

Principles of Engineering Research: concepts, methods and applications

Spring 2026

Instructor: **Dr. Wenwen Xu, Zheng Yang**

Office Hours: Wed. Morning 9:30 AM -12:00 PM

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Course Description

Engineering research turns real-world phenomena into testable questions, models, and validated insights that can be translated into design rules and applications. Using two flagship case studies: chiral seed pod opening and geometrically frustrated rose petals, students learn how to: (i) extract a research problem from observations, (ii) build minimal models (geometry, mechanics, energy), (iii) plan experiments and simulations, (iv) analyze data with scaling and dimensionless groups, and (v) communicate results in professional formats.

Course Objectives

The goal of this course is to cultivate students' ability to think and work like interdisciplinary scientists. Students will understand the full scientific method and how to use it to do real research. They will learn to observe a phenomenon, ask a clear question, state a testable hypothesis, and design a controlled experiment with defined variables and measurements. They will practice collecting data, analyzing results and drawing evidence-based conclusions. Students will also learn to communicate their findings clearly and to iterate—refining questions, methods, and models—while combining ideas from chemistry, physics, and mathematics to solve real-world problems.

Learning Outcomes:

By the end of the semester, students should be able to:

- **Explain fundamental mechanisms** of the coffee-ring effect using concepts from chemistry, physics, and mathematics.
- **Apply the scientific method** to design, conduct, and refine experiments with clear hypotheses, controls, and reproducibility.
- **Analyze and interpret data** using statistical tools, graphical visualization, and computational models.
- **Integrate interdisciplinary perspectives** to connect microscopic mechanisms with macroscopic observations and applications.
- **Communicate scientific findings** clearly and effectively in English, both in writing (reports and papers) and orally (presentations and discussions).

- **Develop problem-solving and critical-thinking skills** that can be transferred to other areas of science and engineering.
- **Collaborate in teams** to plan, execute, and present research projects in a professional manner.

Course Format

- **Lectures and seminars** will introduce core concepts and theories.
- **Hands-on lab sessions** will provide opportunities to apply theoretical knowledge.
- **Discussions and group projects** will facilitate collaboration and critical thinking.

Additional Materials: Laboratory notebook, Python/Matlab (optional)

Assessment & Grading

- Attendance & Participation: 15%
- Homework: 30%
- Project reports: 40%
- Final Presentation & Showcase (Week 16): 15 %

Code of Academic Conduct

Upon accepting admission to SCUPI, you immediately assume to follow the SCUPI academic integrity guidelines. Contact a staff in the administrative office if you are not aware of it. The guidelines should be followed in homework, examinations, and other academic work. Violations of these guidelines may result in zero points for an exam/final paper or failure of the course.

Course Schedule

Week 1-8 topic 1: Seed pod strip

Week 1: Introduction: the inspiration from nature

Week 2: Mathtool toolbox overview behind the model

Week 3: Multivariable calculus basics I (how to describe a curves/surfaces for modeling)

Week 4: Multivariable calculus basics II (how to quantify curvature from data) (HW 1)

Week 5: Linear algebra I (how to use tensors to describe the surface)

Week 6: Linear algebra II (reference tensors a, b and energy landscape) (HW 2)

Week 7: Build the analog and reproduce helixes I

Week 8: Build the analog and reproduce helixes II (Analysis and Report preparation)

Week 9-16 topic 2: Rose petal

Week 9: Introduction: Geometrically frustrated rose petals (compatibility)
Week 10: Rose petal metrology lab I
Week 11: Rose petal metrology lab II
Week 12: Simplified math model to describe rose petal I (without curvature)
Week 13: CAD design and FDM 3D printing
Week 14: Class discussion and recap
Week 15: Presentation I
Week 16: Presentation II

*** This schedule may be adjusted depending on class progress and performance.