Complex Engineering Problem

Why are we interested in Complex Engineering Problem (CEP) ?

- There are certain characteristics that we/PEC desire in our engineers to be → Programme Learning Outcomes (PLOs)
- ALL PLOs are with respect to Complex Engineering Problems/Activities

FES PLOs

- **PLO 1: Engineering Knowledge** → Ability to apply knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of **complex engineering problems**.
- **PLO 2: Problem Analysis** → Ability to identify, formulate, research literature, and analyze **complex engineering problems** reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.
- **PLO 3: Design/Development of Solutions** → Ability to design solutions for **complex engineering problems** and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.
- **PLO 4: Investigation** → Ability to investigate **complex engineering problems** in a methodical way including literature survey, design and conduct of experiments, analysis and interpretation of experimental data, and synthesis of information to derive valid conclusions.
- **PLO 5: Modern Tool Usage** → Ability to create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to **complex engineering activities**, with an understanding of the limitations.
- **PLO 6: The Engineer and Society** → Ability to apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solution to **complex engineering problems.**
- **PLO 7: Environment and Sustainability PLO 8: Ethics**
- **PLO 9: Individual and Team Work**
- **PLO 10: Communication**
- Ability to communicate effectively, orally as well as in writing, on **complex engineering activities** with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
- **PLO 11: Project Management**
- **PLO 12: Lifelong Learning**

So what exactly is a Complex Engineering Problem/Activity?

- Basically, it comes from the tasks which the engineers are required to tackle once they work in a professional environment
  - Those tasks are
    - 1) **Engineering Problems** → Require Expertise of an Engineering discipline, and
    - 2) **Complex Problems** → Complexity is a very broad term, and can have one or more of attributes, such as
      - Required in-depth knowledge of **more than one disciplines/knowledge areas**
      - Has **no ready-made/obvious solution** and hence requires in-depth investigation of the 'context' e.g. making a local dam, bridge, military equipment etc.
      - Not Precisely Specified/Vague → Have a **number of unknowns**
      - A **large number of parameters to optimize**
      - **Multiple technological constraints**
      - Has associated **Financial, Social, Environmental, Time, Resources Constraints**
      - In short they are **complex!**

Complex problems

- *Involve **wide-ranging or conflicting technical, engineering and other issues***
- ***Have no obvious solution** and require abstract thinking, originality in analysis to formulate suitable models*
- ***Requires research-based knowledge** much of which is at, or informed by, the forefront of the professional discipline and which allows **a fundamentals-based, first principles analytical approach***
- *Involve **infrequently encountered issues***
- *Are **outside problems encompassed by standards and codes of practice** for professional engineering*
- ***Involve diverse groups of stakeholders** with widely varying needs*
- *Have significant consequences in a range of contexts*
- *Are high level problems including **many component parts or sub-problems***

Characteristics

Technical Problems

- **Isolatable boundable problem**
- **Universally similar type**
- **Stable and/or predictable problem parameters**
- Multiple low-risk experiments are possible
- **Limited set of alternative solutions**
- Involve few or homogeneous stakeholders
- **Single optimal and testable solutions**
- Single optimal solution can be clearly recognized

Complex Problems

- **No definitive problem boundary**
- **Relatively unique or unprecedented**
- **Unstable and/or unpredictable problem parameters**
- Multiple experiments are not possible
- **No bounded set of alternative solutions**
- Multiple stakeholders with different views or interest
- **No single optimal and/or objectively testable solution**
- No clear stopping point

Table 2: Range of Complex Problem Solving

	Attribute	Complex Problems
1	Preamble	Engineering problems which cannot be resolved without in-depth engineering knowledge, and have some or all of the characteristics listed below:
2	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.
3	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.
4	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.
5	Familiarity of issues	Involve infrequently encountered issues
6	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.
7	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.
8	Consequences	Have significant consequences in a range of contexts.
9	Interdependence	Are high level problems including many component parts or sub-problems.

Fill this form to map your chosen Complex Engineering Problems in the respective courses to fit the standard as laid out by the PEC.

