Transforming Antimicrobial Peptides into Medicines via AI-Empowered High-Throughput Nanoparticle Synthesis Platforms

Tagline:

Accelerating antimicrobial nanomedicine through the powerful trinity of microfluidics, automation, and AI.

Supervisors:

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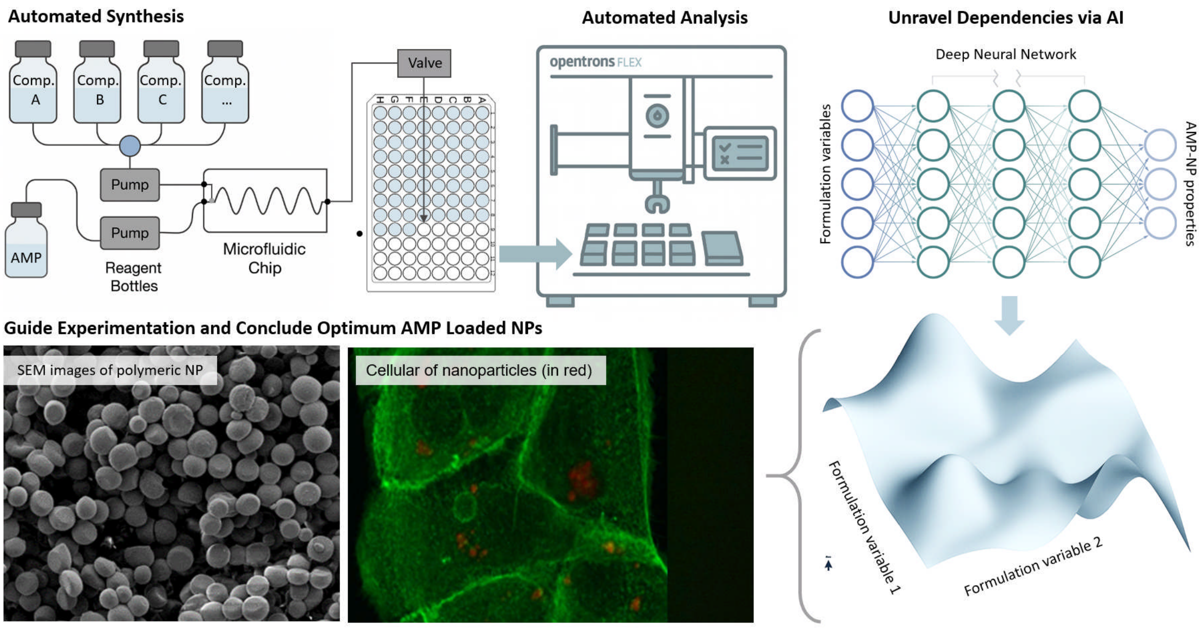

Industrial Project Partners: NHS, Accelerated Materials, Metalchemy, Cordouan Technologies

Abstract:

Antimicrobial peptides (AMPs) are natural molecules produced by the immune system and represent one of the most promising avenues for developing new treatments against drug-resistant infections. Their rapid action and ability to target bacteria in several ways make it difficult for antimicrobial resistance to emerge. Despite this promise, AMPs have proven challenging to turn into effective medicines, as they are fragile, easily broken down, and prone to losing their activity before reaching the site of infection.

Encapsulating AMPs within nanoparticles can protect them and help deliver them precisely where they are needed. However, designing suitable AMP-nanoparticle combinations is complicated. Many formulation ingredients, concentration ratios, and processing conditions influence their behaviour, creating a vast and complex landscape that traditional experimentation cannot navigate efficiently.

This project addresses this challenge by bringing together I) microfluidic/flow-based nanoparticle synthesis, which underpins modern nanoparticle drug delivery systems including the Pfizer–BioNTech COVID-19 vaccine, together with II) high-throughput experimentation via laboratory automation and III) AI navigation of the complex landscape described.

This powerful combination not only supports the creation of AMP based nanomedicines, but also addresses a central challenge in modern medicine: many promising drugs lack effective delivery systems. Hence, this project not only allows the student to make a real-world impact, but also provides, through our strong network of industry and healthcare partners, a rare opportunity to develop a highly sought-after interdisciplinary skill set that is in demand across both academia and industry.

Approach and Methods:

- **Formulate model antimicrobial peptides using microfluidic flow reactors**
  Using our established microfluidic nanoprecipitation platforms, the student will learn to formulate key AMPs such as LL-37, Melittin, and Temporin B into polymeric and lipid nanoparticles. This flow-based approach is widely used in modern nanomedicine development and provides precise, scalable control over nanoparticle synthesis.

- **Automate synthesis and characterisation using robotics**
  By integrating automated microfluidic reactors with our robotic systems for sample handling and analysis, the student will work with a platform that performs nanoparticle synthesis and characterisation autonomously. This setup enables fast, reproducible, and high-throughput experimentation while giving the student hands-on experience with state-of-the-art automation.

- **Generate rich, large-scale formulation datasets to leverage AI technologies**
  Using this automated platform, the student will produce hundreds to thousands of AMP-nanoparticle formulations. Each experiment will capture key variables such as formulation components, process conditions, particle size, stability, loading efficiency, and antimicrobial activity, creating a dataset suitable for data-driven optimisation.

- **Apply user-friendly AI tools for data analysis and guided optimisation**
  The student will apply, not develop, AI methods using easy-to-use platforms such as AMLearn®. These tools will help identify correlations, determine the

most influential formulation parameters, and guide iterative optimisation decisions.

