Design of Experiments Essentials (DOE^2)

Bass Masri, JMP® Asia Pacific

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Bass Masri

Don’t count the days. Make the days count!

- A passion for analytics and statistics with more than 20 years of work experience in engineering, science and process improvement.
- Tertiary education includes a Bachelor Degree in Science and Masters in Applied Statistics from Macquarie University, Sydney Australia.

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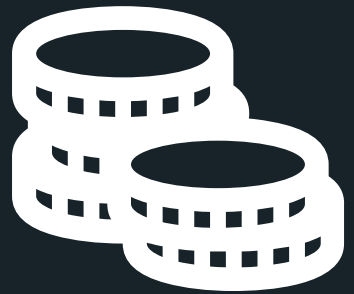
Agenda

Design of Experiments Essentials (DOE^2)

- Design of experiments is a structured approach for collecting data and making important discoveries.
- In this reactor case study, we demonstrate how a response can be efficiently optimized for five factors using a design of experiment.
- Today, we focus on why we use DoE, the process workflow, experimental designs and design diagnostics ...



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Why use design of experiments?

Quality, Delivery, Cost. In that order!

- Design of experiments can be used to improve products and processes by identifying the factors that are important.
- Unlike studying one factor at a time, with a limited number of trials, you can learn a lot about a process.
- Ultimately you improve process performance through better decisions around: Quality, Delivery, Cost.

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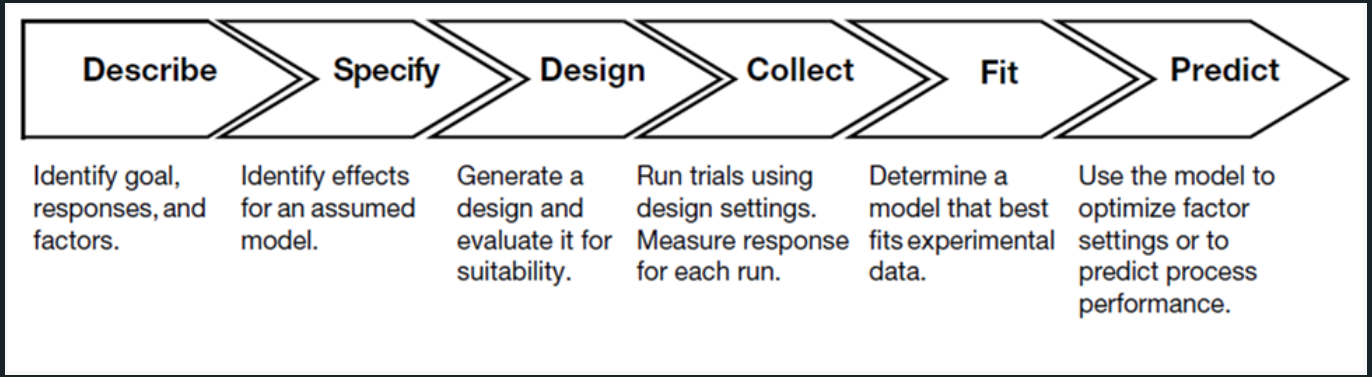
Process Workflow

Everything is a process!

- This six-step framework provides the structure for designing an experiment, running the experimental trials and analyzing results.



