Astronomy Education, Volume 1

Evidence-based instruction for introductory courses

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Preface

This book is intended to be a practical resource for introductory astronomy instructors, many of whom have received no formal training in teaching and learning. Astronomy is one of the most popular subjects for non-science majors, and it often represents their last formal exposure to science. Introductory astronomy classes therefore play a critical role in science literacy, as well as informing a broad audience about the dramatic recent progress in our understanding of the universe. Our intention is to provide information and resources for instructors who will be teaching for the first time or those who want to add to their toolkits and improve their students' learning. The book's authors are all experienced astronomy education researchers, instructors, curriculum designers, instructional designers, and professional development specialists who work in the field and share their insights with the reader.

Many books exist on implementing better teaching and learning practices in education and science in general; this one is intended for a specific audience of undergraduate astronomy instructors. It provides examples, resources, and advice for astronomy specifically. The goal is to acquaint instructors with teaching methods that are validated by research, and to include tools that go far beyond the traditional, passive model of an instructor delivering a lecture. Topics include learner-centered practices, designing effective courses by thinking about goals, using different astronomy curricula, online resources and visualizations, ideas for utilizing the planetarium, engaging students in astronomical research and citizen science projects, advice for teaching at community colleges, and making your courses more inclusive to all students. Thanks to the ebook format, each chapter has links to online instructional resources as well as references to the education research literature.

Editor biographies

Chris Impey

Chris Impey is a University Distinguished Professor of Astronomy and Associate Dean of the College of Science at the University of Arizona. He has over 180 refereed publications on observational cosmology, galaxies, and quasars, and his research has been supported by $20 million in NASA and NSF grants. He has won eleven teaching awards and has taught two online classes with over 180,000 enrolled and 2 million minutes of video lectures watched. Chris Impey is a past Vice President of the American Astronomical Society and he has been an NSF Distinguished Teaching Scholar, the Carnegie Council's Arizona Professor of the Year, and most recently, a Howard Hughes Medical Institute Professor. He's written over 50 popular articles on cosmology and astrobiology, two introductory textbooks, a novel called Shadow World, and eight popular science books: The Living Cosmos, How It Ends, Talking About Life, How It Began, Dreams of Other Worlds, Humble Before the Void, Beyond: The Future of Space Travel, and Einstein's Monsters: The Life and Times of Black Holes.

Sanlyn Buxner

Sanlyn Buxner is an Assistant Research Professor in the Department of Teaching, Learning, and Sociocultural Studies at the University of Arizona where she also serves as the Director of Graduate Studies. In addition, she is a Research Scientist and Education and Communication Specialist at the Planetary Science Institute. She is the current Education and Public Outreach Officer for the Division for Planetary Sciences of the American Astronomical Society and serves on the Executive Committee for the Education Section of the American Geophysical Union. Her research focuses on studying innovations in higher education STEM settings and assessing scientific and quantitative literacy of students and lifelong learners. She also studies the impact of research experiences on middle and high school teachers' classroom practices and student outcomes.

Contributors

Janelle M. Bailey is a faculty member in the Department of Teaching and Learning at Temple University, where her research focuses on astronomy and Earth science teaching and learning as well as science teacher education. She is a past president of the American Association of Physics Teachers (AAPT) and serves as a reviewer for several research and practitioner journals. Janelle earned her PhD in Teaching & Teacher Education (minor in Astronomy) with a focus on Astronomy Education from the University of Arizona; an MEd in Science Education from the University of Georgia; and a BA in Astrophysics from Agnes Scott College. She previously worked on the faculty of the University of Nevada, Las Vegas, and as a physics and chemistry teacher in Wyoming.

Kelly Borden is a career informal science educator. She is currently the Director of Teen Programs at the Adler Planetarium where she leads a team of educators, program facilitators, and curriculum developers within the Department of Citizen Science. Previously, she led Zooniverse educational efforts by designing and implementing curricula to bring citizen science into formal and informal learning environments.