Course Code						Course Title	

Problem Statement	

Complex Engineering Problems			
Engineering problems which cannot be resolved without in-depth engineering knowledge, and have some or all of the characteristics listed below:	**Mapped**		**Please write your comments against each attribute in the space below. Attach more sheets if necessary. (Optional)**
	Yes	**No**	
Involve wide-ranging or conflicting technical, engineering and other issues.	☐	☐	
Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models	☐	☐	
Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	☐	☐	
Involve infrequently encountered issues	☐	☐	
Are outside problems encompassed by standards and codes of practice for professional engineering.	☐	☐	
Involve diverse groups of stakeholders with widely varying needs	☐	☐	
Have significant consequences in a range of contexts	☐	☐	
Are high level problems including many component parts or sub-problems.	☐	☐	

Instructor's Name and Signature	

Table 3: Range of Complex Engineering Activities

	Attribute	Complex Activities
1	Preamble	Complex activities means (engineering) activities or projects that have some or all of the following characteristics listed below:
2	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).
3	Level of interaction	Require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, engineering or other issues.
4	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.
5	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.
6	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.

Complexity

COMPLEXITY DEFINITIONS

Type	Problem	Activity
PROFESSIONAL ENGINEER	**COMPLEX ENGINEERING PROBLEMS** have some or all of the following characteristics: a) Involve wide-ranging or conflicting technical, engineering, and other issues b) Have no obvious solution and require originality in analysis c) Involve infrequently encountered issues d) Are outside problems encompassed by standards and codes of practice for professional engineering e) Involve diverse groups of stakeholders with widely varying needs f) Have significant consequences in a range of contexts g) g) Cannot be resolved without in-depth engineering knowledge.	**COMPLEX ENGINEERING ACTIVITIES** means engineering activities or projects that have some or all of the following characteristics: a) Involve the use of diverse resources (and, for this purpose, resources includes people, money, equipment, materials and technologies) b) Require resolution of critical problems arising from interactions between wide ranging technical, engineering and other issues c) Have significant consequences in a range of contexts d) Involve the use of new materials, techniques, or processes or the use of existing materials, techniques, or processes in innovative ways.

CEP Examples and Implementation

Example

Problem: Fig. 1 shows a block diagram of a control system where the plant is a DC motor given in Fig. 2. The physical parameters / electrical and mechanical constants are provided in Table 1. Design a PID controller in a modern software for this plant to meet the following specifications. Also explain the effect of simple P, I and D on the transient and steady state behavior through simulations. Provide a comparison of transient specifications with some other controller (research papers)

- Settling time less than 2 seconds
- Overshoot less than 5%
- Steady-state error less than 1%