- Source: JMP® Help > Design of Experiments Guide

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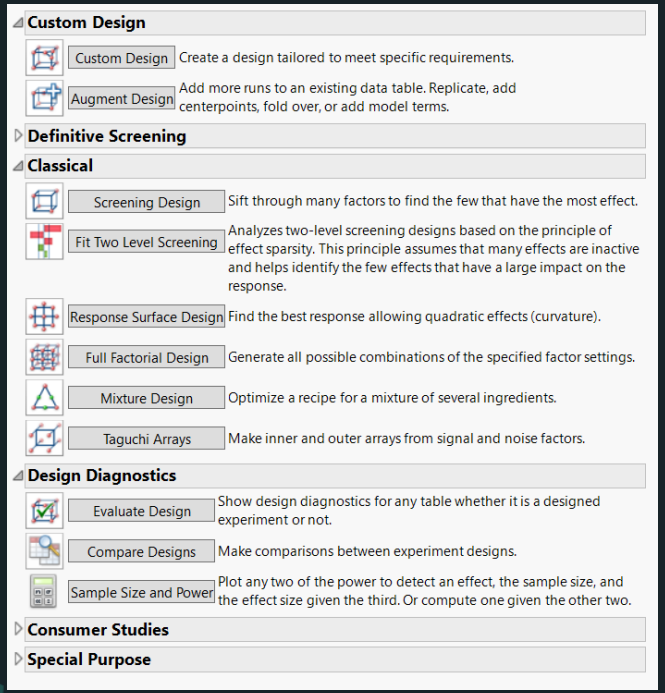
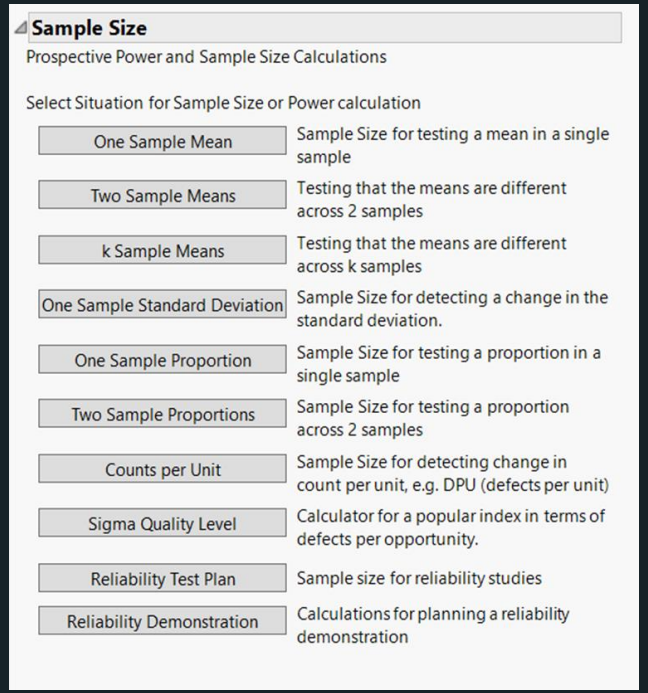
Design Diagnostics

Power and Sample Size …





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Design of Experiments

Learning Outcomes and Essential Terms

- Outcome: Design a controlled set of tests to model and explore the relationship between the process inputs and outputs.

- Terminology we will cover
  - factors
  - responses
  - treatments
  - runs
  - effects
  - interactions

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Action Plan

Reactor Case Study

- Situation: You want to study the effects of five two-level factors: Feed Rate, Catalyst, Stir Rate, Temperature and Concentration on the response: Percent Reacted.
- Problem: A higher Percent Reacted ensures higher quality products. In a full factorial design, you perform an experimental run at every combination of the factor levels.
- Impact: The sample size for a full factorial study is $2^{K \text{ factors}}$, that is 2^5 factorial = 2x2x2x2x2 = 32 runs. Budget for the design has been allocated and approved.
- Need: You need to determine what factors and 2-way interactions are significant and identify what are the optimal settings to maximize Percent Reacted.