Erik Brogt is a Reader in Academic Development at the University of Canterbury in Christchurch, New Zealand. He received his MSc in Astronomy from the University of Groningen (the Netherlands), and his PhD in Teaching and Teacher education from the University of Arizona. As an academic developer, Erik supports faculty in all matters related to teaching, learning, pedagogy, and curriculum and assessment design to help them shape their classes to optimize student learning. Erik's research interests are in Discipline-Based Education Research, working with faculty to investigate their teaching, academic development, and the educational psychology of university teaching and learning environments. He is a Fellow of the Higher Education Research and Development Society of Australasia, a Fellow of the Staff and Educational Development Association, and a Senior Fellow of the Higher Education Academy.

Marc Buie is an Institute Scientist at the Southwest Research Institute office in Boulder, Colorado. He is a member of the science team for the *New Horizons* and *Lucy* missions. He is an observational planetary scientist and works with telescopes around and above Earth, both big and small, and works primarily on studies of bodies in the outer solar system. Along the way, he has been heavily involved in both automated observatory operation and founded the Research and Education Collaborative Occultation Network (RECON), which is a new kind of citizen science project.

Carie Cardamone brings her passion for making science education inclusive and exciting to her work as the Associate Director for STEM and Professional Schools at

the Tufts University's Center for the Enhancement of Learning & Teaching, and as a Program Presenter at Boston's Museum of Science Planetarium & Observatory. As a member of Galaxy Zoo's science team, her research program encompasses the evolution of galaxies and attitudinal changes of introductory science students participating in Citizen Science projects.

Kim Coble is a Professor of Physics and Astronomy at San Francisco State University (SFSU), with expertise in physics and astronomy education research and extensive experience teaching reformed introductory physics and astronomy classes. Her research centers on understanding students' ideas about modern topics in science (such as cosmology), recognizing the strengths that diverse learners bring to the classroom and to STEM professions, and creating innovative, active-learning environments that engage students in realistic scientific practices. She is currently the chair of the Education Committee of the American Astronomical Society (AAS) and serves on the Committee for the Status of Minorities in Astronomy. She was a member of the AAS Task Force on Diversity and Inclusion in Graduate Astronomy Education, served on the Committee on Diversity of the American Association of Physics Teachers (AAPT), and was an organizer of the Inclusive Astronomy 2015 conference. At SFSU, she is the director for the Learning Assistant program, a member of the Faculty Agents of Change, and a faculty collaborator for the Center for Science and Math Education. She was formerly an NSF Astronomy and Astrophysics Fellow and obtained her PhD from the University of Chicago.

Douglas Duncan is an astronomer at the University of Colorado. He earned degrees at Caltech and UC Santa Cruz and was part of the project that first found sunspot cycles on other stars; he then joined the staff of the *Hubble Space Telescope*. In 1992, Duncan accepted a joint appointment at the University of Chicago and the Adler Planetarium, beginning a trend of modernization of planetariums which has spread throughout the U.S. At Colorado, he oversaw the modernization of the Fiske Planetarium into the most technically advanced planetarium in the U.S. Duncan is the author of "Clickers in the Classroom," a guide to the powerful technology that enables teachers to know what all of their students are thinking, not just the ones that raise their hands. He has served as the National Education Coordinator for the American Astronomical Society, and in 2011, received the prestigious Richard Emmons award presented to the "Outstanding University Astronomy Teacher in the U.S."

Patrick Durrell is a Distinguished Professor of Physics & Astronomy at Youngstown State University and is the Director of the Ward Beecher Planetarium. He has been teaching introductory astronomy classes for over 20 years and has long been interested in integrating his teaching and the latest advances in planetarium technology.

Julie Feldt was the Citizen Science Education Specialist within the Zooniverse team at the Adler Planetarium from 2013 to 2017. She wrote the Planet Hunters educators

guide and assisted in the development of the classroom.zooniverse.org Galaxy Zoo curriculum. Julie currently works as the Membership Coordinator and part of the guest services team at the Mid-Hudson Children's Museum in Poughkeepsie, NY.

Rica Sirbaugh French is a Professor of Astronomy and Physics and directs the Astronomy Program at MiraCosta College. She spent years researching star clusters and planetary nebulae before realizing she preferred other targets: non-science majors and their instructors. With collaborators at the Center for Astronomy Education (CAE) she is part of the nation's largest college-level astronomy education research initiative and facilitates professional development experiences for educators nationwide. She has served on the AAS Education Committee, the board of the North County Higher Education Alliance, managed a professional development program for the California Community Colleges Chancellor's Office, and maintains resources for faculty at https://tiny.cc/rfrenchfacultyshare.

