ALL

Biobots, Xenobots, and Anthrobots

© 2026 Claire Isabel Webb

Empirical Science Papers

Blackiston, Douglas, Emma Lederer, Sam Kriegman, Simon Garnier, Joshua Bongard, and Michael Levin. "A Cellular Platform for the Development of Synthetic Living Machines." *Science Robotics* 6, no. 52 (2021): 1571. https://doi.org/10.1126/scirobotics.abf1571.

Gumuskaya, Gizem, Pranjal Srivastava, Ben G. Cooper, Hannah Lesser, Ben Semegran, Simon Garnier, and Michael Levin. "Motile Living Biobots Self-Construct from Adult Human Somatic Progenitor Seed Cells." *Advanced Science* 11, no. 4 (2024): 2303575. https://doi.org/10.1002/advs.202303575.

Kriegman, Sam, Douglas Blackiston, Michael Levin, and Josh Bongard. "A Scalable Pipeline for Designing Reconfigurable Organisms." *Proceedings of the National Academy of Sciences* 117, no. 4 (2020): 1853–59. https://doi.org/10.1073/pnas.1910837117.

—. Kriegman, Sam, Douglas Blackiston, Michael Levin, and Josh Bongard. "Kinematic Self-Replication in Reconfigurable Organisms." *Proceedings of the National Academy of Sciences* 118, no. 49 (2021): e2112672118. https://doi.org/10.1073/pnas.2112672118.

Reviews & Theoretical Foundations

Blackiston, Douglas, Sam Kriegman, Joshua Bongard, and Michael Levin. "Biological Robots: Perspectives on an Emerging Interdisciplinary Field." *Soft Robotics* 10, no. 4 (2023): 686–94. https://doi.org/10.1089/soro.2022.0142.

Bongard, Josh, and Michael Levin. "Living Things Are Not (20th Century) Machines: Updating Mechanism Metaphors in Light of the Modern Science of Machine Behavior." *Frontiers in Ecology and Evolution* 9 (2021): 650726. https://doi.org/10.3389/fevo.2021.650726.

—. "There's Plenty of Room Right Here: Biological Systems as Evolved, Overloaded, Multi-scale Machines." *Biomimetics* 8, no. 1 (2023): 110. https://doi.org/10.3390/biomimetics8010110.

Clawson, Wesley P., and Michael Levin. "Endless Forms Most Beautiful: Teleonomy and the Bioengineering of Chimeric and Synthetic Organisms." *Biological Journal of the Linnean Society* (2023). https://doi.org/10.1093/biolinnean/blac073.

Davies, Jamie A. "Synthetic Morphology: Prospects for Engineered, Self-Constructing Anatomies." *Journal of Anatomy* 212, no. 6 (2008): 707–19.

Davies, Jamie A., and Michael Levin. "Synthetic Morphology with Agential Materials." *Nature Reviews Bioengineering* 1, no. 1 (2023): 46–59. https://doi.org/10.1038/s44222-022-00001-9.

Ebrahimkhani, Mo R., and Michael Levin. "Synthetic Living Machines: A New Window on Life." *iScience* 24, no. 5 (2021): 102505. https://doi.org/10.1016/j.isci.2021.102505.

Kamm, Roger D., and Rashid Bashir. "Creating Living Cellular Machines." *Annals of Biomedical Engineering* 42, no. 2 (2014): 445–59.

Kamm, Roger D., Rashid Bashir, Natasha Arora, Roy D. Dar, Martha U. Gillette, Linda G. Griffith, et al. "Perspective: The Promise of Multi-Cellular Engineered Living Systems." *APL Bioengineering* 2, no. 4 (2018): 040901. https://doi.org/10.1063/1.5038337.

Levin, Michael. "The Computational Boundary of a 'Self': Developmental Bioelectricity Drives

Multicellularity and Scale-Free Cognition." *Frontiers in Psychology* 10 (2019): 2688. https://doi.org/10.3389/fpsyg.2019.02688.

—."Bioelectric Signaling: Reprogrammable Circuits Underlying Embryogenesis, Regeneration, and Cancer." *Cell* 184, no. 8 (2021): 1971–89. https://doi.org/10.1016/j.cell.2021.02.034.