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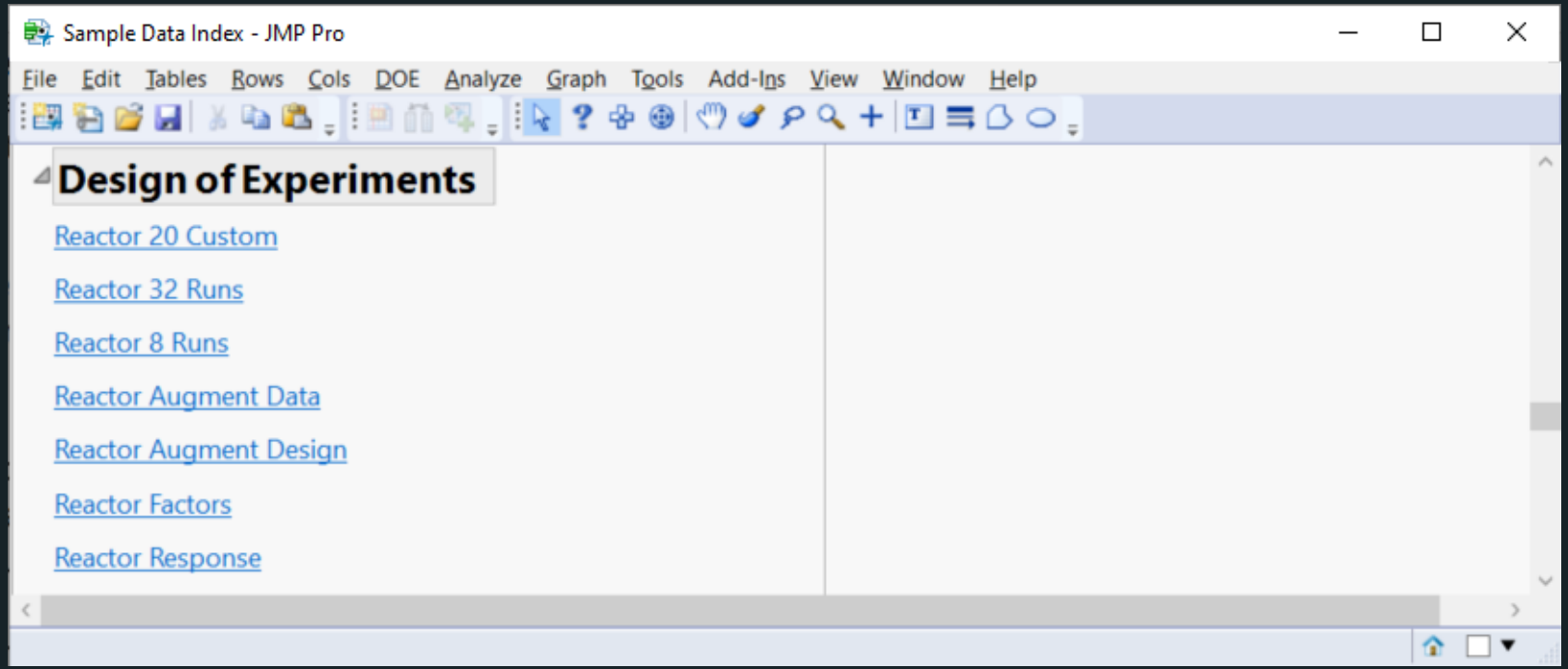
Data Tables

Help > Sample Data > Design of Experiments / Reactor …



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Describe

Identify goal, response and factors

Full Factorial Design

Responses

Response Name	Goal	Lower Limit	Upper Limit	Importance
Percent Reacted	Maximize	90	100	1

Factors

Add N Factors 1

Name	Role	Values
Feed Rate	Continuous	10 15
Catalyst	Continuous	1 2
Stir Rate	Continuous	100 120
Temperature	Continuous	140 180
Concentration	Continuous	3 6

2x2x2x2x2 Factorial

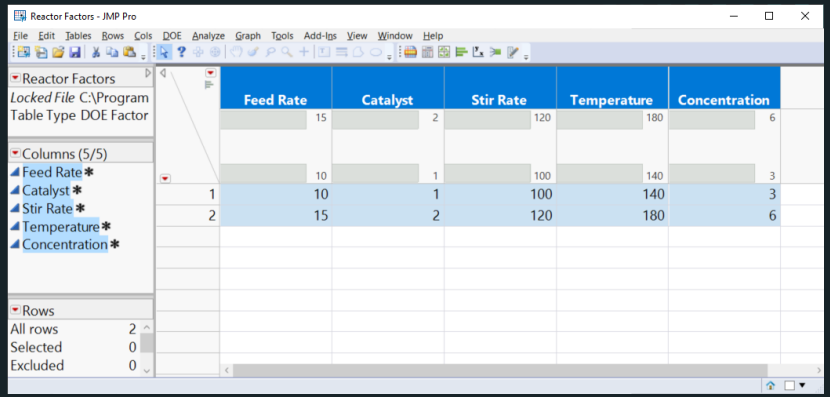
Output Options

Run Order: Randomize

Number of Runs: 32

Number of Center Points: 0

Number of Replicates: 0



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Specify

Identify main and interaction effects for the model

Factors

Name	Role	Values
Feed Rate	Continuous	10 15
Catalyst	Continuous	1 2
Stir Rate	Continuous	100 120
Temperature	Continuous	140 180
Concentration	Continuous	3 6