- **Evaluate biological performance of optimised formulations**
  The student will test the most promising formulations for antimicrobial activity, stability, and functionality to identify candidates with strong therapeutic potential.

Impact and Outlook:

The integration of flow-based nanoparticle formulation, high-throughput automation, and AI-guided optimisation creates a powerful platform with impact far beyond AMP nanomedicines. These technologies address one of the most persistent challenges in modern drug development as many promising therapeutics lack suitable delivery systems. By providing a blueprint for accelerated and systematic formulation, this approach can support a wide spectrum of emerging treatments, including cancer immunotherapies, nucleic acid-based medicines (not only vaccines), and other complex biological therapeutics.
The project also offers substantial long-term value in training the next generation of researchers. Working across chemical engineering and the School of Pharmacy, and engaging directly with industrial and healthcare partners, the student will develop a rare interdisciplinary skill set that spans nanoparticle design, flow chemistry, automation, and applied AI. Such a combination is increasingly sought after in modern pharma and biotech environments, where digital, data-driven, and autonomous approaches are rapidly reshaping research and manufacturing. This training will therefore equip the student with a flexible and competitive career profile, opening pathways in academia and industry such as pharmaceutical R&D, and other emerging technology sectors. Together, these impacts support the development of new medicines while providing lasting benefits for the student's career.

Training and Student Development:

The student will gain interdisciplinary training in:

- Nanoparticle synthesis and characterisation
- Microfluidics for high-throughput experimentation on nanomaterial synthesis
- Automation and robotics in pharmaceutical R&D
- Application of AI in process development and materials discovery
- Antimicrobial testing and biological evaluation

- Workflow integration and data management for self-driven laboratories
- Project management and coordination within a multidisciplinary environment
- Scientific writing and effective communication within a multidisciplinary environment
- Networking, career development, and professional self-promotion

The project includes close collaboration with industry partners such as Metalchemy Ltd, Cordouan Technologies, and Accelerated Materials, as well as the NHS, providing real-world context, translational insight, and valuable opportunities for career mentoring and networking with industrial and clinical experts.

Research Environment:

The student will be embedded in the research groups of **Dr. Maximilian Besenhard** and **Dr. Maryam Parhizkar**, which together provide a highly interdisciplinary and well-established research environment. Both groups include an active community of PhD students, postdoctoral researchers, and technical staff with expertise in microfluidics, nanoparticle synthesis, automation, robotics, and data-driven methods. This concentration of skills, together with fully operational and well-maintained infrastructure for all key activities of the project, positions the student to hit the ground running and benefit from comprehensive support across both groups. All required equipment (automated flow set-ups, robots, integrated analysers etc.), workflows, and technical know-how are already in place, ensuring a highly reliable and well-prepared environment where the student can begin productive work from day one.
The project is jointly hosted between UCL Chemical Engineering and the UCL School of Pharmacy, offering the student exposure to two world-leading academic environments. Chemical Engineering provides strong foundations in process development, automation, and materials manufacturing and is deeply committed to equality, diversity, and inclusion, holding the prestigious Athena SWAN Gold Award.
More information: https://www.ucl.ac.uk/engineering/chemical-engineering/about/athena-swan.
The School of Pharmacy complements this with world-class expertise in drug delivery, biological evaluation, and translational pharmaceutical science. It has a long-standing commitment to EDI, holding an Athena SWAN Bronze Award and actively working toward Silver status. The School's EDI Committee and active BAME awareness and support group contribute to a welcoming and inclusive atmosphere for students from all backgrounds.
A significant portion of the experimental work will take place at UCL's Manufacturing Futures Lab (MFL), a flagship facility that brings together advanced manufacturing, automation, and materials science. The MFL houses more than £6 million of cutting-

edge equipment, including microfluidic reactors, robotic platforms, high-throughput characterisation instruments, and advanced process analytics—all essential for the integrated workflow of this project. Its interdisciplinary structure, spanning engineering, chemistry, and pharmaceutical sciences, makes it an ideal environment for developing high-throughput and AI-enabled nanoparticle formulation strategies. The Precision Manufacturing Workshop, located within the MFL, further supports rapid prototyping and customisation of reactors and analytical tools, enabling unique experimental capabilities.
More information: https://www.ucl.ac.uk/engineering/research/centres-institutes-and-labs/manufacturing-futures-lab.

Desirable Prior Experience:

- Background in an aligned engineering or science discipline such as, but not limited to, chemical, pharmaceutical, biochemical, or mechanical engineering; pharmaceutical sciences; materials science; or related areas. Applicants from computer science with relevant interest are also welcome.
- Motivation to learn about nanoparticle formulation, microfluidics, or data analysis is highly valued.
- Motivation to work in AMR and nanomedicine and to learn how AI can guide experiments and support process and material development is highly valued.

References:

1. Oliveira Júnior et al., *Nat. Rev. Microbiol.* (2025) https://doi.org/10.1038/s41579-025-01200-y
2. De Soricellis et al., *Int. J. Pharm.* 677 (2025) https://doi.org/10.1016/j.ijpharm.2025.125668
3. Jose & Lapkin, *Nat. Chem. Eng.* 2 (2025) https://doi.org/10.1038/s44286-025-00291-x
   4–11. Additional references available in full project document

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Keywords:

Antimicrobial peptides, AMR, drug delivery, nanoparticle formulation, flow chemistry, high-throughput experimentation, automation and robotics, artificial intelligence