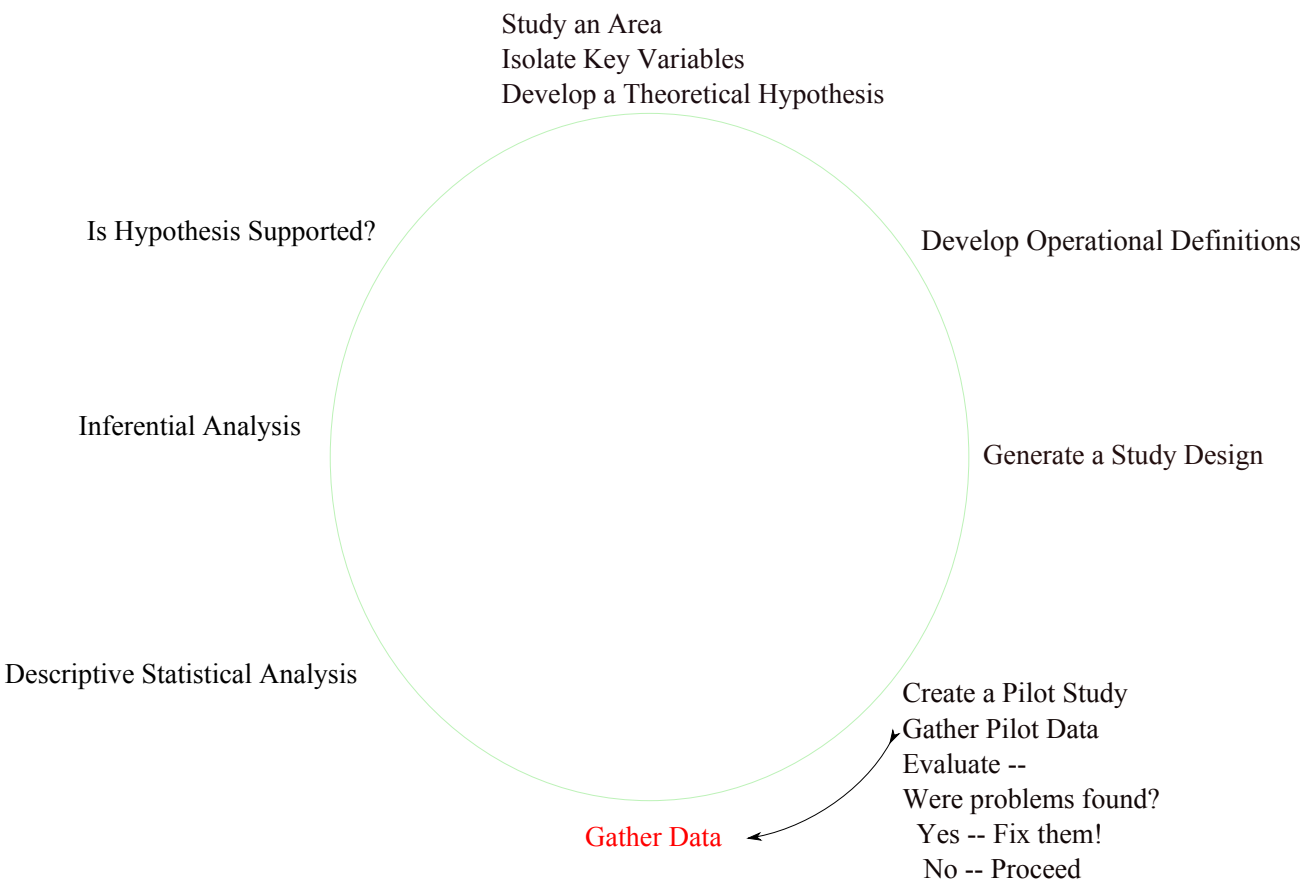


The Scientific Method

Descriptive Statistical Analysis

- Descriptive statistical analysis takes the lists of numbers and tries to describe what, if anything, is "there" in the way of important results.
- A wide variety of numerical and graphical methods are employed, and many of them have been developed only recently.

