Lean Six Sigma Green Belt Certification Course

simplilearn

Design of Experiments

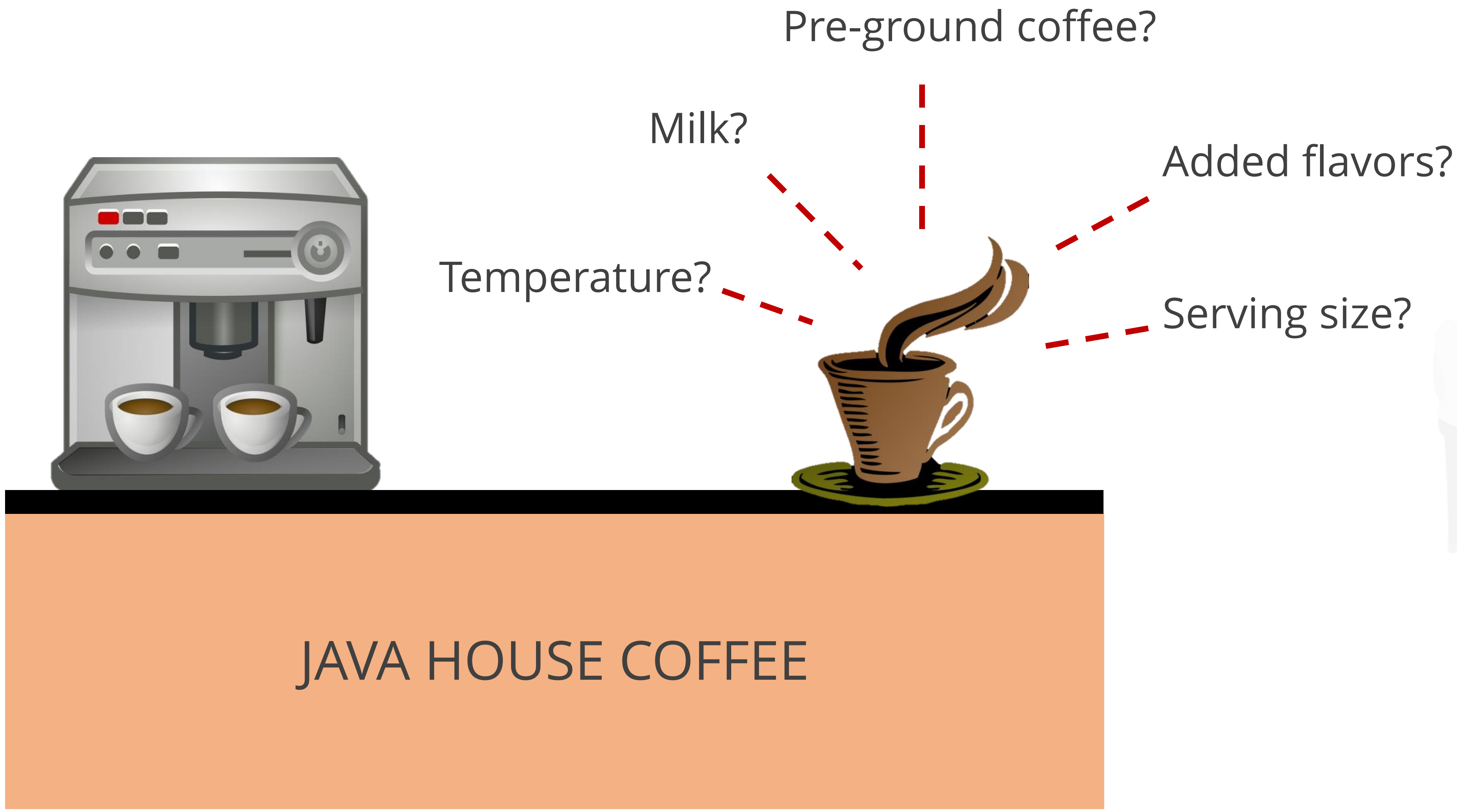
Learning Objectives

By the end of this lesson, you will be able to:

- Explain the concept of Design of Experiments (DOE)
- Compare DOE with regression analysis
- Identify the meaning of the basic terms used when conducting experiments
- Explain the effects of DOE error on repetition, replication, randomization, and blocking