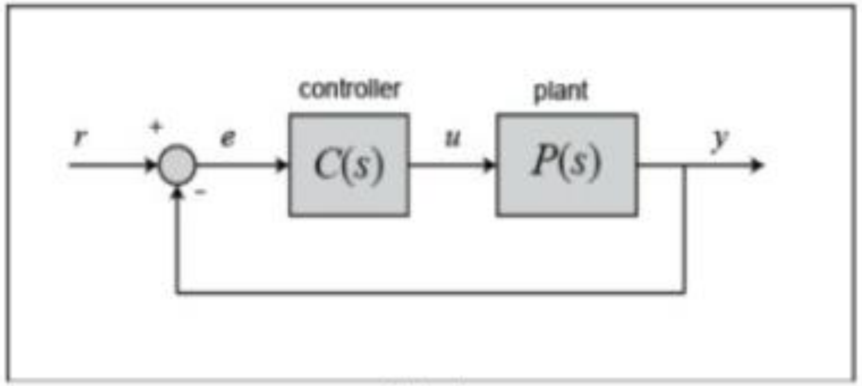

Fig. 1

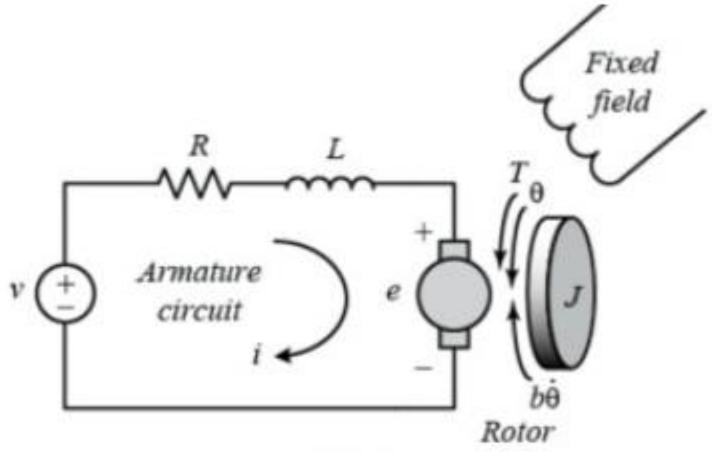

Fig. 2

Table 1

Parameter	Value
Moment of inertia of the rotor (J)	0.01 kg.m^2
Motor viscous friction constant (b)	0.1 N.m.s
Electromotive force constant (Ke)	0.01 V/rad/sec
Motor torque constant (Kt)	0.01 N.m/Amp
Electric resistance (R)	1 Ohm
Electric inductance (L)	0.5 H

A COMPLEX ENGINEERING PROBLEM IS ONE FOR WHICH THERE IS NO OBVIOUS SOLUTION AND TO FIND WHICH YOU MAY HAVE TO GO BEYOND THE SKILLS YOU'VE LEARNED IN THIS COURSE. YOU MAY END UP TAKING DESIGN CHOICES THAT MAKE YOUR SOLUTION FUNDAMENTALLY DIFFERENT FROM THAT OF YOUR CLASSFELLOWS.

Swimming Pool Design

A client wants you to design a swimming pool with a drain with the following requirements.

- *Nature of Design:* The design is to be purely mechanical with minimal (preferably no) human intervention. No electronics should be involved.

- *Pool Capacity:* The pool should be able to hold to of water but the exact individual dimensions are up to you. You can have a pool that is two meters deep or one that is five meters deep so long as the dimensions are not absurd.

- *Drain Lid:* The drain is to be located either at the bottom of one of the side walls of the pool or on the floor of the pool; but the drain should have a lid connected with hinges to stench the flow during the normal course of operation. The shape of the lid (circular, rectangular, elliptical) and the manner in which it is hinged to the drain pipe (central axis or an edge) are up to you. The lid may open inwards or outwards.

- *Drain Pipe:* Determine the size of the drain pipe such that you can empty at least 95% of the swimming pool in 4 to 5 minutes when the drain is open. Do you think this is a reasonable time for a pool this size? Describe the key factors taken into account to decide this. If the time requirement is unreasonable, then redesign the pool and suggest an adequate time limit. Determine the hydrostatic force on the lid that the hinge will have to counter.

You may carry out any further analysis or add any other features you like (but they should be justified through proper analysis). For instance your pool may be able to drain automatically if the water rises above a certain level. If your additions are good enough, you will get extra credit.

Write a three page (maximum) report on your design, clearly showing the assumptions, design decisions, and calculations. You are likely to get more credit if your design is innovative and different from the ones presented by others and does not seem to be lifted directly from the textbook.

It is highly recommended that you carry out your computations systematically in a spreadsheet software (Excel) or some package (MATLAB, Mathematica).

Example

Filtering is one of the most common applications in digital signal processing. Filters attenuate some of the undesired aspects of the signal partially or completely or enhance some of the desired aspect of the signal. In context of speech and audio signal processing, the undesired aspect is generally the noise coupled with the signal due to external and internal noise inducing factors and corrupts the useful information. Therefore, the goal of the filter in this scenario is to remove the frequencies related to noise from audio signal.

CEP Statement:

Design a digital signal processing-based system, which is capable to enhance the speech signal quality by modifying its spectrum.

In the planning stage, select the signal processing blocks to enhance the speech signal quality and justify your selection. In the implementation stage specify the parameters of each block and justify why these parameters are chosen. Also analyze the noisy speech signal and enhanced speech signal after noise removal.

Course Project Problem - *Face the Music*

The purpose this project is to familiarize you with the process of studying and solving real-life engineering problems related to Signals & Systems from real measurements and simulated effects.

1 Preparations

- Carefully read through the entire problem and discuss your strategy with your team-mates.
- Document your solutions, codes, work distribution, and ways-of-working properly, as you will need them for the presentation.