Model

Intercept
Feed Rate
Catalyst
Stir Rate
Temperature
Concentration
Feed Rate*Catalyst
Feed Rate*Stir Rate
Catalyst*Stir Rate
Feed Rate*Temperature
Catalyst*Temperature
Stir Rate*Temperature
Feed Rate*Concentration
Catalyst*Concentration
Stir Rate*Concentration
Temperature*Concentration

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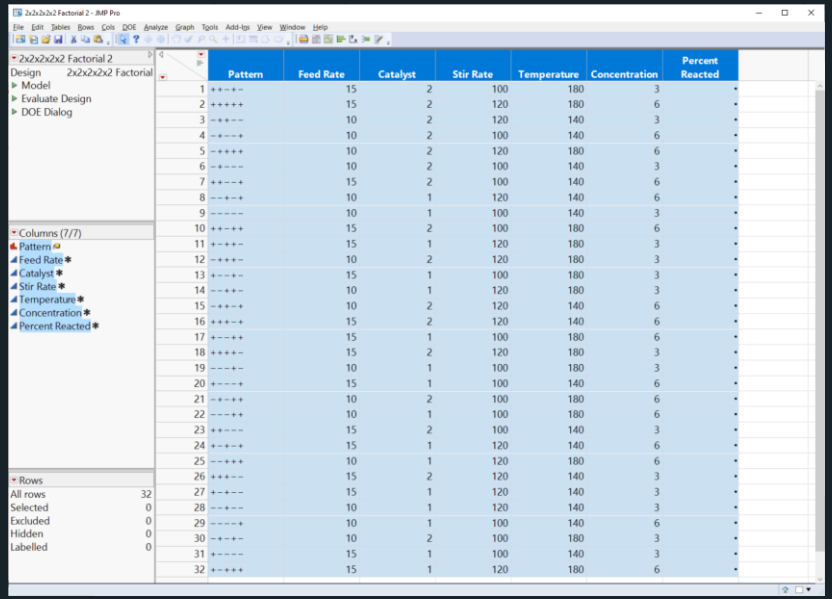
Design

Generate a design and evaluate



Pattern	Feed Rate	Catalyst	Stir Rate	Temperature	Concentration	Percent Reacted
1 ++-+-	15	2	100	180	3	.
2 +++++	15	2	120	180	6	.
3 -++--	10	2	120	140	3	.
4 -++-+	10	2	100	140	6	.
5 -++++	10	2	120	180	6	.
6 -+---	10	2	100	140	3	.
7 ++--+	15	2	100	140	6	.
8 ---+-	10	1	120	140	6	.
9 -----	10	1	100	140	3	.
10 ++-++	15	2	100	180	6	.
11 +-++-	15	1	120	180	3	.
12 -+++-	10	2	120	180	3	.
13 +--+-	15	1	100	180	3	.
14 --++-	10	1	120	180	3	.
15 -++-+	10	2	120	140	6	.
16 +++-+	15	2	120	140	6	.
17 +--++	15	1	100	180	6	.
18 ++++-	15	2	120	180	3	.
19 ---+-	10	1	100	180	3	.
20 +---+	15	1	100	140	6	.
21 -+-++	10	2	100	180	6	.
22 ---++	10	1	100	180	6	.
23 ++---	15	2	100	140	3	.
24 +-+-+	15	1	120	140	6	.
25 --+++	10	1	120	180	6	.
26 +++--	15	2	120	140	3	.
27 +-+--	15	1	120	140	3	.
28 --+--	10	1	120	140	3	.
29 ----+	10	1	100	140	6	.
30 -+-+-	10	2	100	180	3	.
31 +----	15	1	100	140	3	.
32 +-+++	15	1	120	180	6	.