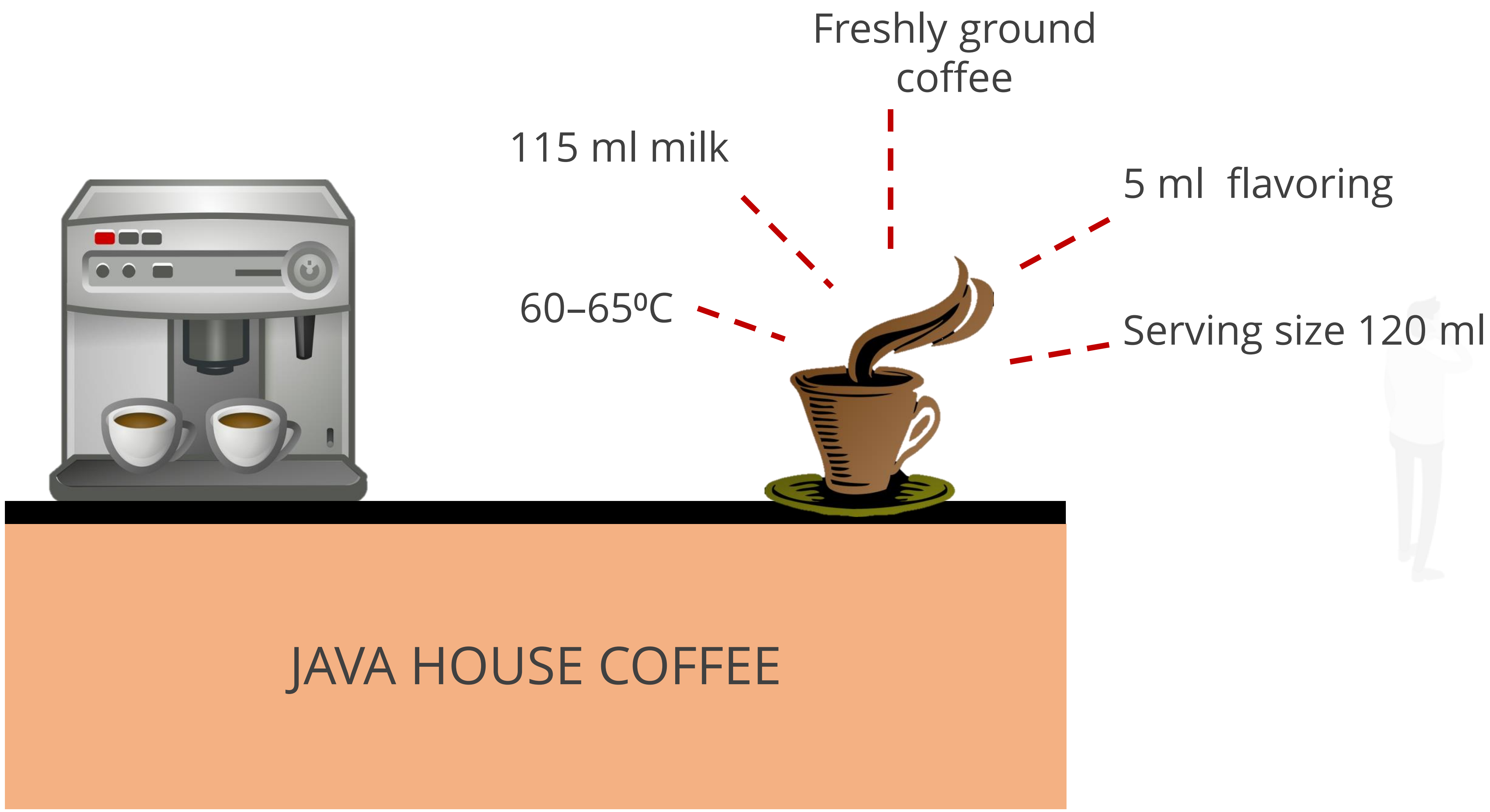
Introduction

The problem



Introduction

The solution



Design of Experiments (DOE)