Erin Galyen is an Associate Professor of Practice in the Office of Instruction and Assessment at the University of Arizona in Tucson. She earned an MS in Astronomy from San Diego State University and a PhD in Teaching and Teacher Education from the University of Arizona. She has taught introductory astronomy lecture and laboratory-style classes at various two- and four-year colleges. Erin currently supports graduate students and faculty in learning about and implementing evidence-based teaching approaches and coordinates a Certificate in College Teaching program. Erin's academic interests focus on learner-centered education, the scholarship of teaching and learning, academic development, and future faculty preparation.

Adrienne Gauthier is a learning designer at Dartmouth College. She collaborates with STEM faculty through course design projects that focus heavily on learner-centered strategies. Other projects include managing the undergraduate Learning Fellows Program, designing MOOCs, and investigating new educational technologies. Previously, she worked as an instructional technologist and astronomy educator in the Department of Astronomy at the University of Arizona, working with faculty and other astronomy community professionals to innovate with technology-enhanced learning. These included student creative projects and IYA 2009 in Second Life, co-designing online and hybrid astronomy courses, collaborating on the Astronomy Visualization Metadata standard, and managing open online astronomy resources like Astropedia, now known as TeachAstronomy.com.

Alyssa Goodman is the Robert Wheeler Willson Professor of Applied Astronomy at Harvard University, co-Director for Science at the Radcliffe Institute for Advanced Study, and a Research Associate of the Smithsonian Institution. Goodman's research focuses on new ways to visualize and analyze the tremendous data volumes created by large and/or diverse astronomical surveys, and on improving our understanding of the structure of the Milky Way Galaxy. She works closely with colleagues at the American Astronomical Society, helping to expand the use of the

WorldWide Telescope program, in both research and in education. Goodman was awarded the Newton Lacy Pierce Prize from the American Astronomical Society in 1997, was named a Fellow of the American Association for the Advancement of Science in 2009, and chosen as Scientist of the Year by the Harvard Foundation in 2015.

Harry Houghton is an education researcher and technology specialist with the WorldWide Telescope Ambassadors program and with the Science Education Department at the Center for Astrophysics | Harvard & Smithsonian. His specialization is in the proper implementation of technology resources in K–12 curricula. He began using WWT as part of the ThinkSpace research project, for which he created media resources, based on the WWT platform, for the Seasons and Moon Phases curricula.

Erin Johnson was previously Program Facilitator for the WorldWide Telescope Ambassadors Program, where she helped cultivate relationships with partner teachers and schools, and participated in development of WWT-based curricula. Erin's experience in special education provides a lens for critically engaging students with various learning styles. She is now Program Manager for Harvard University's Public School Partnerships team.

Edwin Ladd is a Professor of Physics and Astronomy at Bucknell University in Lewisburg, PA. The recipient of the Bogar Award for Excellence in Teaching in the Natural Sciences, Ladd has over 20 years experience teaching experiential lab-based Astro101-type courses to undergraduate students. He led the development of WWT activities designed for introductory astronomy labs, with support from the National Science Foundation.

Kevin Lee is a Research Associate Professor at the University of Nebraska–Lincoln (UNL). His appointment is shared by an academic department where his duties focus on instruction and an educational center where he works on curriculum development, outreach, teacher training, and technology support. He oversees the Astronomy Education at the University of Nebraska website at http://astro.unl.edu, which houses computer simulations, a library of dynamic peer instruction questions, a suite of interactive ranking and sorting tasks, and a growing library of astronomy demonstration videos available on YouTube. The simulations have been used globally by astronomy faculty for more than 10 years. He has recently returned to UNL after a three-year stint as a rotating program officer in the National Science Foundation's Division of Undergraduate Education.

John Keller is a PI for RECON along with Marc Buie. Keller is the Director of the Fiske Planetarium and a planetary scientist with research interests in astronomy education and teacher preparation. Previously, he was co-Director for the Center for Engineering, Science, and Mathematics Education (CESAME) at California Polytechnic State University in San Luis Obispo, and Executive Director for the

STEM Teacher and Researcher (STAR) Program, which provides paid summer research experiences at national labs for aspiring science and math teachers.