The Scientific Method



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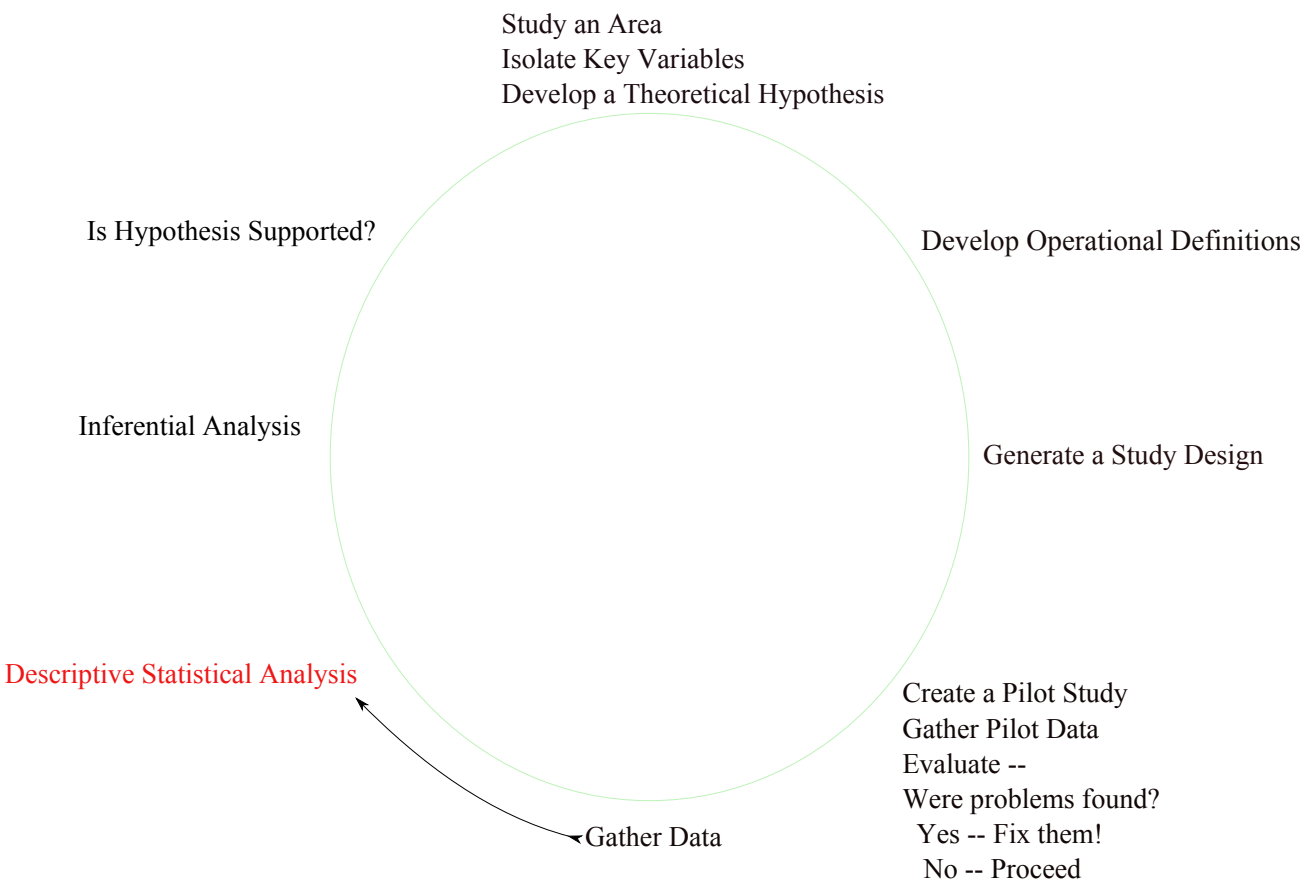
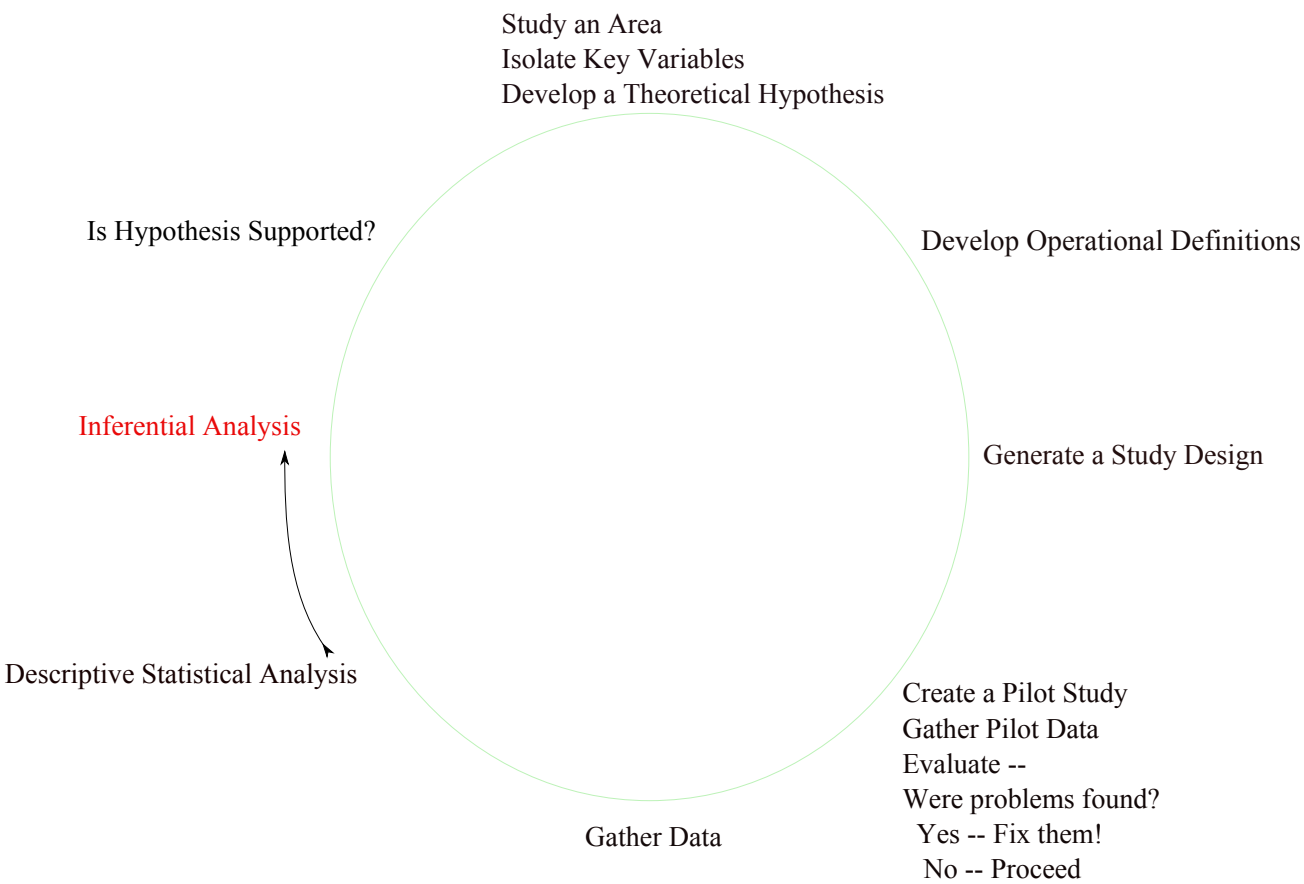