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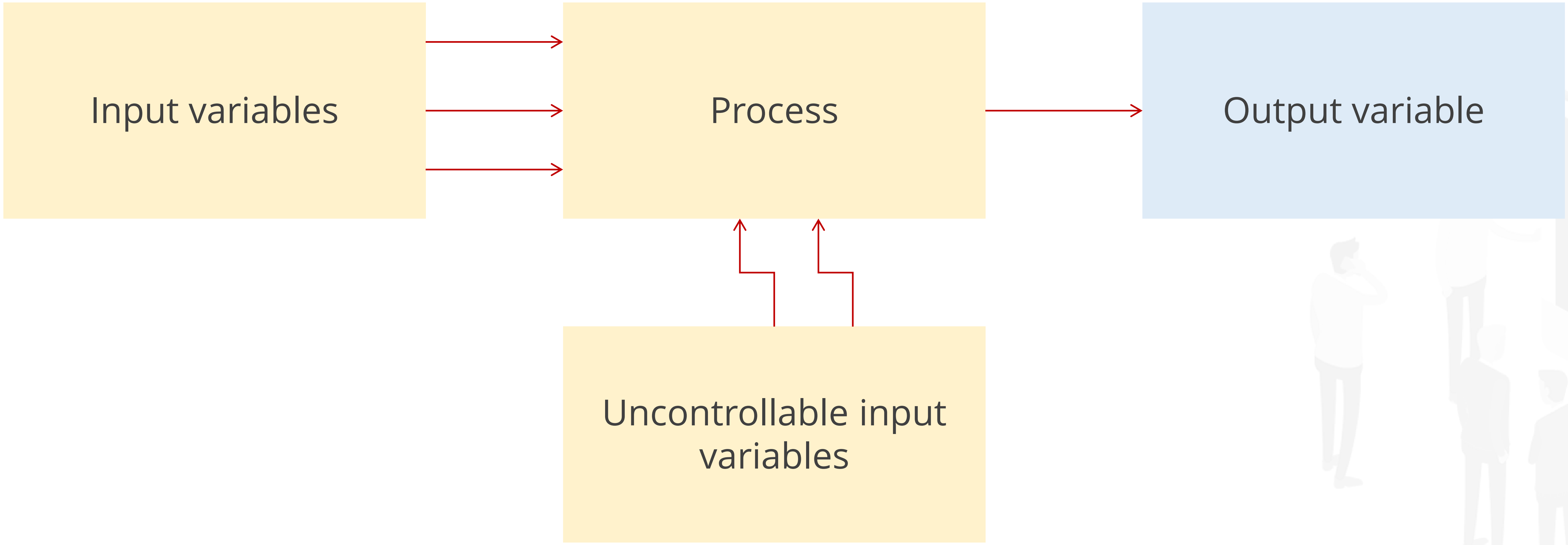

Design of Experiments (DOE)

DOE

- Is a one-stop method for analyzing all influencing factors simultaneously
- Used when known sources of variation have been eliminated but process is still not capable; if process is capable then DOE may not be required
- Identifies which variables individually affect key measures
- Determines variable combinations or interactions that impact capability
- Provides mathematical model to predict and optimize the response or process output under recommended settings
- Is preferred over One Factor at a Time (OFAT) experiments because it allows for accelerated learning and is less time-consuming

Regression Analysis

Regression analysis generates a line on a scatter plot that quantifies the relationship between X and Y to understand variation impact.

High percentage of variability in Y (R^2> 70%)

Changes in X

- Predict future values of Y given X and X given Y
- Regress Y on one or more Xs simultaneously

DOE vs. Regression Analysis

DOE	Regression
• Determines cause and effect	• Uncovers relationships
• Tries bold or creative solutions	• Uses existing data
• Clears results on the impact variable	• Results left open to interpretation
• Measures impact on variability	• Cannot measure variability impact
• Provides reliable information on interactions	• Provides risky information on interactions
• Requires leadership support and investment	• Does not require leadership support

Basic Terms

Response
Factors
Levels
Interactions
Treatment
Trial
Experimental unit

Basic Terms

Terms	Description
Response	• Dependent variables or outcomes of an experimental treatment that varies as changes are made to factors **Examples**: Product strength, average hold time, sales, response time
Factors	
Levels	
Interactions	
Treatment	
Trial	
Experimental unit	

Basic Terms

Response
Factors
Levels
Interactions
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Experimental unit

- Independent or input variables that are changed during an experiment to validate their impact on the output
- Can be qualitative and/or quantitative

