Course Project

# Numerical and Machine Learning Methods for Differential Equations in Biomedical Engineering

Dear students,

- Second-year students (SBE2250) can work on the project in groups of 6-8 students, while first-year students (SBEG108) can work on the project in groups of 10-11 students. Please clearly indicate the contribution of each group member.
- For the course projects, you are required to pick a problem in biomedical engineering, show how it can be modeled by differential equations (partial differential equations for SBE2250 students and ordinary differential equations for SBEG108 students), implement a numerical scheme for solving these equations, and implement an equivalent machine learning (or deep learning) scheme for solving these equations.
- More specifically, you need to do the following:

1) Pick a problem.
   Second-year students (SBE2250) should pick one of the 13 problems in any of the following two books (attached):

   **[Schiesser-PDE-R-2014]** William E. Schiesser, *"Differential Equation Analysis in Biomedical Science and Engineering: Partial Differential Equation Applications with R"*, Wiley 2014

   - *2. Pattern Formation 43*
   - *3. Belousov–Zhabotinskii Reaction System 103*
   - *4. Hodgkin–Huxley and Fitzhugh–Nagumo Models 127*

- *5. Anesthesia Spatiotemporal Distribution 163*
- *6. Influenza with Vaccination and Diffusion 207*
- *7. Drug Release Tracking 243*
- *8. Temperature Distributions in Cryosurgery 287*

**[Schiesser-PDE-MATLAB-2013]** *William E. Schiesser, "Partial Differential Equation Analysis in Biomedical Engineering: Case Studies with MATLAB", Cambridge University Press (2013)*

- *2 Antibody binding kinetics 148*
- *3 Acid-mediated tumor growth 184*
- *4 Retinal O2 transport 221*
- *5 Hemodialyzer dynamics 284*
- *6 Epidermal wound healing 308*
- *7 Drug distribution from a polymer matrix 339*

First-year students (SBEG108) should pick one of the <u>seven problems</u> in the following book (attached):

**[Schiesser-ODE-R-2014]** "Differential Equation Analysis in Biomedical Science and Engineering: Ordinary Differential Equations with R", by William E. Schiesser, Wiley 2014

- 2. Diabetes Glucose Tolerance Test 79
- 3. Apoptosis 145
- 4. Dynamic Neuron Model 191
- 5. Stem Cell Differentiation 217
- 6. Acetylcholine Neurocycle 241
- 7. Tuberculosis with Differential Infectivity 321
- 8. Corneal Curvature 337

2) Send your selection to your representative who should in turn send all group selection to the instructor at <mrushdi@eng1.cu.edu.eg>. No topic can be picked by more than one group.
3) Read and reproduce the results from the selected chapter.
4) Survey the literature for relevant papers on the same topic.

5) **Implement two numerical solution schemes for your problem (in addition to the one used in the selected book chapter).**
6) **Implement an equivalent machine learning (or deep learning) scheme for solving the ODE/PDE equations.**

   Check these resources for further information:

   ***Physics-based Deep Learning***

   https://physicsbaseddeeplearning.org/intro.html

   https://github.com/thunil/Physics-Based-Deep-Learning

   ***Physics-informed machine learning***

   https://www.nature.com/articles/s42254-021-00314-5

   ***Integrating Physics-Based Modeling With Machine Learning: A Survey***

   https://beiyulincs.github.io/teach/fall_2020/papers/xiaowei.pdf

   ***py-pde***

   *Python package for solving partial differential equations using finite differences.*

   https://github.com/zwicker-group/py-pde

7) Compare the numerical and learning-based schemes based on accuracy and time metrics (consult the selected book chapter and reviewed papers for suitable metrics).

8) Write a report of 4 pages in the LATEX-based IEEE conference template <https://www.ieee.org/conferences/publishing/templates.html>. You may use Overleaf www.overleaf.com for LaTeX document preparation with the IEEE conference template.

9) The report shall include an introduction to the problem, a literature review (surveying recent papers on the problem), explanation of the ODE/PDE model, numerical solution steps, simulation results for the numerical and machine-learning solutions, as well as suggestions for improvements and future work.

10) Submit a one-PDF-file report, all LaTeX source files, and the code files (Python, R, or MATLAB).

11) Create a page for the project on **GitHub** mirroring all the information in the report, and any additional results you couldn't include in the 4-page report.

12) Give a presentation on the chosen problem. The presentation should include the following:
    - Overview of the BME problem under consideration (10%)
    - Explanation of the ODE/PDE model (10%)
    - Explanation of the numerical and learning-based solution steps (25%)
    - Demonstrations and results of the numerical and learning-based solutions (35%)
    - A short survey of recent papers, books, and tools on the BME problem under consideration (10%)
    - Suggestions for improvements and future work (10%)

- All project selections must be made and communicated to the course instructor by **Sunday May 11, 2025**.

  Second-year students (SBE2250) must submit their projects by **7 AM on Wednesday June 18th, 2025**. Online group presentations should be tentatively scheduled on that day.

  First-year students (SBEG108) must submit their projects by **7 AM on Thursday June 19th, 2025**. Online group presentations should be tentatively scheduled on that day.

- Grading criteria:
  - Presentation (30%)
  - Four-page report (30%)
  - Experimental results and discussion (30%)
  - GitHub page (10%)

Thanks,

Muhammad Rushdi