Steve Kortenkamp is an astronomer at the University of Arizona and teaches astronomy courses in the Flandrau Planetarium. He develops custom computer animations allowing teachers and students to more easily visualize science concepts. Currently, he is working to adapt his techniques to include 3D-printed resources for students who are blind or visually impaired. Kortenkamp is also an accomplished children's author. His most recent book, *Exploring Mars*, was written in an interactive Choose Your Own Adventure style and is available as an audio book.

Bethany Cobb Kung is an Associate Professor of Honors and Physics at the George Washington University (GW). She graduated from Williams College in 2002 and received her PhD in astronomy at Yale University in 2008 for research on massive stellar explosions called gamma-ray bursts. From 2008 to 2010, she did research at the University of California, Berkeley as a National Science Foundation Astronomy & Astrophysics Postdoctoral Fellow. As a dedicated educator at GW, she specializes in teaching astronomy and physics to non-science-majoring students and was awarded the 2016 Morton A. Bender Teaching Award. More broadly, she works across many fronts to support great teaching at GW.

Karen Masters is a professor at Haverford College and astronomer/astrophysicist researching galaxies in the universe. She is the Sloan Digital Sky Survey (SDSS)-IV Spokesperson and the Project Scientist of the Galaxy Zoo citizen science/Zooniverse project. She obtained her PhD in Astronomy from Cornell University, and after a postdoc at Harvard spent ten years working at Portsmouth University (as a postdoc, then faculty), before moving to Haverford as an Associate Professor in 2018 January. As well as her research in extragalactic astronomy, she has previously published research on informal science learning via citizen science projects.

Bryan Méndez is an astronomer and education specialist at UC Berkeley's Space Science Laboratory. Dr. Méndez works to educate and inspire others about the wonder and beauty of the universe. He develops programs for the public through the web and museums; develops educational resources for students, teachers, and the public; conducts professional development for science educators; and teaches courses in astronomy and physics at UC Berkeley and local community colleges.

Kate Meredith has more than 25 years of teaching and curriculum development experience in both formal and informal education. She has engaged in curriculum development and project management for the Zooniverse, the Sloan Digital Sky Survey, the Lawrence Hall of Science, the Adler Planetarium Space and Science Museum, and the University of Chicago Yerkes Observatory.

Thomas Nelson is the Director of External Relations at City of Asylum, a literary nonprofit in Pittsburgh, PA, that gives sanctuary to endangered writers from around

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Michelle Nichols is Director of Public Observing at the Adler Planetarium in Chicago, IL. She earned a Bachelor of Science degree in Physics and Astronomy from the University of Illinois at Urbana-Champaign in 1995, and a Master's of Education degree in Curriculum and Instruction from National-Louis University in 2002. Ms. Nichols directs the Adler's Doane Observatory and leads the Adler's various telescope and sky observing efforts, both via on-site programs and outreach to the community.

Stella S. R. Offner is an assistant professor at the University of Texas at Austin. Previously, she was faculty at the University of Massachusetts, Amherst. She first began using WWT for education and outreach as an NSF Astronomy & Astrophysics postdoctoral fellow at the Center for Astrophysics | Harvard & Smithsonian. Dr. Offner's research focuses on understanding how stars like the Sun form. She is the recipient of a Hubble Postdoctoral fellowship, an NSF CAREER Award, and a Cottrell Scholar Award.

Catherine Pilachowski holds the Daniel Kirkwood Chair in Astronomy at Indiana University Bloomington. She incorporates aspects of the RBSE curriculum into her courses for non-science majors to engage students in the excitement of astronomy and to improve student learning.

Julia Plummer, an Associate Professor at Pennsylvania State University, has a combined PhD in Astronomy and Education from the University of Michigan. She has spent more than a decade teaching children and adults in the planetarium and other informal settings. Her research focuses on how embodied cognition and embodied design support spatial thinking in astronomy, as well as the role of informal settings in engaging young children in science practices through astronomy.