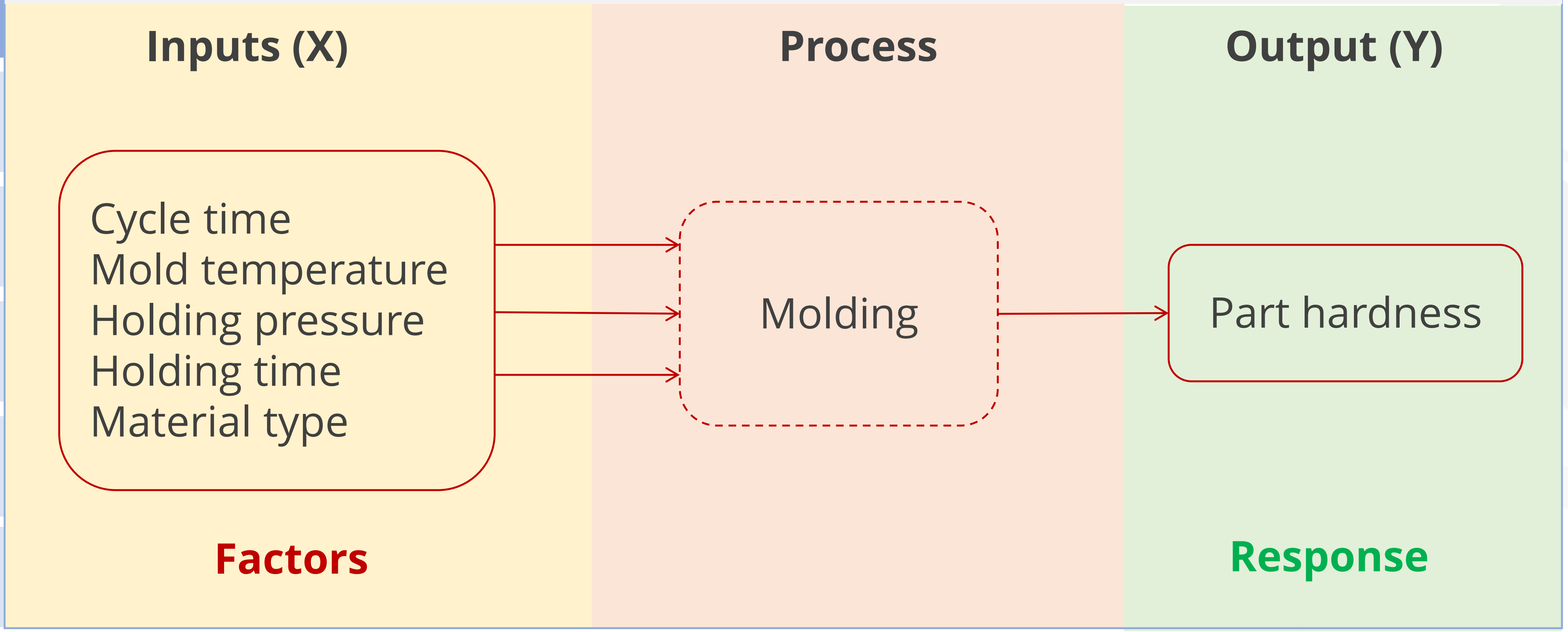
Examples:

Machine, temperature, procedural change, price

Basic Terms

- Response
- **Factors**
- Levels
- Interactions
- Treatment
- Trial
- Experimental unit

Objective: To achieve uniform dimensions for a part at a particular target value



Basic Terms

Response
Factors
Levels
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Experimental unit

- Settings or conditions of the factors that are tested during the experiment
- Two levels recommended per factor
    - Level 1 is normally coded as “-” and could represent status quo
    - Level 2 is normally coded as “+” and could represent the change tested

Note: The difference between level 1 and level 2 settings should be significant to detect impact.

Basic Terms

- Response
- Factors
- **Levels**
- Interactions
- Treatment
- Trial
- Experimental unit

DOE conducted on two factors at two levels to determine the impact related to plastic part hardness

Quantitative factor

Qualitative factor

Factors	Level -	Level +
Mold temperature	700°	900°
Plastic type	Filler	No filler

Basic Terms

Response
Factors
Levels
Interactions
Treatment
Trial
Experimental unit

- When the combination of two factors creates a result that is different from the result produced by the individual factors

Examples:
Baking time and temperature

Basic Terms

- Response
- Factors
- Levels
- Interactions
- **Treatment**
- Trial
- Experimental unit

- A unique set of factors at specific levels whose effect on the response variable is of interest