The Scientific Method

Inferential Statistical Analysis

- Suppose the descriptive analysis seems to indicate that "something is there," that is, that the manipulation had an effect.
- Ever-present is the possibility that what "is there" is just a mirage, created by "the luck of the draw."
- That is where the science of *inferential statistics* comes into play.
- Inferential statistics are techniques that attempt to apply mathematical and statistical theory to assess the likelihood that a result was caused by luck, as opposed to being indicative of a real scientific phenomenon.

The Scientific Method



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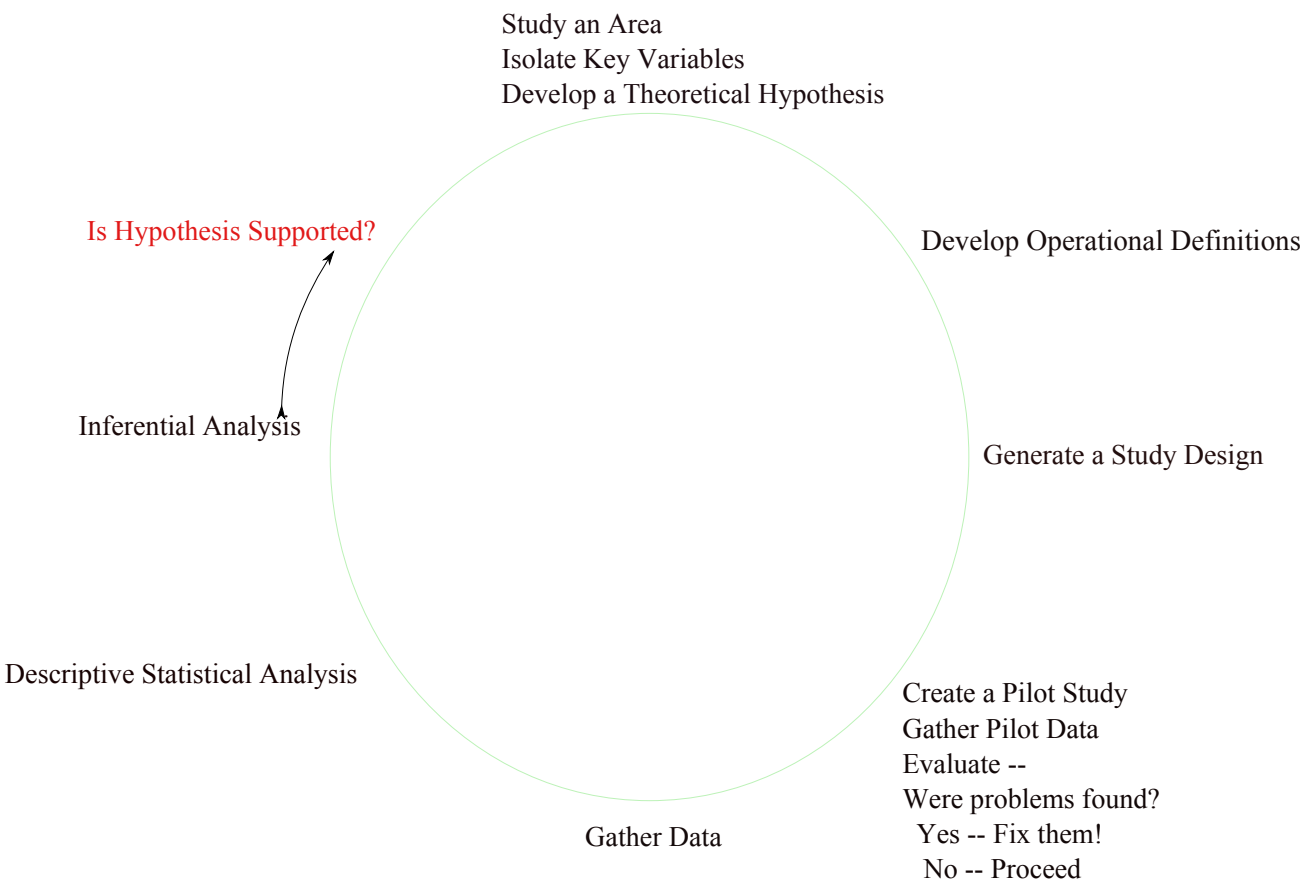

