# *Section* 1.4 – Design of Experiments

## Describe the Characteristics of an Experiment

### *Definition*

An ***experiment*** is a controlled study conducted to determine the effect of varying one or more explanatory variables or ***factors*** has on a response variable. Any combination of the values of the factors is called a ***treatment***.

The ***experimental unit*** (or ***subject***) is a person, object or some other well-defined item upon which a treatment is applied.

A ***control group*** serves as a baseline treatment that can be used to compare to other treatments.

A ***placebo*** is an innocuous medication, such as a sugar tablet, that looks, tastes, and smells like the experimental medication.

### *Definitions*

***Blinding*** refers to nondisclosure of the treatment an experimental unit is receiving.

A ***single-blind*** experiment is one in which the experimental unit (or subject) does not know which treatment he or she is receiving.

A ***double-blind*** experiment is one in which neither the experimental unit nor the researcher in contact with the experimental unit knows which treatment the experimental unit is receiving.

### *Example*

Lipitor is a cholesterol-lowering drug made by Pfizer. In the Collaborative Atorvastatin Diabetes Study (CARDS), the effect of Lipitor on cardiovascular disease was assessed in 2838 subjects, ages 40 to 75, with type 2 diabetes, without prior history of cardiovascular disease. In this placebo-controlled, double-blind experiment, subjects were randomly allocated to either Lipitor 10 mg daily (1428) or placebo (1410) and were followed for 4 years. The response variable was the occurrence of any major cardiovascular event.

Lipitor significantly reduced the rate of major cardiovascular events (83 events in the Lipitor group versus 127 events in the placebo group). There were 61 deaths in the Lipitor group versus 82 deaths in the placebo group.

*a)* What does it mean for the experiment to be placebo-controlled?
*b)* What does it mean for the experiment to be double-blind?
*c)* What is the population for which this study applies? What is the sample?
*d)* What are the treatments?
*e)* What is the response variable? Is it qualitative or quantitative?

***Solution***

***a)*** The placebo is a medication that looks, smells, and tastes like Lipitor. The placebo control group serves as a baseline against which to compare the results from the group receiving Lipitor. The placebo is also used because people tend to behave differently when they are in a study. By having a placebo control group, the effect of this is neutralized.

***b)*** Since the experiment is double-blind, the subjects, as well as the individual monitoring the subjects, do not know whether the subjects are receiving Lipitor or the placebo. The experiment is double-blind so that the subjects receiving the medication do not behave differently from those receiving the placebo and so the individual monitoring the subjects does not treat those in the Lipitor group differently from those in the placebo group.

***c)*** The population is individuals from 40 to 75 years of age with type 2 diabetes without a prior history if cardiovascular disease. The sample is the 2838 subjects in the study.

***d)*** The treatments are 10 mg of Lipitor or a placebo daily.

***e)*** The response variable is whether the subject had any major cardiovascular event, such as a stroke, or not. It is a qualitative variable.

## *Example*

The English Department of a community college is considering adopting an online version of the freshman English course. To compare the new online course to the traditional course, an English Department faculty member randomly splits a section of her course. Half of the students receive the traditional course and the other half is given an online version. At the end of the semester, both groups will be given a test to determine which performed better.

*a)* Who are the experimental units?

*b)* What is the population for which this study applies?

*c)* What are the treatments?

*d)* What is the response variable?

*e)* Why can't this experiment be conducted with blinding?