Examples:
Molding temperature at high setting and baking time at low setting

Basic Terms

Response	
Factors	
Levels	
Interactions	• An experimental run for a specific treatment
Treatment	
Trial	
Experimental unit	

Basic Terms

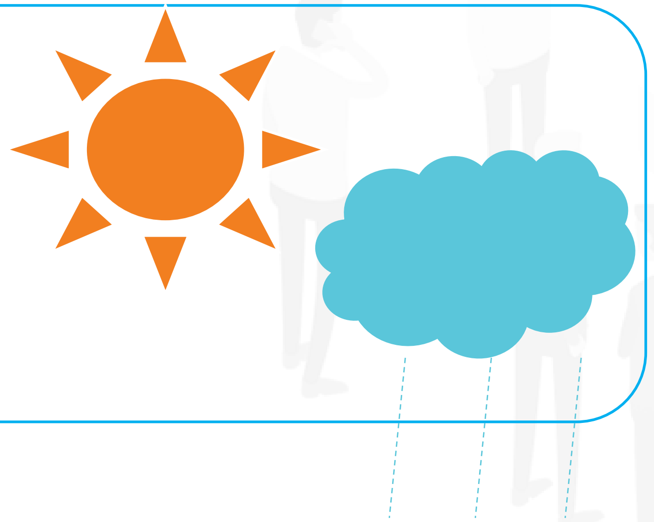
Response
Factors
Levels
Interactions
Treatment
Trial
Experimental unit

- Quantity of material to which one trial of a single treatment is applied to create a response

DOE Error

Error is variation in experimental units that have been exposed to the same treatment.

Examples:
Humidity | Season | Geographic location | Shift



Repetition and Replication

Repetition

During a treatment setup, several samples are run without changing the setting.

This shows short-term variability.

Replication

The entire experiment is repeated with a change in the setting of experimental conditions between trials.

This shows long-term variability.

Repetition and replication provide an estimate of experimental error and help determine the statistical significance of the differences in readings.

Error and Randomization and Blocking

- Running the trial without any order
- The use of randomization helps with:
  - Noise factors that are completely random and uncontrollable
  - Avoiding time-related changes, uncontrollable variables, and tool wear
  - Eliminating bias in expert opinions

Randomization

- Setting the DOE so that controllable noise factors are incorporated into the experiment or held at a constant level throughout

Blocking

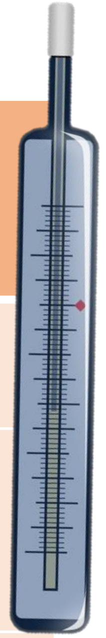
Full Factorial Experiment

Full factorial experimental design

- Contains all combinations of all levels of all factors
- Ensures no possible treatment combinations get omitted
- Is preferred over other designs

Full Factorial Experiment

Factor B: Oven Time (X_2)	Factor A: Draw Temperature (X_1)	
	700 °F	**900 °F**
30 minutes	Y_1 Y_2	Y_5 Y_6
60 minutes	Y_3 Y_4	Y_7 Y_8



Factor A = Temp: Low (-) 700 ºF; High (+) 900 ºF **Factor B** = Time: Low (-) 30 minutes; High (+) 60 minutes					**Responses**	
Trial	**DOE Order**	**A**	**B**	**AB**	**1**	**2**
1	3	-	-	+	Y1	Y2
2	1	+	-	-	Y3	Y4
3	4	-	+	-	Y5	Y6
4	2	+	+	+	Y7	Y8

The tables depict a two-way heat treatment experiment, where Y is the Part hardness.

Full Factorial Experiment

Main Effect is the average response change going from one setting to the other.

Factor B: Oven Time (X_2)	Factor A: Draw Temperature (X_1)	
	700°	**900°**
30 minutes	Y_1 Y_2	Y_5 Y_6
60 minutes	Y_3 Y_4	Y_7 Y_8

An analysis of the response helps in understanding how:		
A **change in temperature** at which the material is drawn creates a difference in the average part hardness	A **change in oven time** creates a difference in the average part hardness	Interaction between temperature and time affects the average part hardness