Edward E. Prather is a Professor in the Department of Astronomy, at the University of Arizona (UA). Ed is the Executive Director of the Center for Astronomy Education (CAE) at UA. His research focuses on investigating the teaching and learning of topics in STEM. Ed and his collaborators have conducted numerous research studies to uncover students' conceptual, reasoning, and problem-solving difficulties over a wide array of physical science topics taught in astronomy, astrobiology, physics, geoscience, and planetary science. The results from these studies have informed the development of innovative active-learning instructional strategies shown to intellectually engage learners and significantly improve their understandings, problem-solving abilities and self-efficacy related to learning about science. Additional efforts have focused on the development of classroom assessment tools, educational technologies, and public outreach activities. Ed has also led

the development of a variety of education materials in support of several NASA- and NSF-funded science missions. Dissemination of this work has been provided through industry-leading active-learning professional development workshops that have reached thousands of science educators around the world.

Andrew W. Puckett is an Associate Professor of Physics and Astronomy at Columbus State University. He is co-discoverer of more than 40 minor planets in our solar system. Since 2005, he has been designing observing projects in asteroid orbit refinement for students from high school to undergraduate level. Andy also develops software to support such projects, including the Polaris and OrbitMaster programs described in this book.

Travis A. Rector is a Professor of Physics and Astronomy at the University of Alaska Anchorage. For the last 20 years, he has been developing curriculum designed to engage students in authentic research experiences in astronomy. He was a co-developer of the RBSE program at the National Optical Astronomy Observatory.

Philip Rosenfield was a recent director of the WorldWide Telescope program for the American Astronomical Society. Previously, he was an NSF Astronomy and Astrophysics Postdoctoral Fellow at the Center for Astrophysics | Harvard & Smithsonian where he used data from the *Hubble Space Telescope* to constrain, in a fully probabilistic framework, uncertain physics in stellar evolution models. He earned a PhD in Astronomy from the University of Washington. He has taught astronomy, science communication, science teaching pedagogy, and software engineering skills to scientists, and has been deeply involved in inclusion and equity programming.

Philip Sadler is the Director of the Science Education Department at the Center for Astrophysics | Harvard & Smithsonian, and he is Harvard's F.W. Wright Senior Lecturer in Astronomy. In 1977, he invented Starlab, the first practical portable planetarium, now used throughout the world. His current research interests include assessment of students' misconceptions and how they change with instruction, the transition to college of students who wish to pursue STEM careers, and the professional development of science teachers. Dr. Sadler has won the *Journal of Research in Science* Teaching Award, the AIP's Computers in Physics Prize, the American Astronomical Society Education Prize, and the American Association of Physics Teachers' Millikan Medal.

Wayne Schlingman is the director of the Arne Slettebak Planetarium at The Ohio State University. He completed his graduate work at the University of Arizona and then went on to work at the University of Colorado Boulder as a Science Teaching Fellow working with the non-science-major introductory astronomy classes, creating and adapting activities for in-class recitations. While at Colorado, he also worked with the staff and students of the newly remodeled Fiske Planetarium,

encouraging the use of active-engagement learner-centered instructional strategies in public talks. While at OSU, he has continued this work as well as developed partnerships between many disciplinary programs, from Earth science, chemistry, art, music, optometry, and more.

Christine Shupla manages the Lunar and Planetary Institute (LPI) Education and Public Engagement staff, assisting with all of the program efforts. She joined the LPI education team in 2005 October after many years in the planetarium field and has led a variety of its programs, including professional development and materials development for out-of-school-time programmers, librarians, teachers, and informal science educators. She leads LPI's scientist engagement efforts, providing professional development and resources to assist planetary scientists in their efforts to share their science with public audiences. She holds a Bachelor of Arts in Astronomy from the University of Texas in Austin, and a Master of Arts in Curriculum & Instruction from the University of North Carolina at Chapel Hill.

Angela Speck is an astrophysicist who recently left the University of Missouri after 17 years. She was a Professor and the Director of Astronomy, and built the MU astronomy program starting with her arrival at MU. She is now the Chair of the Physics & Astronomy Department at UT-San Antonio, where she is looking forward to combining her passions for science, communication, and social justice work. Dr. Speck's academic career exemplifies the idea that there should be a strong synergy between the research, teaching, and service components for any faculty member. She is originally from Yorkshire (England), has a doctorate in Astronomy from University College London, and was named after the iconic Angela Davis.