***Solution***

***a)*** The students in the class

***b)*** All students who enroll in the class

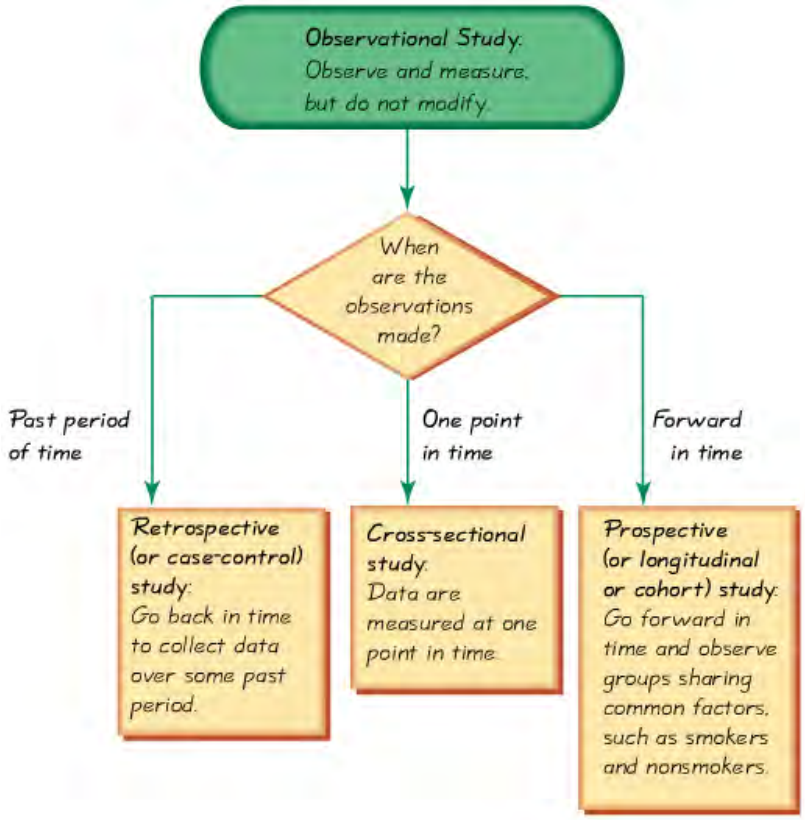
***c)*** Traditional vs. online instruction

***d)*** Exam score

***e)*** Both the students and instructor know which treatment they are receiving

## Explain the Steps in Designing an Experiment

To ***design*** an experiment means to describe the overall plan in conducting the experiment.




## Steps in Conducting an Experiment

***Step* 1:** Identify the problem to be solved.

- Should be explicit
- Should provide the experimenter direction
- Should identify the response variable and the population to be studied.
- Often referred to as the *claim*.

***Step* 2:** Determine the factors that affect the response variable.

- Once the factors are identified, it must be determined which factors are to be fixed at some predetermined level (the control), which factors will be manipulated and which factors will be uncontrolled.

***Step* 3:** Determine the number of experimental units.

***Step* 4:** Determine the level of the predictor variables

1. **Control:** There are two ways to control the factors.
   - ***a)*** Fix their level at one predetermined value throughout the experiment. These are variables whose effect on the response variable is not of interest.
   - ***b)*** Set them at predetermined levels. These are the factors whose effect on the response variable interests us. The combinations of the levels of these factors represent the treatments in the experiment.

2. ***Randomize*:** Randomize the experimental units to various treatment groups so that the effects of variables whose level cannot be controlled is minimized. The idea is that randomization "averages out" the effect of uncontrolled predictor variables.

***Step* 5:** Conduct the Experiment

***a)*** ***Replication*** occurs when each treatment is applied to more than one experimental unit. This helps to assure that the effect of a treatment is not due to some characteristic of a single experimental unit. It is recommended that each treatment group have the same number of experimental units.

***b)*** Collect and process the data by measuring the value of the response variable for each replication. Any difference in the value of the response variable is a result of differences in the level of the treatment.

***Step* 6:** Test the claim

- This is the subject of inferential statistics.
- Inferential statistics is a process in which generalizations about a population are made on the basis of results obtained from a sample. Provide a statement regarding the level of confidence in the generalization. Methods of inferential statistics are presented later in the text.

***Randomization*** is used when subjects are assigned to different groups through a process of random selection. The logic is to use chance as a way to create two groups that are similar.

***Replication*** is the repetition of an experiment on more than one subject. Samples should be large enough so that the erratic behavior that is characteristic of very small samples will not disguise the true effects of different treatments. It is used effectively when there are enough subjects to recognize the differences from different treatments.

> Use a sample size that is large enough to let us see the true nature of any effects, and obtain the sample using an appropriate method, such as one based on *randomness*.

***Blinding*** is a technique in which the subject doesn't know whether he or she is receiving a treatment or a placebo. Blinding allows us to determine whether the treatment effect is significantly different from a placebo effect, which occurs when an untreated subject reports improvement in symptoms.