Full Factorial Experiment

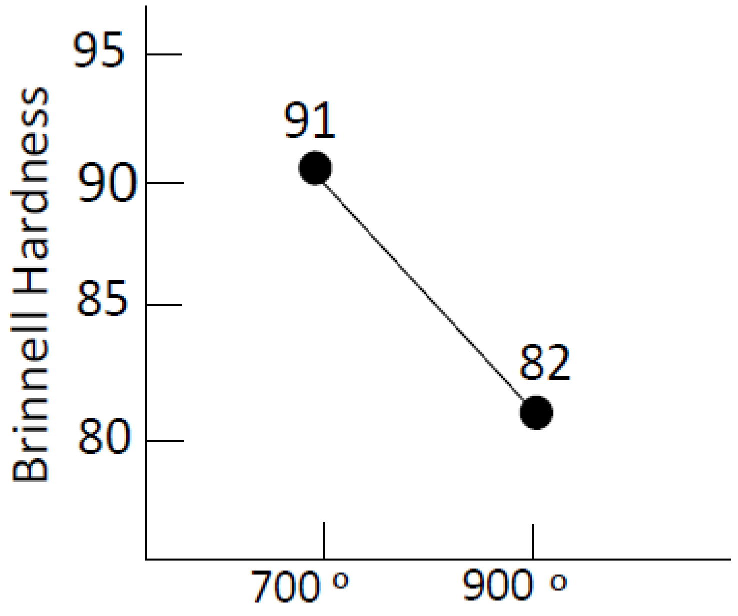
Factor B: Oven Time	Factor A: Draw Temperature	
	$A_1 = 700°$	$A_2 = 900°$
$B_1 = 30$ minutes	90 87	84 87
$B_2 = 60$ minutes	95 92	79 78

The table depicts a two-way heat treatment experiment.

Main Effect Plot (Draw Temp.)

$$\bar{A}_1 = \frac{90 + 87 + 95 + 92}{4} = 91$$

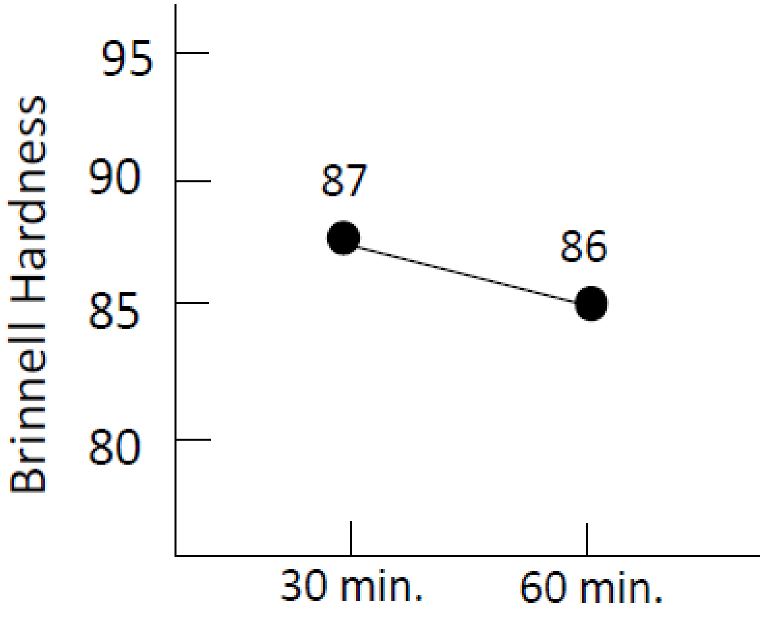
$$\bar{A}_2 = \frac{84 + 87 + 79 + 78}{4} = 82$$



Main Effect Plot (Oven Time)

$$\bar{B}_1 = \frac{90 + 87 + 84 + 87}{4} = 87$$

$$\bar{B}_2 = \frac{95 + 92 + 79 + 78}{4} = 86$$



Results:
Changing the draw temperature seems to change the average hardness

Results:
Changing the oven time seems to have no major change in the average hardness