2 Student in a symphony orchestra

2.1 Keynotes and overtones

The sound from most acoustic instruments consist of a fundamental frequency, often termed a keynote, and some overtones. The phases of the overtones typically depend on the instrument and are partly correlated with the swinging of the keynote. This, together with the relation between the power of the overtones, produces the perceived sound of the instrument.

If the keynote has frequency f_0, what are the frequencies of the overtones? This will depend on the type of instrument, but for string instruments, the overtones can be well represented[1] as

$$f_k = kf_0,$$

with $k = 1, 2, \ldots$. Load the files `cello.mat` and `trombone.mat`. These files contain the time-domain signals of a tone played by a cellist and a trombonist at The Academic Orchestra in Sweden. You can listen to the tones by using the command `soundsc(cello.x)`.

[1] It is worth noting that the stiffness of the string will actually produce some frequency offsets such that the overtones will not be exact multiples of the fundamental frequency. A more precise model of the overtones taking the string stiffness into account can be found as

$$f_k = kf_0\sqrt{1 + Bk^2}$$

where B is a positive stiffness parameter.

Import the data (`cello` or `trombone`) into Matlab and estimate the frequency content using some appropriate method (note: the `.dt` parts of the data contain the sampling period T_s

Examine the result using both a linear and logarithmic scale.

1. ***How long are the recorded samples in time (seconds)?***
2. ***What are the frequencies of the cello and trombone keynotes?***
3. ***Do the overtones appear at integer multiples of the keynotes?***
4. ***How many overtones can you see for the cello and the trombone sounds?*** (hint: use the logarithmic scale for magnitude).
5. These sounds were recorded using a really bad tape-recorder, and thus contain a lot of noise.

   Q. Can you see a strong noise peak at a particular frequency? What is the significance of that particular frequency? (Hint: the tape recorder was not battery charged.)
6. Now assume that due to a buggy component in the recording system the cello recording got corrupted in the following way (note that the equation below represents the corrupting system)

$$\text{cello\_corrupted}[n] = n \times \text{cello}[2n+1] + 5$$

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Q. Simulate the corrupted data.

Q. Assuming that you have access only to the corrupted data, do you think it is possible to recover the original data? (justify your answer).

Q. If your answer to the above is Yes, then write a code to recover the original data.

7. Similarly assume that the trombone recording got corrupted in the following way

$$\text{trombone\_corrupted}[n] = \frac{1}{2}\Big(\text{trombone}[n] + \text{trombone}[n-1]\Big)$$

Q. Simulate the corrupted data. What has the buggy component done to the signal?

Q. Assuming that you have access only to the corrupted data, do you think it is possible to recover the original data? (justify your answer).

Q. If your answer to the above is Yes, then write a code to recover the original data.

- Elements to note:

- Comprehensive problem with real-life application (music processing)

- Unfamiliar problem (e.g., question 5)

- Multiple solutions (e.g., in question 6 while theoretically system is non-invertible, in practice one can recover most of the samples)

The project is to develop a PV powered remote water quality monitoring plant for pisciculture. The significances are as follows.

