Mechanics Across Scales: From Structures to Living Systems

The word *mechanics* comes from the Greek *mēchanē*, a contrivance or means. Since the *Mechanical Problems* of the Aristotelian school and the work of Archimedes, mechanics has sought to explain how bodies move, deform, withstand forces, and ultimately fail. This lecture follows that question across many orders of magnitude, from bridges and buildings to engineered materials, nanostructures and individual living cells.

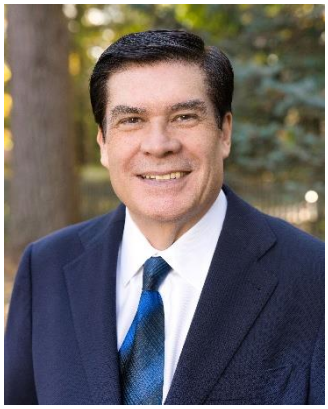
Galileo saw that size is never neutral: a structure cannot simply be made larger or smaller and behave the same way. Much of my career has been an encounter with that insight at scales Galileo could not reach. As dimensions shrink, surfaces, defects and discreteness come to dominate, and classical laws must be re-examined with new theories and instruments, often of a resolution never before achieved.

I will describe how new experimental techniques, combined with computational models, allowed us to investigate how materials only a few atoms thick deform and fail. We also explored how nature uses hierarchy and architecture to create strong, tough materials from relatively weak constituents. Our research eventually extended beyond inanimate materials to living cells, where the challenge was not only to observe but also to intervene without destroying what we sought to understand. Using localized electric fields, we learned to open individual cells briefly, deliver genes, and sample their contents while keeping them alive.

Our most recent work asks how cells communicate. By combining nanoscale optical sensors with live-cell imaging and machine learning, we can follow in real time the molecular signals that individual cells release. We can also link those signals to changes in each cell's shape and behavior. This turns a static snapshot of biology into a moving picture of a conversation among cells.

These advances point toward a larger goal: reconstructing interacting human tissues and organs, including the immune system, on engineered platforms. Artificial intelligence would then design, run and interpret the experiments in a closed loop. Such systems could improve predictions of human responses to drugs and disease and reduce reliance on animal studies. Ultimately, they could help uncover biological mechanisms faster than human-guided experimentation alone.

The thread through all of this is that mechanics offers a common language across disciplines and scales. I will close by reflecting on why the most fertile questions often arise at the boundaries between fields, and what that implies for how we educate and organize science.



Biosketch: Horacio D. Espinosa is the Walter P. Murphy Professor of Mechanical Engineering and Director of the Theoretical and Applied Mechanics Program at Northwestern University. He received his Ph.D. in Solid Mechanics from Brown University in 1992. His research spans the deformation and failure of materials across scales, the development of experimental techniques for micro- and nanomechanics, architected materials, and technologies for single-cell manipulation and analysis. He has published more than 400 technical papers. Espinosa is a member of the U.S. National Academy of Engineering and Academia Europaea, and a Fellow of the National Academy of Inventors, AAAS, ASME, and the Society for Experimental Mechanics (SEM). His distinctions include the SES Prager Medal, ASME Drucker Medal, TMS William Nix Medal, ASCE Z.P. Bažant Medal, and SEM P.S. Theocaris Award and Murray Medal. He is a former president of the Society of Engineering Science and former chair of the U.S. National Committee on Theoretical and Applied Mechanics.