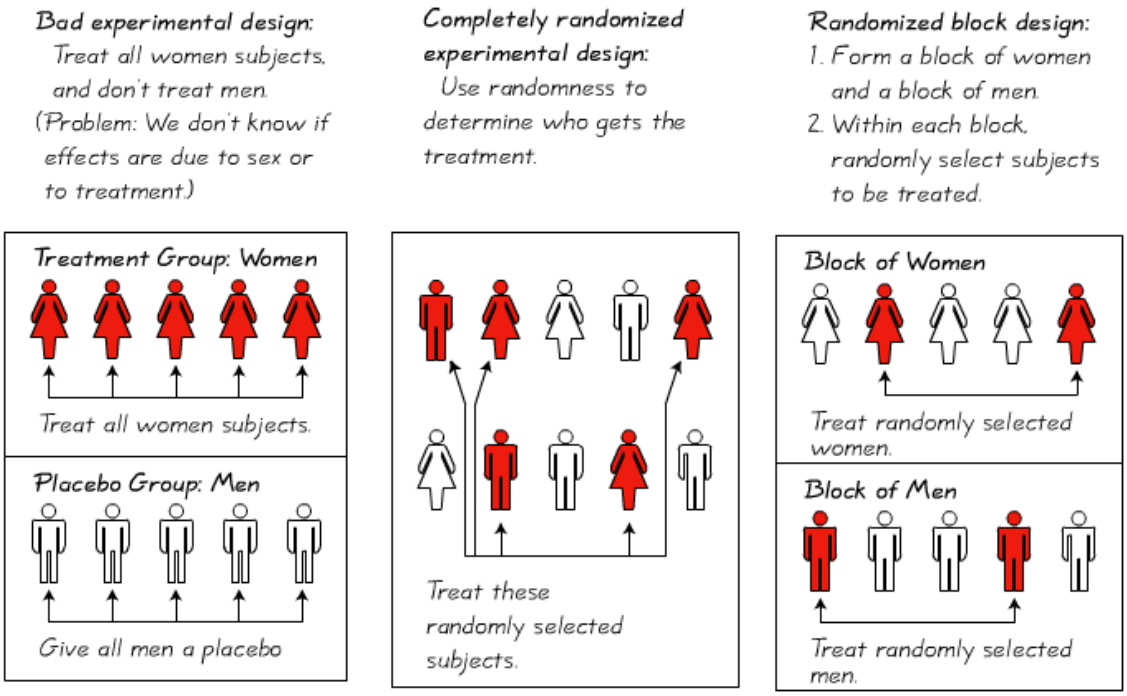
***Double-Blind*** : Blinding occurs at two levels:

1. The subject doesn't know whether he or she is receiving the treatment or a placebo
2. The experimenter does not know whether he or she is administering the treatment or placebo

***Completely Randomized Experimental Design*** assign subjects to different treatment groups through a process of random selection

***Randomized Block Design*** a block is a group of subjects that are similar, but blocks differ in ways that might affect the outcome of the experiment.

***Rigorously Controlled Design*** carefully assign subjects to different treatment groups, so that those given each treatment are similar in ways that are important to the experiment




***Matched Pairs Design*** compare exactly two treatment groups using subjects matched in pairs that are somehow related or have similar characteristics

### *Example*

In 1954, a large-scale experiment was designed to test the effectiveness of the Salk vaccine in preventing polio, which had killed or paralyzed thousands of children. In that experiment, 200,745 children were given a treatment consisting of Salk vaccine injections, while a second group of 201,229 children were injected with a placebo that contained no drug. The children being injected did not know whether they were getting the Salk vaccine or the placebo. Children were assigned to the treatment or placebo group a process of random selection, equivalent to flipping a coin. Among the children given the Salk vaccine, 33 later developed paralytic polio, but among the children given a placebo, 115 later develop paralytic polio.

## Explain the Completely Randomized Design

### *Definition*

A ***completely randomized design*** is one in which each experimental unit is randomly assigned to a treatment.

### *Example*

A farmer wishes to determine the optimal level of a new fertilizer on his soybean crop. Design an experiment that will assist him.

***Solution***

***Step* 1**: The former wants to identify the optimal level of fertilizer for growing soybeans. We define optimal as the level that maximizes yield. So the response variable will be crop yield.