Design Diagnostics

D Efficiency	100
G Efficiency	100
A Efficiency	100
Average Variance of Prediction	0.118056
Design Creation Time (seconds)	0

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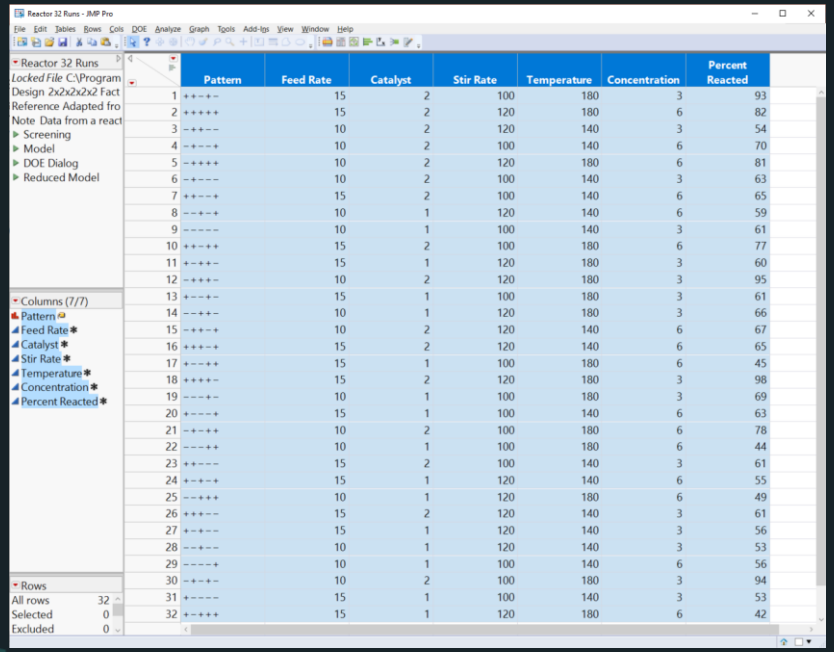
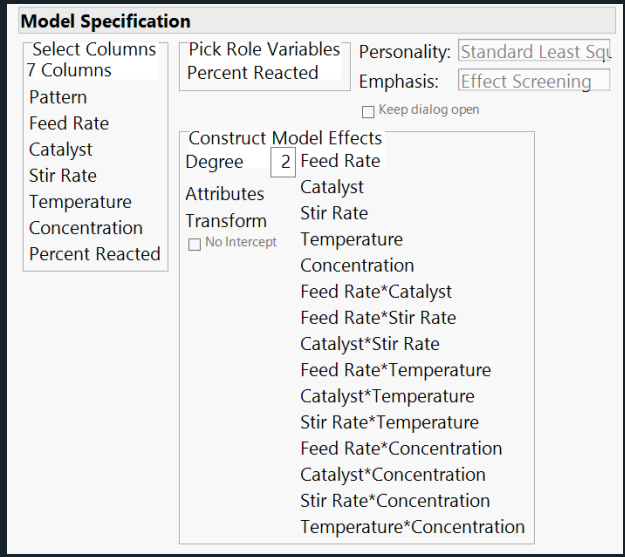
Collect

Run trial using design settings



	Pattern	Feed Rate	Catalyst	Stir Rate	Temperature	Concentration	Percent Reacted
1	++−+−	15	2	100	180	3	93
2	+++++	15	2	120	180	6	82
3	−++−−	10	2	120	140	3	54
4	−+−−+	10	2	100	140	6	70
5	−++++	10	2	120	180	6	81
6	−+−−−	10	2	100	140	3	63
7	++−−+	15	2	100	140	6	65
8	−−+−+	10	1	120	140	6	59
9	−−−−−	10	1	100	140	3	61
10	++−++	15	2	100	180	6	77
11	+−++−	15	1	120	180	3	60
12	−+++−	10	2	120	180	3	95
13	+−−+−	15	1	100	180	3	61
14	−−+−−	10	1	120	180	3	66
15	−++−+	10	2	120	140	6	67
16	+++−+	15	2	120	140	6	65
17	+−−++	15	1	100	180	6	45
18	++++−	15	2	120	180	3	98
19	−−−+−	10	1	100	180	3	69
20	+−−−+	15	1	100	140	6	63
21	−+−++	10	2	100	180	6	78
22	−−−++	10	1	100	180	6	44
23	++−−−	15	2	100	140	3	61
24	+−+−+	15	1	120	140	6	55
25	−−+++	10	1	120	180	6	49
26	+++−−	15	2	120	140	3	61
27	+−+−−	15	1	120	140	3	56
28	−−+−−	10	1	120	140	3	53
29	−−−−+	10	1	100	140	6	56
30	−+−+−	10	2	100	180	3	94
31	+−−−−	15	1	100	140	3	53
32	+−+++	15	1	120	180	6	42