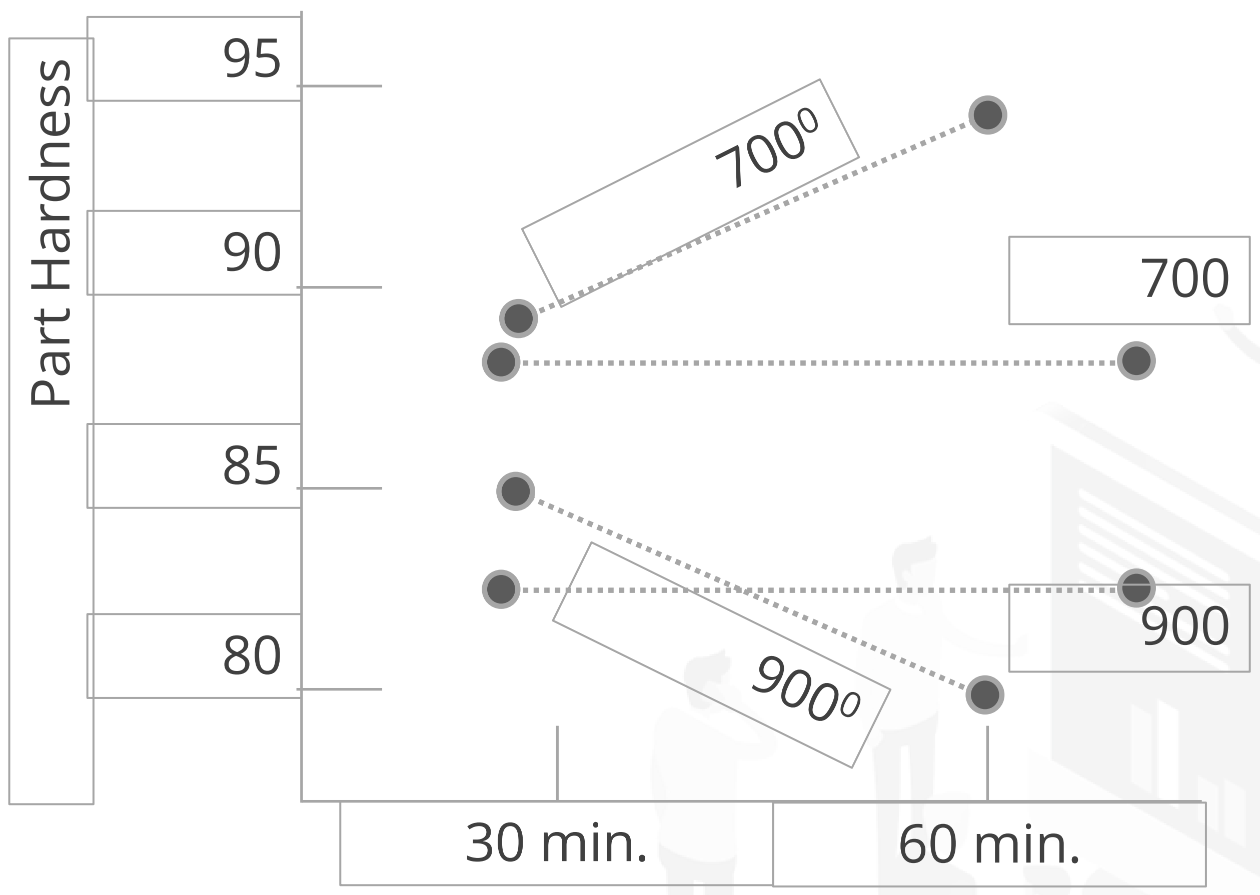
Full Factorial Experiment

Factor B: Oven Time	Factor A: Draw Temperature	
	A_1 = 700°	A_2 = 900°
B_1 = 30 minutes	90 87	84 87
B_2 = 60 minutes	95 92	79 78

	A_1	A_2
B_1	88.5	85.5
B_2	93.5	78.5

The mean of the factors

$$\overline{A_1B_1} = \frac{90+87}{2} = 88.5$$



Results: The interaction plot shows that low temperature and high oven time should be selected to achieve the highest desired output of hardness. The parallel lines indicate the output if no interactions occur between the main effects.

Runs

The number of experiments in a DOE setting is known as Runs.

The number of runs in a:

- Full Factorial Runs = Levels^factors
- Half Fractional Factorial Runs = Levels^(factors-1)

Runs

For Half Fractional factorial experiments, the number of runs is levels to the power of factors minus 1.