—. "Technological Approach to Mind Everywhere: An Experimentally Grounded Framework for Understanding Diverse Bodies and Minds." *Frontiers in Systems Neuroscience* 16 (2022): 768201. https://doi.org/10.3389/fnsys.2022.768201.

—. "Darwin's Agential Materials: Evolutionary Implications of Multiscale Competency in Developmental Biology." *Cellular and Molecular Life Sciences* 80, no. 6 (2023): 142. https://doi.org/10.1007/s00018-023-04790-z

Pezzulo, Giovanni, and Michael Levin. "Top-Down Models in Biology: Explanation and Control of Complex Living Systems above the Molecular Level." *Journal of the Royal Society Interface* 13, no. 124 (2016): 20160555.

Cultural Impact

Altamirano, Marco. "The Uncanny Valley of Xenobots." *Nautilus*, 2022. https://nautil.us/the-uncanny-valley-of-xenobots-238434.

Levin, Michael. "Living Things Are Not Machines (Also, They Totally Are)." *Noema*, March 18, 2025. https://www.noemamag.com/living-things-are-not-machines-also-they-totally-are/.

Levin, Michael, and Daniel C. Dennett. "Cognition All the Way Down." *Aeon*, 2020. https://aeon.co/essays/how-to-understand-cells-tissues-and-organisms-as-agents-with-agendas.

Levin, Michael, and Rafael Yuste. "Modular Cognition." *Aeon*, March 8, 2022. https://aeon.co/essays/how-evolution-hacked-its-way-to-intelligence-from-the-bottom-up.

Levy, Max G. "Cells Form Into 'Xenobots' on Their Own." *Quanta Magazine*, March 31, 2021. https://www.quantamagazine.org/cells-form-into-xenobots-on-their-own-20210331/.

Webb, Claire Isabel. "De-Extinction Report." *Autre*, November 18, 2025. https://autre.love/autre-21-wip/2025/11/18/de-extinction-report.

Weil, Elizabeth. "What is it Like to Be a Cucumber?" *New York Magazine,* 2026. https://nymag.com/intelligencer/article/biologist-michael-levin-minds.html

Yuste, Rafael, and Michael Levin. "New Clues about the Origins of Biological Intelligence." *Scientific American*, December 11, 2021. https://www.scientificamerican.com/article/new-clues-about-the-origins-of-biological-intelligence/.

Historical Papers (chronological)

Lamarck, Jean-Baptiste. *Zoological Philosophy: An Exposition with Regard to the Natural History of Animals.* Translated by Hugh S. R. Elliot. London: Macmillan, 1914. First published 1809 as *Philosophie zoologique*. https://archive.org/details/ZoologicalPhilosophy.

Turing, Alan M. "On Computable Numbers, with an Application to the *Entscheidungsproblem*." *Proceedings of the London Mathematical Society*, 2nd ser., 42 (1937): 230–65. https://doi.org/10.1112/plms/s2-42.1.230.

von Neumann, John. "The General and Logical Theory of Automata." In *Cerebral Mechanisms in Behavior: The*

Hixon Symposium, edited by Lloyd A. Jeffress, 1–41. New York: John Wiley & Sons, 1951.

Turing, Alan M. "The Chemical Basis of Morphogenesis." *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 237, no. 641 (1952): 37–72. https://doi.org/10.1098/rstb.1952.0012.

von Neumann, John. *Theory of Self-Reproducing Automata*. Edited and completed by Arthur W. Burks. Urbana: University of Illinois Press, 1966.

Langton, Christopher G. "Self-Reproduction in Cellular Automata." *Physica D: Nonlinear Phenomena* 10, no. 1–2 (1984): 135–44. https://doi.org/10.1016/0167-2789(84)90256-2.

Langton, Christopher G., ed. *Artificial Life: The Proceedings of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems*. Redwood City, CA: Addison-Wesley, 1989.

Kay, Lily E. *Who Wrote the Book of Life? A History of the Genetic Code.* Stanford: Stanford University Press, 2000.

Noble, Denis. "Physiology Is Rocking the Foundations of Evolutionary Biology." *Experimental Physiology* 98 (8): 1235–43. 2013.

Riskin, Jessica. *The Power of Life: The Invention of Biology and the Revolutionary Science of Jean-Baptiste Lamarck*. New York: Penguin Random House, 2026.