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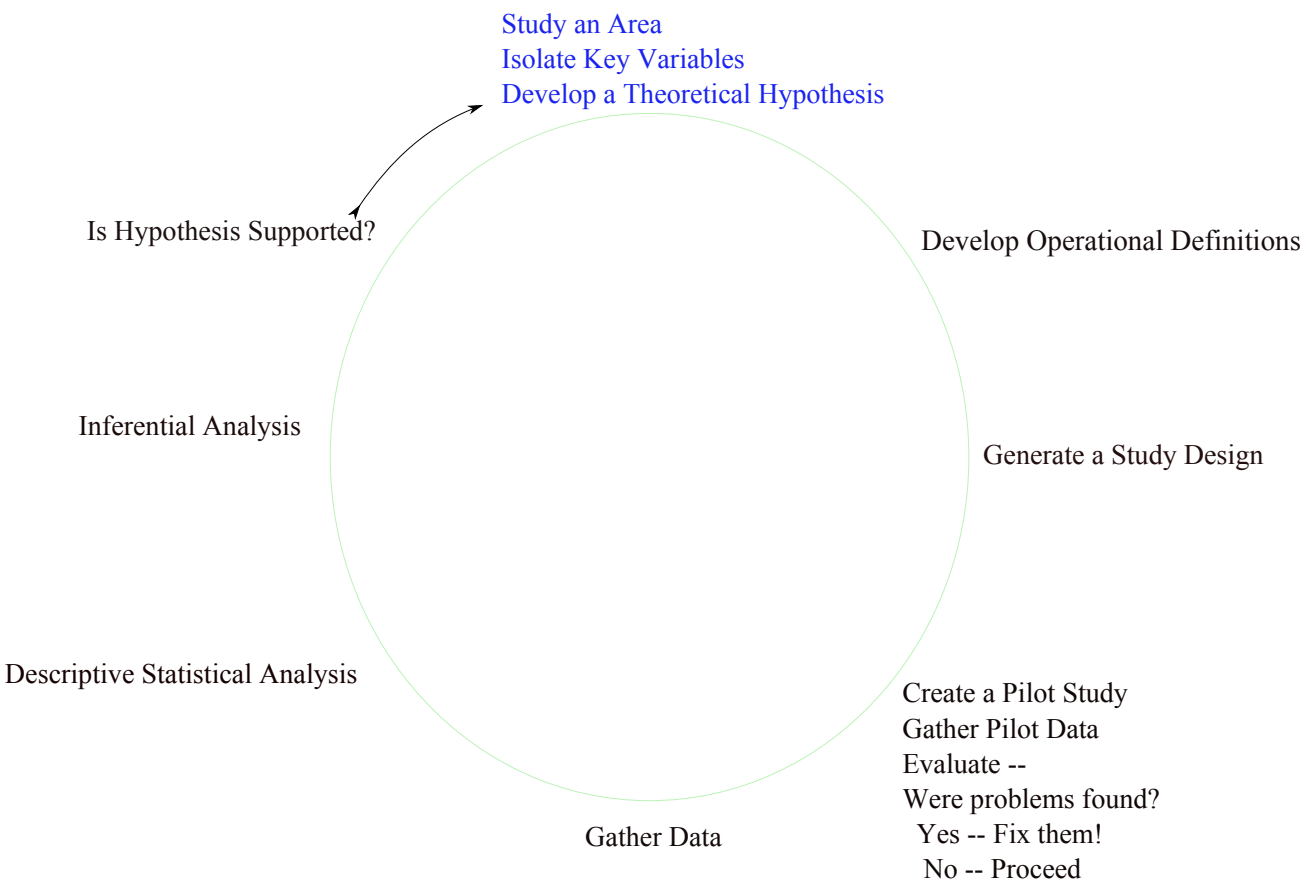

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