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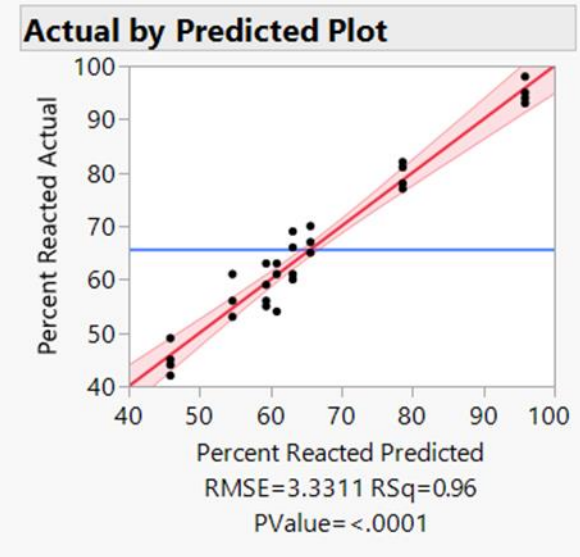
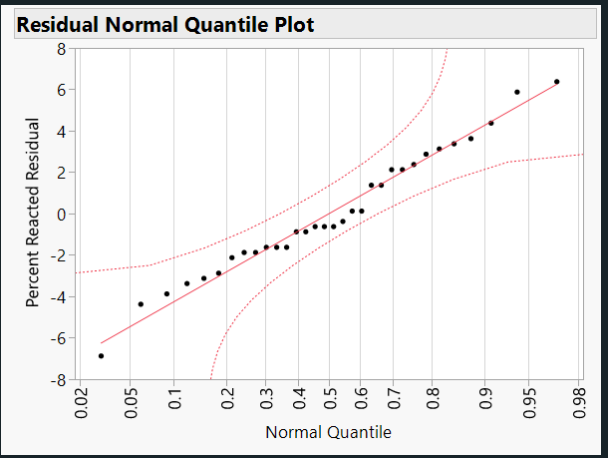
Fit

Determine the model that best fits experimental data



Effect Summary

Source	LogWorth	PValue
Catalyst(1,2)	14.602	0.00000
Catalyst*Temperature	10.763	0.00000
Temperature*Concentration	9.065	0.00000
Temperature(140,180)	8.864	0.00000 ^
Concentration(3,6)	4.825	0.00001 ^



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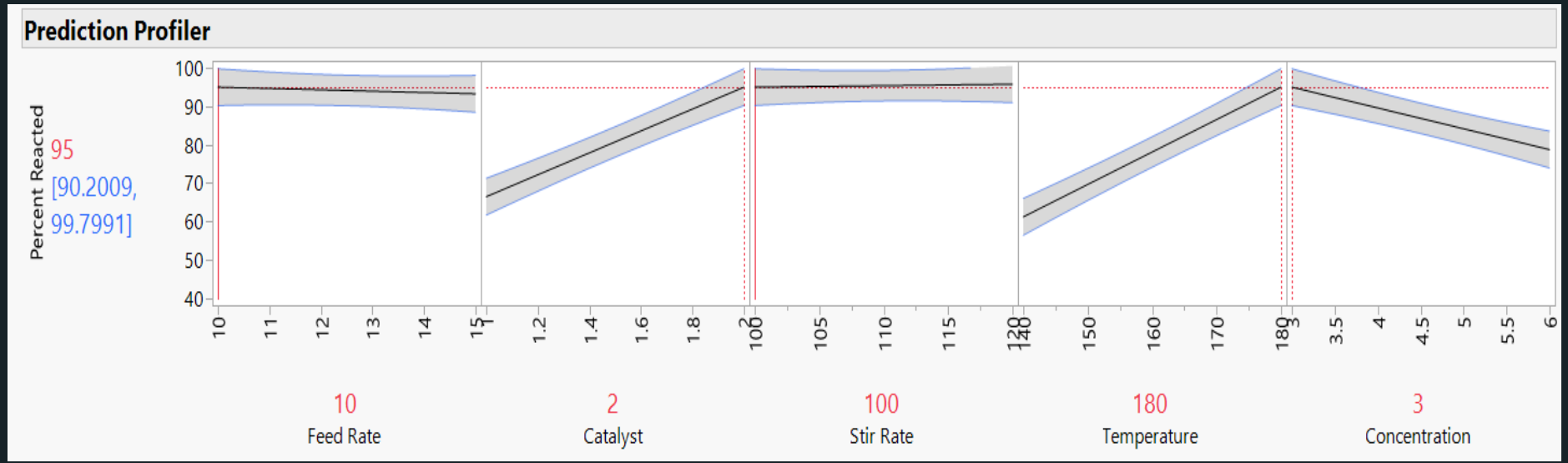
Predict