Science Papers

Biobots, Xenobots, and Anthrobots

© 2026 Claire Isabel Webb

Empirical Science Papers

Blackiston, Douglas, Emma Lederer, Sam Kriegman, Simon Garnier, Joshua Bongard, and Michael Levin. "A Cellular Platform for the Development of Synthetic Living Machines." *Science Robotics* 6, no. 52 (2021): 1571. https://doi.org/10.1126/scirobotics.abf1571.

Gumuskaya, Gizem, Pranjal Srivastava, Ben G. Cooper, Hannah Lesser, Ben Semegran, Simon Garnier, and Michael Levin. "Motile Living Biobots Self-Construct from Adult Human Somatic Progenitor Seed Cells." *Advanced Science* 11, no. 4 (2024): 2303575. https://doi.org/10.1002/advs.202303575.

Kriegman, Sam, Douglas Blackiston, Michael Levin, and Josh Bongard. "A Scalable Pipeline for Designing Reconfigurable Organisms." *Proceedings of the National Academy of Sciences* 117, no. 4 (2020): 1853–59. https://doi.org/10.1073/pnas.1910837117.

—. Kriegman, Sam, Douglas Blackiston, Michael Levin, and Josh Bongard. "Kinematic Self-Replication in Reconfigurable Organisms." *Proceedings of the National Academy of Sciences* 118, no. 49 (2021): e2112672118. https://doi.org/10.1073/pnas.2112672118.

Reviews & Theoretical Foundations

Blackiston, Douglas, Sam Kriegman, Joshua Bongard, and Michael Levin. "Biological Robots: Perspectives on an Emerging Interdisciplinary Field." *Soft Robotics* 10, no. 4 (2023): 686–94. https://doi.org/10.1089/soro.2022.0142.

Bongard, Josh, and Michael Levin. "Living Things Are Not (20th Century) Machines: Updating Mechanism Metaphors in Light of the Modern Science of Machine Behavior." *Frontiers in Ecology and Evolution* 9 (2021): 650726. https://doi.org/10.3389/fevo.2021.650726.

—. "There's Plenty of Room Right Here: Biological Systems as Evolved, Overloaded, Multi-scale Machines." *Biomimetics* 8, no. 1 (2023): 110. https://doi.org/10.3390/biomimetics8010110.

Clawson, Wesley P., and Michael Levin. "Endless Forms Most Beautiful: Teleonomy and the Bioengineering of Chimeric and Synthetic Organisms." *Biological Journal of the Linnean Society* (2023). https://doi.org/10.1093/biolinnean/blac073.

Davies, Jamie A. "Synthetic Morphology: Prospects for Engineered, Self-Constructing Anatomies." *Journal of Anatomy* 212, no. 6 (2008): 707–19.

Davies, Jamie A., and Michael Levin. "Synthetic Morphology with Agential Materials." *Nature Reviews Bioengineering* 1, no. 1 (2023): 46–59. https://doi.org/10.1038/s44222-022-00001-9.

Ebrahimkhani, Mo R., and Michael Levin. "Synthetic Living Machines: A New Window on Life." *iScience* 24, no. 5 (2021): 102505. https://doi.org/10.1016/j.isci.2021.102505.

Kamm, Roger D., and Rashid Bashir. "Creating Living Cellular Machines." *Annals of Biomedical Engineering* 42, no. 2 (2014): 445–59.

Kamm, Roger D., Rashid Bashir, Natasha Arora, Roy D. Dar, Martha U. Gillette, Linda G. Griffith, et al. "Perspective: The Promise of Multi-Cellular Engineered Living Systems." *APL Bioengineering* 2, no. 4 (2018): 040901. https://doi.org/10.1063/1.5038337.

Levin, Michael. "The Computational Boundary of a 'Self': Developmental Bioelectricity Drives

Multicellularity and Scale-Free Cognition." *Frontiers in Psychology* 10 (2019): 2688. https://doi.org/10.3389/fpsyg.2019.02688.

—."Bioelectric Signaling: Reprogrammable Circuits Underlying Embryogenesis, Regeneration, and Cancer." *Cell* 184, no. 8 (2021): 1971–89. https://doi.org/10.1016/j.cell.2021.02.034.

