Course Title

AI-Accelerated Bioengineering with Applications in Aptamer-Based Biosensing

Course Description
This course explores how biochemistry and artificial intelligence intersect in **real-world biomedical applications**, with a focus on **aptamers and aptamer-based biosensors** for diagnostics, therapeutics monitoring, and environmental health. Students will learn the biochemical foundations of aptamers, biosensor design, and biomarker discovery, and see how AI tools can assist this work. Emphasis is placed on **clinical and translational applications**, case studies of **commercialized aptamer technologies**, and understanding the **biosensor market and regulatory landscape**.

Prerequisites
- Basic understanding of biochemistry and molecular biology.
- Introductory knowledge of machine learning and data science (conceptual emphasis; advanced coding not required).
- Basic familiarity with Python or R is helpful but not central.

Course Duration
One semester (15 weeks)

Course Structure (Weeks 1–15)

Week 1–2: Introduction to AI-Driven Biochemistry & Aptamers
Topics:
1. Overview of AI in modern biomedicine (high level)
2. Biochemical foundations: nucleic acids, proteins, ligands
3. Introduction to aptamers: SELEX, structure, binding principles
4. Historical evolution of AI in biochemical and diagnostic research

Learning Outcomes
1. Explain what aptamers are and how they differ from antibodies in biosensing.
2. Describe how AI supports (not replaces) experimental biochemistry and biosensor development.
3. Recognize key milestones in AI applications to biochemical and biomedical problems.

Week 3–4: Biochemical & Clinical Data in Biosensing
Topics
1. Types of data in biomedical/diagnostic contexts (biomarker panels, assay readouts, clinical metadata)
2. Data from biochemical and biosensor experiments: calibration curves, limits of detection, specificity
3. Public biochemical and biomedical datasets (e.g., PDB for aptamer–protein complexes, NCBI, clinical biomarker datasets)
4. Basics of data quality for assays: reproducibility, noise, and biological variability

Learning Outcomes
1. Identify and interpret key data types used to evaluate aptamer biosensors.
2. Assess quality of biochemical and clinical data relevant to diagnostics.
3. Access and use major biochemical/biomedical databases to support biosensor design and evaluation.

Week 5–6: Practical AI Support for Biomedical Questions (Light on Computation)

Topics

1. Conceptual overview of supervised learning for **clinical classification** (e.g., disease vs. healthy based on biomarker signals)
2. Simple models for dose–response and assay calibration (e.g., logistic fits, basic regression)
3. Unsupervised methods for **biomarker pattern discovery** (clustering patient profiles, aptamer binding patterns)
4. How to interpret model outputs in a **biomedical context** (sensitivity, specificity, ROC curves)

Learning Outcomes

1. Relate basic ML concepts (classification, regression, clustering) to real biomedical questions (diagnosis, prognosis, monitoring).
2. Interpret model performance metrics in terms of clinical relevance (false positives/negatives, risk of misdiagnosis).
3. Understand when sophisticated AI is useful vs. when simple biochemical analysis is sufficient.

Week 7–8: Aptamer-Based Biosensors – Design, Formats & Real-World Uses

Topics

1. Biochemical design of aptamer biosensors: target selection, affinity, specificity, stability
2. Biosensor formats: electrochemical, optical, colorimetric, lateral-flow, microfluidic platforms
3. **Case studies of real-world aptamer biosensors**:
   - Thrombin, VEGF, and small-molecule sensing
   - Point-of-care diagnostics (e.g., rapid tests)
4. Role of AI in optimizing aptamer sequences and sensor conditions (at a conceptual level, not code-heavy)

Learning Outcomes

1. Describe the design principles of aptamer-based biosensors for clinically relevant targets.
2. Compare different biosensor formats in terms of sensitivity, speed, and clinical usability.
3. Explain how AI can assist with aptamer sequence optimization and assay condition tuning.

Week 9–10: Translational Biomedicine – From Bench to Bedside & the Aptamer Market

Topics

1. Translating aptamer biosensors into clinical diagnostics (validation, clinical trials, regulatory considerations)
2. **Commercialized aptamer technologies** and platforms (e.g., multiplex aptamer assays, proteomic panels, point-of-care kits)
3. Market landscape for biosensors:
   - Diagnostic segments (oncology, infectious disease, cardiovascular, fertility, etc.)
   - Competitive position of aptamers vs. antibodies and small molecules
   - Cost, scalability, and manufacturing considerations
4. How industry uses AI for **market analysis, performance monitoring, and post-market surveillance**

Learning Outcomes

1. Identify examples of commercially available aptamer-based diagnostics or biosensing platforms.
2. Discuss the opportunities and challenges for aptamers in the biosensor market.
3. Understand the path from lab prototype to commercial product (regulation, reimbursement, clinical adoption).