***Step* 2**: Some factors that affect crop yield are fertilizer, precipitation, sunlight, method of tilling the soil, type of soil, plant, and temperature.

***Step* 3**: In this experiment, we will plant 60 soybean plants (experimental units)

***Step* 4**: We list the factors and their levels.

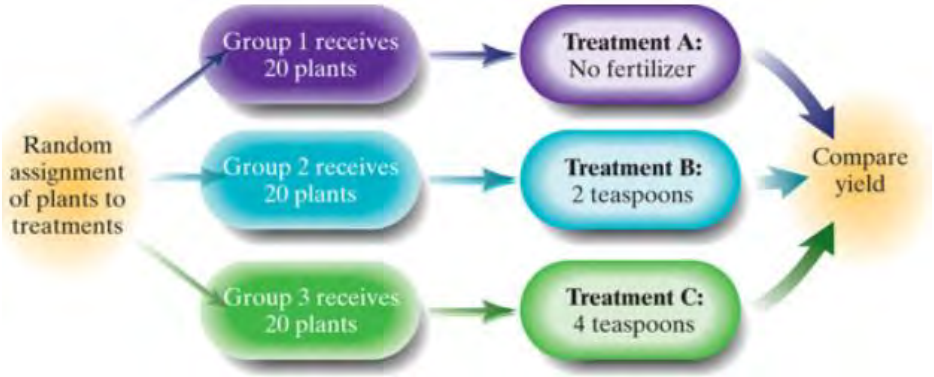
***Fertilizer***: This factor will be controlled and set at three levels. We wish to measure the effect of varying the level of this variable on the response variable, yield. We will set the treatments (level of fertilizer) as follows.


*Treatment* ***A***: 20 soybean plants receive no fertilizer.
*Treatment* ***B***: 20 soybean plants receive 2 teaspoons of fertilizer per gallon of water every 2 weeks.
*Treatment* ***C***: 20 soybean plants receive 4 teaspoons of fertilizer per gallon of water every 2 weeks.

***Step* 5**: ***a)*** We need to assign each plant to a treatment group. First, we will number the plants from 1 to 60 and randomly generate 20 numbers. The plants corresponding to these numbers get treatment ***A***. Next we number the remaining plants 1 to 40 and randomly generate 20 numbers. The plants corresponding to these numbers get the treatment ***B***. The remaining plants get treatment C. Now we till the soil, plant the soybean plants, and fertilizer according to the schedule prescribed.

***b)*** At the end of the growing season, we determine the crop yield for each plant.

***Step* 6**: We determine any difference in yield among the three treatment groups.



## *Example*

The octane of fuel is a measure of its resistance to detonation with a higher number indicating higher resistance. An engineer wants to know whether the level of octane in gasoline affects the gas mileage of an automobile. Assist the engineer in designing an experiment.

***Solution***

***Step* 1**: The response variable is miles per gallon.

***Step* 2**: Factors that affect miles per gallon:
Engine size, outside temperature, driving style, driving conditions, characteristics of car

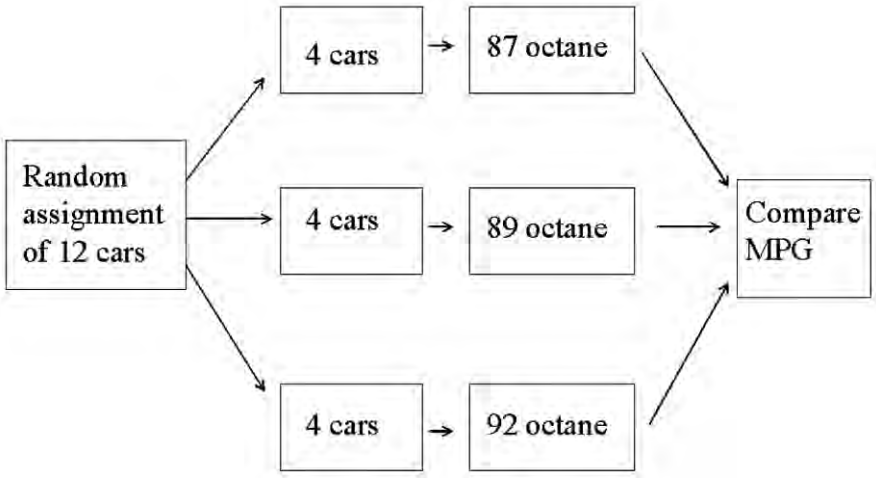
***Step* 3:** We will use 12 cars all of the same model and year.