Mark SubbaRao, is an astronomer and Director of the Space Visualization Laboratory at the Adler Planetarium and President of the International Planetarium Society. His area of research is cosmology, particularly the large-scale structure of the Universe. He was a builder of the Sloan Digital Sky Survey, which produced a 3D map of over one million galaxies. Dr. SubbaRao utilizes the capabilities of the Adler's immersive theaters in his scientific visualization work.

Susan E. Sunbury is an Educational Researcher in the Science Education Department of the Center for Astrophysics | Harvard & Smithsonian with more than 20 years of experience in the development and facilitation of formal and informal educational programs as well as extensive experience researching and evaluating curriculum projects. Additionally, she taught for seven years in elementary- and middle-school science classrooms and has taught science education courses at three universities.

Laura Trouille is co-PI for Zooniverse and Vice President of Citizen Science at the Adler Planetarium, where she leads the Adler–Zooniverse web development and Teen Programs teams. She is also a Research Associate at Northwestern University. While earning her PhD in Astrophysics, she also earned the Center for the Integration of Research, Teaching and Learning (CIRTL) Delta certificate for

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Patricia Udomprasert is Project Director for the WorldWide Telescope Ambassadors Program at Harvard University. Her interests include science education research on technology in classrooms and development of innovative curricula involving the use of rich 3D visualizations to support spatial thinking and modeling of complex phenomena. She holds a PhD in Astronomy from Caltech and formerly taught high school astronomy, physics, and math.

Nicole P. Vogt is an affiliate professor of astronomy at New Mexico State University. Her General Education Astronomy Resource (GEAS) projects include an adaptive online tutor, laboratory exercises suitable for both traditional and distance learners, and short films highlighting diverse members of underrepresented groups in astronomy. She develops applications for analysis of telescope images and spectra, and leads small-group workshops to support instructor usage.

Colin S. Wallace is a Teaching Assistant Professor in the Department of Physics and Astronomy at the University of North Carolina at Chapel Hill. He earned his PhD in Astrophysical and Planetary Sciences in 2011 from the University of Colorado Boulder. Before coming to UNC-Chapel Hill, he did a three-year postdoc at the Center for Astronomy Education (CAE) at the University of Arizona. His scholarly work focuses on astronomy and physics education research.

Matthew Wenger is an education program manager at Steward Observatory at the University of Arizona. He develops and teaches online astronomy classes and conducts research on student learning in different astronomy courses. His research interests also include free-choice and informal learning contexts. He previously was an educator for informal programs at the Adler Planetarium and a graduate associate at the Flandrau Planetarium and Science Center at the University of Arizona.

Michelle M. Wooten is a postdoctoral scholar in physics education at Michigan State University. In addition to studying the impact of curricular interventions in secondary and postsecondary science learning contexts, Michelle studies methodological approaches used toward the study of science learning, including their historical formulations and effects.

Curtis Wong retired from a 35 year career at the intersection of media, arts, technology, public broadcasting, astronomy, and education to eventually build the WorldWide Telescope with Jonathan Fay at Microsoft. His collaboration with PBS produced innovative programs that redefined the nature of television and have been recognized with awards, including the British Academy Award, Emmy, and Webby

nominations for innovative programs. He currently works with some of the top Leonardo da Vinci scholars around the world to build a translation device to allow everyone to understand Leonardo da Vinci's notebooks such as the Codex Leicester.

Erika Wright is an Education Specialist in the Science Education Department at the Center for Astrophysics | Harvard & Smithsonian. With a Master's Degree in Museum Education and nearly 10 years of experience in museums and informal learning institutions, including the Smithsonian's National Museum of Natural History and NASA's Goddard Visitor Center, she focuses on broadening access to the STEM community through informal learning opportunities. At the Center for Astrophysics, she contributes to NASA- and NSF-funded curricula and programming centered around the MicroObservatory Robotic Telescopes and WorldWide Telescope, as well as social media and science communication efforts for NASA's TEMPO Mission.