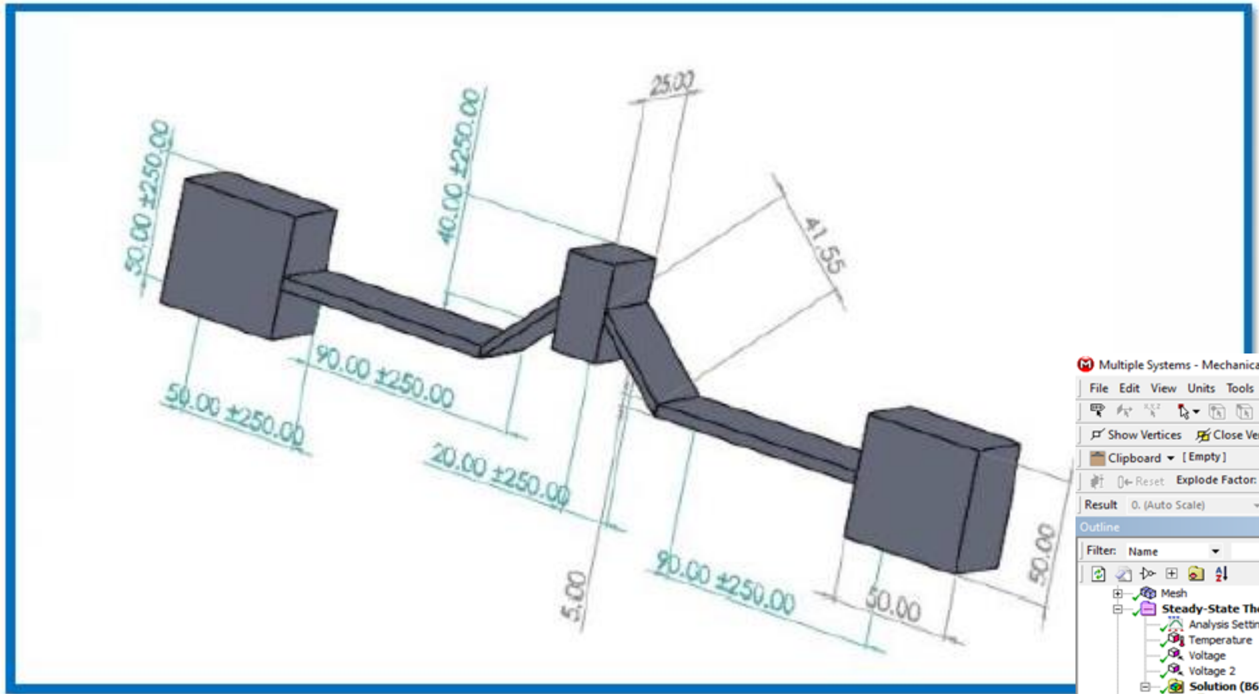
- Pisciculture has become an important part of economy and nutrition in Bangladesh
- Fish production has more than doubled since 2000
- Sweet water fish cultivated in ponds and water bodies contributes a significant fraction to this growth
- Fish yield and quality depends on water quality as determined by the pH level, dissolved oxygen content and other parameters

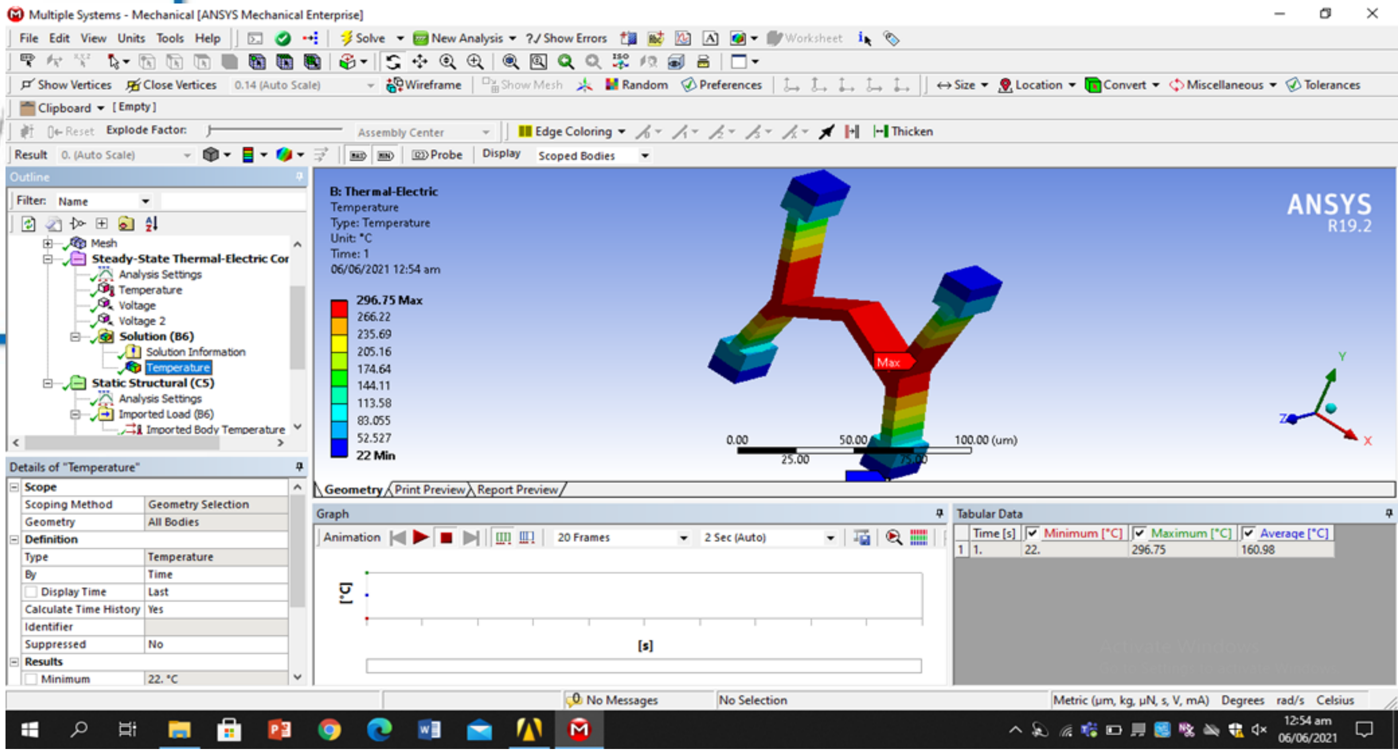
Continual monitoring of water quality and prompt remedial action when needed can increase yield and quality of fish even further.