***Step* 4**: We list the variables and their level

- Octane level - manipulated at 3 levels. Treatment A: 87 octane, Treatment B: 89 octane, Treatment C: 92 octane
- Engine size - fixed
- Temperature - uncontrolled, but will be the same for all 12 cars.
- Driving style/conditions - all 12 cars will be driven under the same conditions on a closed track - fixed.
- Other characteristics of car - all 12 cars will be the same model year, however, there is probably variation from car to car. To account for this, we randomly assign the cars to the octane level.

***Step* 5**: Randomly assign 4 cars to the 87 octane, 4 cars to the 89 octane, and 4 cars to the 92 octane. Give each car 3 gallons of gasoline. Drive the cars until they run out of gas. Compute the miles per gallon.

***Step* 6:** Determine whether any differences exist in miles per gallon.



## Explain the Matched-Pairs Design

### *Definition*

A ***matched-pairs design*** is an experimental design in which the experimental units are paired up. The pairs are matched up so that they are somehow related (that is, the same person before and after a treatment, twins, husband and wife, same geographical location, and so on). There are only two levels of treatment in a matched-pairs design.

### *Example*

An educational psychologist want to determine listening to music has an effect on a student's ability to learn. Design an experiment to help the psychologist answer the question.

***Solution***

We match students according to IQ and gender. For example, we match two females with IQs in the 110 to 115 range.
For each pair of students, we flip a coin to determine which student is assigned the treatment of a quiet room or a room with music playing in the background.
Each student will be given a statistics textbook. After 2 hours the students will enter a testing center and take a short quiz on the material in the section. We compute the difference in the scores of each matched pair. Any differences in scores will be attributed to the treatment.


## Explain the Randomized Block Design

Grouping similar (homogeneous) experimental units together and then randomizing the experimental units within each group to a treatment is called blocking. Each group of homogeneous individuals is called a ***block***.

***Confounding*** occurs when the effect of two factors (explanatory variables) on the response variable cannot be distinguished.

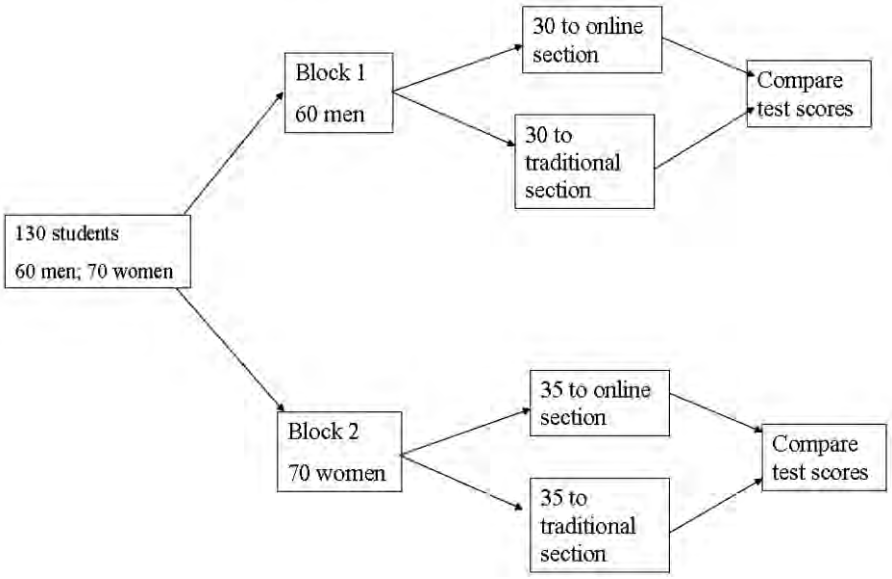
A ***randomized block design*** is used when the experimental units are divided into homogeneous groups called blocks. Within each block, the experimental units are randomly assigned to treatments.

