Bioelectronics: The Path Here and the Journey to Come

The use of electronic materials to probe and control biological systems has grown enormously in recent years, with applications often being the main research focus. Although biological discovery through these materials is just as exciting, it has not yet received the same amount of coverage in the scientific literature. This special issue of iScience aims to fill that gap.

Here, we introduce you to the field-leading guest editors of this special issue, Anne Andrews and Roísin Owens. Throughout, they tap into their expertise to offer an insightful overview of the field of bioelectronics, discussing what makes it unique, the impact of its discoveries on the real world, and how to excel as a scientist within it. They not only provide their perspectives on the field in its current state and describe where it may be headed but also give a narrative to their constantly evolving career paths that have led them both to this highly collaborative and cutting-edge discipline.

Anne Andrews, a Professor of Psychiatry and Chemistry & Biochemistry at the University of California, Los Angeles, received her PhD in Chemistry as a Department of Education Fellow at the National Institute of Mental Health. Her current research is solutions-driven, with a focus on the development of minimally invasive bioelectronics that can be implanted long-term. Specifically, her interests lie in understanding the serotonin neurotransmitter system and developing and utilizing biosensors to discover previously inaccessible information about the functioning of this system.
Róisín Owens earned her PhD in Biochemistry and Molecular Biology at Southampton University. She is currently a University Lecturer in the Department of Chemical Engineering and Biotechnology at the University of Cambridge. Her lab is investigating interactions of the gut-brain-microbiome axis by utilizing organic bioelectronic devices for non-invasive monitoring. Additionally, her lab is using organic electronic technology to develop novel methods for antibiotic screening with the goal of improving the processes of drug discovery and therapeutics.

An Unpredictable Path

Andrews: I am academically trained as an Analytical Chemist and Biochemist. However, I carried out my pre- and postdoctoral research at the US National Institute of Mental Health. There, I became interested in psychiatric disorders, particularly anxiety and mood disorders, and the role that serotonin plays in their etiology and treatment. As a chemist, I wanted to investigate serotonin neurotransmission in behaving animals to understand how this neurochemical encodes anxiety-related information.

It was in this context that I was challenged to think about how we might dramatically improve in vivo neurotransmitter sensing, not just for serotonin, but for virtually any neurotransmitter, and to overcome shortcomings associated with the existing methods. I began to envision a type of implantable device that would enable high spatial and temporal resolution measurements of serotonin, as well as other neurotransmitters, and that would be fully electronic and highly multiplexed, potentially at the nanoscale. My group has worked collaboratively for more than 15 years to make this a reality. We now have sensors for small molecule neurotransmitters that use nucleic acid aptamers to impart chemical selectivity, i.e., chemical resolution, and thin-film semiconductor field-effect transistors for signal transduction and multiplexing.

Owens: My original interest in bioelectronics was sparked through a chance conversation with a colleague (now my husband!) from Materials Science when I was a postdoc at Cornell’s school of veterinary medicine. As a biologist it seemed to me that the organic electronic materials used in his lab could provide an excellent interface with biology due to their soft and flexible nature and their mixed ionic and electronic conductivity. We started to work on simple devices—protein-based biosensors. Now we have graduated to guts and brains!

The Importance of Translation

Owens: I think that being mindful of translation and ensuring that we are not generating prototypes that have little chance of being useful in the clinic or in industry is a top priority. It is important that we understand the hurdles involved in fabricating devices, not only reproducibility but that we take into account the huge heterogeneity and variability of biological systems as well.

Andrews: Indeed, the biggest challenge the field faces is advancing bioelectronics beyond proof-of-concept. It is vital that we advance to a level where we can learn new information about biological systems that we haven’t been able to access, as well as learn to control these systems in ways that mimic or reproduce their inherent function.

Communication Is Key

Andrews: The field of bioelectronics is inherently interdisciplinary. I do not think this creates barriers but instead, opportunities. However, to realize these opportunities one needs to begin by learning a specific discipline deeply, e.g., neuroscience, electrical engineering, or chemistry. The devils truly are in the details, which is where deep fundamental knowledge comes into play. Along the way it is important to develop communication skills, to step outside of traditional academic silos, and to cross-train.

Owens: Interdisciplinarity plays a huge role in bioelectronics. We see people with all kinds of training from Chemical Engineering to Physics to Biomedical Engineering and even Mathematicians. Tissue engineering is big in bioelectronics right now, which involves everything from living electrodes to the types of 3D organ on chips that we do. Neural interfacing people are bringing in Computer Scientists, Machine Learning, and AI to tackle challenges with huge datasets and network connectivity. And mainstream cell biologists are taking an interest in devices made by the bioelectronics community as the developments we’re making may be able to help them readout biological data in a new, often highly quantitative and dynamic way. I trained as a biochemist and later acquired skills in cell biology and microbiology. I think that there are relatively few people like me who trained as biologists and are now in the field of bioelectronics.
Through my experience, I have found that good communication is key—being able to talk to and learn from people in other disciplines, while respecting their knowledge and being willing to contribute yours—is invaluable. I think bright, motivated people from almost any scientific background can make it in this field. Entering the physical sciences domain was quite daunting, but now I feel quite at home talking about transistors and materials. A crash course in electronics can be very useful for the uninitiated as well.

What’s to Come

Owens: I’d particularly like to see the translation of bioelectronics devices to be used in society—hospitals, pharmacies, sportswear, analytical labs, etc. Achieving this, however, would require industry to take an avid interest in helping with some of the manufacturing issues we currently face as well as establishing the infrastructure needed to fabricate and prepare devices in a way that is compatible with cells (i.e., sterile!). To facilitate this, changes in the regulation of medical devices and the materials used in them will need to occur as well.

Andrews: The articles within this special issue are a roadmap to the cutting edge and future of bioelectronics. We see that mainstream medicine is going to interface increasingly with bioelectronics. There is increasing representation from scientists in physics and math, particularly computation. Additionally, as the field progresses, ethics and social scientists will be needed to help navigate the new territory created as electronics are interfaced with biological systems, including humans.