Use the model to optimize response



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Findings and Summary

Next Steps

- We learnt about experimental designs and the general steps for how to conduct an experiment, including:

1. Describe response and factors.
2. Identify effects and specify model.
3. Generate and evaluate the design.
4. Conduct experiment and measure response.
5. Fit model, identify optimal settings and predict performance.

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Design of Experiments

Design of experiments (DOE) is a rigorous methodology that enables scientists and engineers to study the relationship between multiple input variables, or *factors*, on key output variables, or *responses*.

In this module, you will learn why designed experiments are better than trial and error and one-factor-at-a-time approaches to gain an understanding of cause and effect relationships and interactions between factors. You will be introduced to several types of designs such as factorial, response surface and custom designs. Finally, you will learn some DOE guidelines and best practices which will help you succeed with experimentation.

Design of Experiments Overview (1:01)

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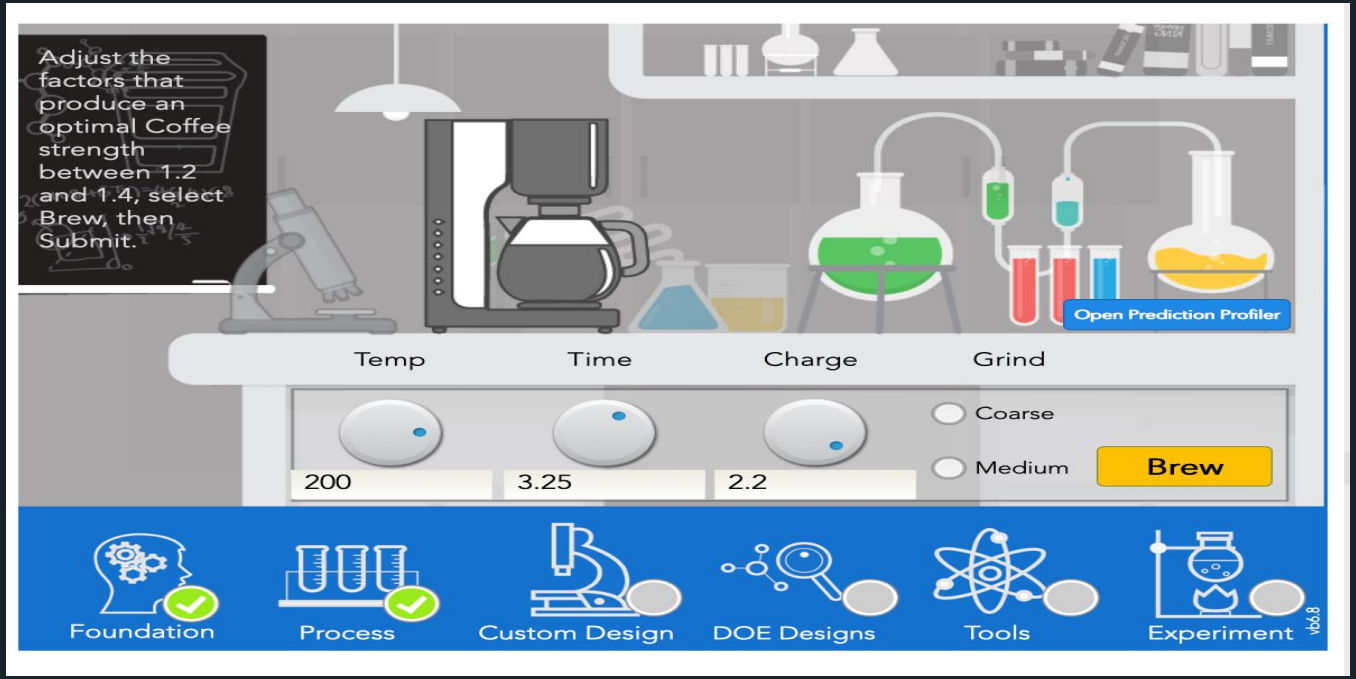