### *Example*

The English Department is considering adopting an online version of the freshman English course. After some deliberation, the English Department thinks that there may be a difference in the performance of the men and women in the traditional and online courses. To accommodate any potential differences, they randomly assign half the 60 men to each of the two courses and they do the same for the 70 women.

***Solution***

This is a randomized block design where gender forms the block. This way, gender will not play a role in the value of the response variable, test score. We do not compare test results across gender.




## *Summary*

Three very important considerations in the design of experiments are the following:

1. Use *randomization* to assign subjects to different groups
2. Use replication by repeating the experiment on enough subjects so that effects of treatment or other factors can be clearly seen.
3. *Control the effects of variables* by using such techniques as blinding and a completely randomized experimental design

## *Errors*

No matter how well you plan and execute the sample collection process, there is likely to be some error in the results.

***Sampling error*** the difference between a sample result and the true population result; such an error results from chance sample fluctuations

***Nonsampling error*** sample data incorrectly collected, recorded, or analyzed (such as by selecting a biased sample, using a defective instrument, or copying the data incorrectly)

# *Exercises* *Section* 1.4 – Design of Experiments

**1.** A school psychologist wants to test the effectiveness of a new method for teaching reading. She recruits 500 first-grade students in District 203 and randomly divides them into two groups. Group 1 is taught by means of the new method, while group 2 is taught by traditional methods. The same teacher is assigned to teach both groups. At the end of the year, an achievement test is administered and the results of the two groups are compared.

*a)* What is the response variable in this experiment?
*b)* Think of some of the factors in the study. How are they controlled?
*c)* What are the treatments? How many treatments are there?
*d)* How are the factors that are not controlled dealt with?
*e)* Which group serves as the control group?
*f)* What type of experimental design is this?
*g)* Identify the subjects.

**2.** A pharmaceutical company has developed an experimental drug meant to relieve symptoms associated with the common cold. The company identifies 300 adult males 25 to 29 years old who have a common cold and randomly divides them into 2 groups. Group 1 is given the experimental drug, while group 2 is given a placebo. After 1 week of treatment, the proportions of each group that still have cold symptoms are compared.

*a)* What is the response variable in this experiment?
*b)* Think of some of the factors in the study. How are they controlled?
*c)* What are the treatments? How many treatments are there?
*d)* How are the factors that are not controlled dealt with?
*e)* What type of experimental design is this?
*f)* Identify the subjects.

**3.** Researchers wanted to compare the effectiveness and safety of an extract of St. John's wort with placebo in outpatients with major depression. To do this, they recruited 200 adult outpatients diagnosed as having major depression and having a baseline Hamilton Rating Scale for Depression (HAM-D) score of at least 20. Participants were randomly assigned to receive either St. John's wort extract, 900 *mg* per day (*mg/d*) for a weeks, increased to 1200 *mg/d* in the absence of an adequate response thereafter, or a placebo for 8 weeks. The response variable was the change on the HAM-D over the treatment period. After analysis of the data, it was concluded that St. John's wort was not effective for treatment of major depression.

*a)* What type of experimental design is this?
*b)* What is the population that is being studied?
*c)* What is the response variable in this study?
*d)* What are the treatments?
*e)* Identify the experimental units.
*f)* What is the control group in this study?

**4.** Researchers wanted to evaluate whether ginkgo, an over-the-counter herb marketed as enhancing memory, improves memory in elderly adults as measured by objective tests. To do this, they recruited 96 men and 132 women older than 60 years and in good health. Participants were randomly assigned to receive ginkgo, 40 *mg* 3 times per day, or a matching placebo. The measure of memory improvement was determined by a standardized test of learning and memory. After 6 weeks of treatment, the data indicated that ginkgo did not increase performance on standard tests of learning, memory, attention, and concentration. These data suggest that, when taken following the manufacturer's instructions, ginkgo provides no measurable increase in memory or related cognitive function to adults with healthy cognitive function.

***a)*** What type of experimental design is this?

***b)*** What is the population being studied?

***c)*** What is the response variable in this study?

***d)*** What is the factor that is set to predetermined levels? What are the treatments?

***e)*** Identify the experimental units.

***f)*** What is the control group in this study?