—. "Technological Approach to Mind Everywhere: An Experimentally Grounded Framework for Understanding Diverse Bodies and Minds." *Frontiers in Systems Neuroscience* 16 (2022): 768201. https://doi.org/10.3389/fnsys.2022.768201.

—. "Darwin's Agential Materials: Evolutionary Implications of Multiscale Competency in Developmental Biology." *Cellular and Molecular Life Sciences* 80, no. 6 (2023): 142. https://doi.org/10.1007/s00018-023-04790-z

Pezzulo, Giovanni, and Michael Levin. "Top-Down Models in Biology: Explanation and Control of Complex Living Systems above the Molecular Level." *Journal of the Royal Society Interface* 13, no. 124 (2016): 20160555.

Further Reading

Agential Biology

© 2026 Claire Isabel Webb

Cultural Impact

Altamirano, Marco. "The Uncanny Valley of Xenobots." *Nautilus*, 2022. https://nautil.us/the-uncanny-valley-of-xenobots-238434.

Levin, Michael. "Living Things Are Not Machines (Also, They Totally Are)." *Noema*, March 18, 2025. https://www.noemamag.com/living-things-are-not-machines-also-they-totally-are/.

Levin, Michael, and Daniel C. Dennett. "Cognition All the Way Down." *Aeon*, 2020. https://aeon.co/essays/how-to-understand-cells-tissues-and-organisms-as-agents-with-agendas.

Levin, Michael, and Rafael Yuste. "Modular Cognition." *Aeon*, March 8, 2022. https://aeon.co/essays/how-evolution-hacked-its-way-to-intelligence-from-the-bottom-up.

Levy, Max G. "Cells Form Into 'Xenobots' on Their Own." *Quanta Magazine*, March 31, 2021. https://www.quantamagazine.org/cells-form-into-xenobots-on-their-own-20210331/.

Webb, Claire Isabel. "De-Extinction Report." *Autre*, November 18, 2025. https://autre.love/autre-21-wip/2025/11/18/de-extinction-report.

Weil, Elizabeth. "What is it Like to Be a Cucumber?" *New York Magazine,* 2026. https://nymag.com/intelligencer/article/biologist-michael-levin-minds.html

Yuste, Rafael, and Michael Levin. "New Clues about the Origins of Biological Intelligence." *Scientific American*, December 11, 2021. https://www.scientificamerican.com/article/new-clues-about-the-origins-of-biological-intelligence/.

Historical Papers (chronological)

Lamarck, Jean-Baptiste. *Zoological Philosophy: An Exposition with Regard to the Natural History of Animals.* Translated by Hugh S. R. Elliot. London: Macmillan, 1914. First published 1809 as *Philosophie zoologique*. https://archive.org/details/ZoologicalPhilosophy.

Turing, Alan M. "On Computable Numbers, with an Application to the *Entscheidungsproblem*." *Proceedings of the London Mathematical Society*, 2nd ser., 42 (1937): 230–65. https://doi.org/10.1112/plms/s2-42.1.230.

von Neumann, John. "The General and Logical Theory of Automata." In *Cerebral Mechanisms in Behavior: The Hixon Symposium*, edited by Lloyd A. Jeffress, 1–41. New York: John Wiley & Sons, 1951.

Turing, Alan M. "The Chemical Basis of Morphogenesis." *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 237, no. 641 (1952): 37–72. https://doi.org/10.1098/rstb.1952.0012.

von Neumann, John. *Theory of Self-Reproducing Automata*. Edited and completed by Arthur W. Burks. Urbana: University of Illinois Press, 1966.

Langton, Christopher G. "Self-Reproduction in Cellular Automata." *Physica D: Nonlinear Phenomena* 10, no. 1–2 (1984): 135–44. https://doi.org/10.1016/0167-2789(84)90256-2.

Langton, Christopher G., ed. *Artificial Life: The Proceedings of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems*. Redwood City, CA: Addison-Wesley, 1989.

Kay, Lily E. *Who Wrote the Book of Life? A History of the Genetic Code.* Stanford: Stanford University Press,

2000.
Noble, Denis. "Physiology Is Rocking the Foundations of Evolutionary Biology." *Experimental Physiology* 98 (8): 1235–43. 2013.
Riskin, Jessica. *The Power of Life: The Invention of Biology and the Revolutionary Science of Jean-Baptiste Lamarck*. New York: Penguin Random House, 2026.