The water quality monitoring plant, powered by PV panels, will continuously sense and record values of certain water parameters and send the data to a cloud storage in real time. An app will download the data continually to the user's smart phone for viewing and monitoring

- **Project requires knowledge of design of PV systems, embedded system with sensors, wireless communication with cloud data storage, integration of sub-systems and physical implementation**
- **No unique way to design. Depth of analysis needed to select a specific solution from many alternatives**
- **Electrical engineers are not typically exposed to issues related to pisciculture. So, the project involves infrequently encountered issues**
- **Project involves a number of interdependent sub-systems (components), such as, PV system, sensor system, wireless communication system , user app**

Design and FEM analysis of micro electrothermal actuators based on SOIMUMPS fabrication process constraints.





The project report should have

- A brief introduction of SOI MUMPS process.
- Detailed Schematic of your proposed electrothermal actuator.
- A brief justification for your proposed design according to the design rules of SOI MUMPS fabrication process.
- A self-explanatory flow chat of all the below mentioned analysis showing inputs and outputs. (Refer to slides to have an idea of the flow charts)
- Electrothermal Analysis to find the maximum temperature rise on the electrothermal actuator for both vacuum and in air conditions.
    - Try to minimize the maximum temperature on the actuator.
    - Include simulation results and figures where possible.
- Thermo-mechanical analysis to find the displacement and force generated by the electrothermal actuator for both vacuum and in air conditions.
    - Try to maximize the displacement and the force generated by the actuator.
    - Include simulation results and figures where possible.
- Static Structural analysis to find the stiffness of the electrothermal actuator first by using the force and then by using the displacement method.
    - Try to minimize the stiffness in your designed electrothermal actuator.
    - Include simulation results and figures where possible.
- Modal analysis to find the resonance frequencies and mode shapes of the electrothermal actuator.
    - Make table of the first six resonance frequencies.
    - Include the figures where possible.
- Electric Analysis to find the DC resistance and power consumption of the electrothermal actuator.
    - How power consumption in your designed electrothermal actuator can be reduced? Justify your answer with proper reasoning.
- How your proposed design is better from any other electrothermal actuator? Justify your answer with proper reasoning.

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Instructor's Name and Signature	

What is required from us?

- FYPs
  - Make sure FYPs supervised by us have the characteristics of CEP i.e.
    - Require in-depth knowledge/investigation
    - No obvious solution
    - Breadth of scope/features
    - Unknowns
    - Multiple technological constraints
    - Considers Social, Environmental and Ethical aspects as well
- Design Open-Ended Labs which have characteristics of CEP
  - At appropriate level – preferably 3rd and 4th year level
- Design projects/assignments based on CEP in our respective courses, **if possible**
  - At appropriate level – preferably 3rd and 4th year level
  - Design project courses
    - Microprocessor Interfacing
    - Other?