Week 11–12: Metabolomics, Enzyme Kinetics & Biosensing for Disease

Topics

1. Biochemical basis of metabolic biomarkers and enzyme activity as diagnostic readouts

2. Aptamer biosensors for metabolites, enzymes, and small molecules in blood, saliva, and other biofluids
3. Integrating metabolomics data with aptamer-based assays (how multi-omics improves diagnosis)
4. Conceptual use of AI for **integrating multi-omics and biosensor data** to support precision medicine

Learning Outcomes

1. Explain how metabolic and enzymatic changes can be detected via aptamer biosensors.
2. Relate multi-omics concepts to the design of more informative diagnostic panels.
3. Interpret integrated data (biosensor + metabolomics) in terms of disease mechanisms and patient stratification.

Week 13–14: Ethics, Safety & Future Trends in Biomedical AI and Biosensing

Topics

1. Ethical issues in AI-enabled diagnostics: bias, access, equity, data privacy, consent
2. Safety, robustness, and reliability of biosensors used in healthcare and public health
3. Future trends:
    - Wearable and implantable biosensors
    - At-home testing, telemedicine integration
    - AI-supported personalized monitoring using aptamer platforms
4. Case studies of both **successful and problematic** deployments of AI in clinical diagnostics

Learning Outcomes

1. Discuss ethical implications of AI-driven diagnostics and personalized biosensing.
2. Critically evaluate claims about new biosensor technologies and their impact on healthcare.
3. Describe emerging directions for aptamer biosensors in preventive and precision medicine.

Week 15: Capstone Project and Presentations

Topics

1. Students design a **biomedical project concept** where aptamer biosensors and AI play a complementary role (e.g., early cancer detection tool, infection triage test, fertility monitoring, environmental health test with human-health implications).
2. Presentation of projects and peer review with emphasis on **clinical relevance, feasibility, and ethical considerations**.

Learning Outcomes

1. Demonstrate the ability to integrate biochemical, biomedical, and AI concepts in a realistic diagnostic or biosensing scenario.
2. Communicate scientific ideas clearly to a mixed audience (scientific and non-technical stakeholders).

Assessment Methods

Diagnostic Assessments (low-stakes, to gauge prior knowledge)

- 2-minute paper (closed) at the start of selected lectures (e.g., “What is one question you have about aptamers in diagnostics?”)
- 2–3 minute True/False or concept-check exercise at the end of lectures (open)
- Short Discussion Board prompts (e.g., comment on a recent aptamer diagnostic paper or news article)

Formative Assessments (feedback-focused, during the term)

These are designed to give **frequent, low-stakes feedback** and help students connect concepts to real biomedical applications:

1. **Weekly Concept Quizlets (Online, 5–10 questions)**

  - Focus on core biomedical ideas: biomarker selection, assay sensitivity/specificity, aptamer vs. antibody comparisons, clinical use cases.
  - Automated feedback with short explanations.
2. **Mini Case Study Write-Ups (2–3 across the term)**
   - Short (1–2 page) analyses of a real-world aptamer biosensor (commercial product or published prototype).
   - Students describe: target, clinical use, assay format, key performance metrics, and potential impact.
3. **In-Class Polls & Think–Pair–Share**
   - Poll questions on trade-offs (e.g., "Would you prioritize sensitivity or time-to-result for this emergency diagnostic?").
   - Students briefly discuss with a partner and share reasoning.
4. **Biomarker & Assay Design Worksheets**
   - Guided worksheets where students propose a simple aptamer-based test for a chosen disease and outline:
     - Target biomarker(s)
     - Sample type (blood, saliva, etc.)
     - Biosensor format
     - Basic performance goals (LOD, specificity)
   - Instructor or TA gives written or verbal feedback.
5. **Capstone Proposal Pitch (Formative Version)**
   - Mid-semester 3–5 minute "elevator pitch" of their capstone idea focusing on the **biomedical need and feasibility** rather than technical AI complexity.
   - Peer and instructor feedback used to refine the final Week 15 project.

Summative Assessments

- **Midterm Exam**
  - Short-answer and applied questions on aptamer biochemistry, biosensor formats, clinical application scenarios, and basic AI concepts (no heavy computation).
- **Final Exam**
  - Case-based questions integrating ethics, clinical translation, and market considerations for biosensors.
- **Capstone Project (Report + Presentation)**
  - Evaluated on biomedical problem definition, soundness of biosensor concept, appropriate/realistic use of AI, and awareness of ethical and market factors.

Extra Efforts

- Float topics for **Open Forum Discussions** (e.g., new aptamer diagnostics in the news, emerging markets, regulatory changes).
- Extended office hours for project and concept support.
- Encourage interaction among students via discussion boards, peer feedback on case studies, and collaborative worksheet sessions.