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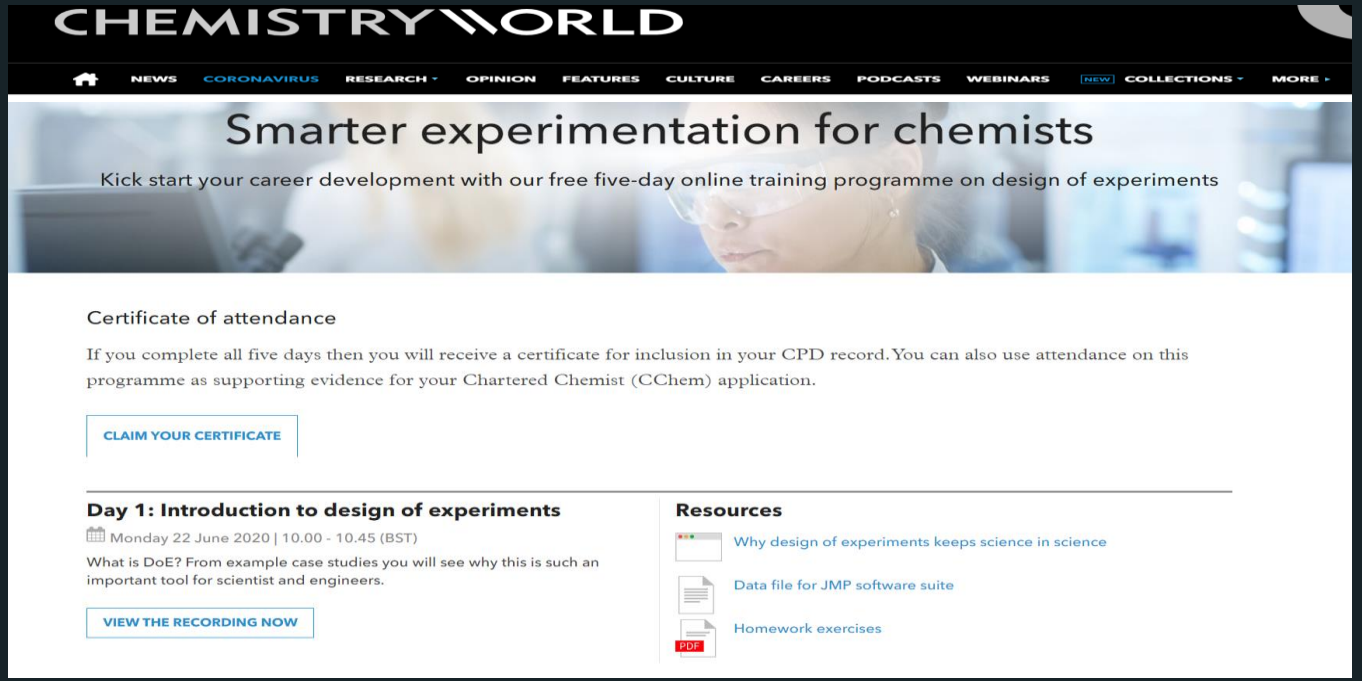
Chemistry World

Royal society of chemistry …



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John Sall

SAS Co-Founder and Executive Vice President John Sall is the creator and chief architect of JMP software.

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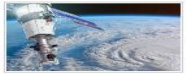

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