Full factorial experiment without replication on 5 factors and 2 levels:	$2^5 = 32$
Full factorial experiment with 1 replication on 5 factors and 2 levels:	32 + 32 = 64
Half fractional factorial experiment without replication on 5 factors and 2 levels:	$2^{5-1} = 16$
Half fractional factorial experiment with 1 replication on 5 factors and 2 levels:	16 + 16 = 32

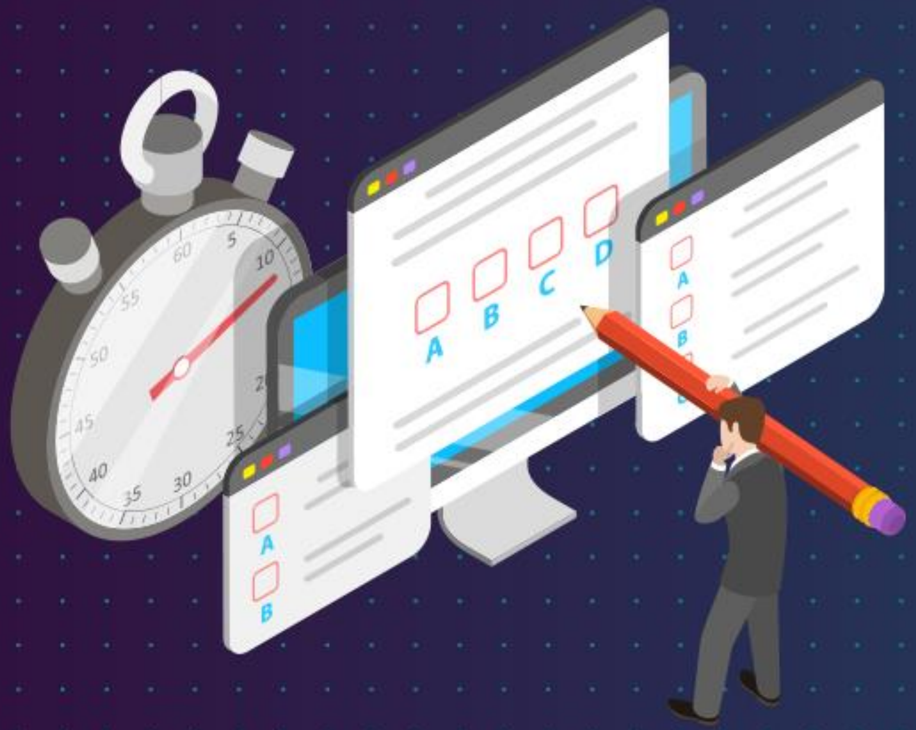
Fractional factorial experiments lose complete information on interactions.

Fun Facts

The use of DOE is growing in the service sector.

Key Takeaways

- DOE is a structured method that tests input variables and their impact on the output variable.
- Error is variation in experimental units that have been exposed to the same treatment.
- Repetition and replication provide an estimate of experimental error and help determine the statistical significance of the differences in readings
- Randomization and Blocking can impact the effects of error.
- Full factorial experimental design contains all combinations of all levels of all factors.
- The number of experiments in a DOE setting is known as Runs.



Knowledge Check

Knowledge Check

1

A chef wants to change the recipe for a fondue to improve its taste. He is considering different cheeses and will run 8 experiments. In this scenario, what is the factor?

A. Experiments

B. Fondue

C. Different cheeses

D. Taste

Knowledge Check

1

A chef wants to change the recipe for a fondue to improve its taste. He is considering different cheeses and will run 8 experiments. In this scenario, what is the factor?

A. Experiments

B. Fondue

C. Different cheeses

D. Taste

The correct answer is **C**

The factor is the independent variable that is changed and in this case it will be the different cheeses.

Knowledge Check

2

A chef wants to change the recipe for a fondue to improve its taste. He is considering different cheeses and will run 8 experiments. In this scenario, what is the response?

A. Experiments

B. Fondue

C. Different cheeses

D. Taste

Knowledge Check

2

A chef wants to change the recipe for a fondue to improve its taste. He is considering different cheeses and will run 8 experiments. In this scenario, what is the response?

A. Experiments

B. Fondue

C. Different cheeses

D. Taste

The correct answer is **D**

The response is the dependent variable that is impacted by changing factors and in this case it will be the taste.

Knowledge Check

3

For a full factorial experiment with 3 factors at two levels that are replicated twice, how are trials expected?

A. 24

B. 8

C. 16

D. 9

Knowledge Check

3

For a full factorial experiment with 3 factors at two levels that are replicated twice, how are trials expected?

A. 24

B. 8

C. 16

D. 9

The correct answer is **A**

The equation is levels to the power of factors. 2 to the power of 3 is 8 and with two replications would be 8 + 8 + 8 = 24.