Astronomy Education, Volume 1

Evidence-based instruction for introductory courses

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Chris Impey and Sanlyn Buxner
University of Arizona, Tucson, AZ 85721, USA

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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 the world. Before leaving academia, he worked most recently as a Research Assistant Professor at the University of Pittsburgh, where his research focused on observational studies of nova explosions and the development of teaching materials for introductory astronomy classes.

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

STEM education research. As a Northwestern University CIERA Postdoctoral Fellow, she continued her supermassive black hole research as well as helped lead the Computational Thinking in STEM project, bringing computational thinking and modeling curricular materials to high school science and math teachers.

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.

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Chapter 1

Learner-Centered Teaching in Astronomy

Erik Brogt and Erin Galyen

In this chapter, we discuss learner-centered teaching from various perspectives. We start with some background on what learner-centered teaching is, how it is related to the educational and psychological theories on how humans learn, and how we need to take students' knowledge, attitudes, and beliefs into account to optimize student learning. Following this, we discuss how we can use learner-centered teaching as a means to promote inclusivity in the classroom and to motivate students to engage with the course. We then talk about how to implement learner-centered teaching (and avoid the most common pitfalls), using backward-design principles, at the course level, before moving to a broader discussion of implementing learner-centered teaching at the department level. We finish the chapter by discussing some of the frequently asked questions about learner-centered teaching.

Chapter Objectives

By the end of this chapter, readers will be able to

1. describe the educational approach known as learner-centered teaching,
2. describe the rationale for using learner-centered teaching in astronomy classes,
3. give examples of ways to implement learner-centered teaching in astronomy classes and programs, and
4. discuss commonly asked questions about and objections to the implementation of learner-centered teaching in astronomy.

1.1 Introduction

Learner-centered teaching (LCT; sometimes used alongside "student-centered," "evidence-based," "reformed," or "scientific" teaching) is a commonly used phrase in the educational literature and likewise in the astronomy education community. It is often compared and contrasted with the teacher-centered (sometimes called "traditional" or lecture-based) approach. As research-informed teachers wanting

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to do right by our students, LCT is grounded in theories on how humans learn and has a strong foundation in research, with LCT-based instruction showing significant increases in student engagement and learning (e.g., National Research Council 2000, 2012; Kober 2015; National Academies of Sciences, Engineering, and Medicine 2018). This approach has been validated not only in college courses in general, but also in teaching astronomy specifically (National Research Council 2012; Kober 2015). Teaching is often discussed using specific methods (e.g., active learning) or strategies (e.g., think–pair–share, group work, lecture tutorials). While these are important to the conversation about astronomy education, this chapter focuses on LCT as an evidence-based approach or paradigm of teaching.

Similar to the geocentric and heliocentric paradigms of the universe, which shaped everything from conversations among scientists to practical data collection and analysis (Kuhn 2012), the LCT paradigm or approach guides thinking about teaching, as well as specific teaching practices and how they are used. This provides the framework for the active-learning and student-engagement techniques described elsewhere in this book, which are must-have tools in our teaching arsenal. Many faculty are actually already using an LCT approach, even if they may not be familiar with the education jargon. In the first part of this chapter, we will discuss LCT as an evidence-based approach to teaching, its basis in research on human learning, how it compares with other evidence-based teaching approaches prevalent in 21st century higher education, and its benefits and drawbacks. We will then focus on ways to implement LCT in classes, be that your own course, a larger program of study, or an entire department, using a complementary course design method—backward design—as a learner-centered planning framework. We finish the chapter by answering some of the most frequently asked questions about LCT.

1.2 What Is Learner-centered Teaching?

If you answered *yes* to any of the questions in Table 1.1, then you are already using a learner-centered astronomy teaching approach to some extent (National Research Council 2012; Kober 2015; Blumberg 2016). What distinguishes LCT and makes it more effective than previous teaching approaches is what lies at its center, i.e., learners and their learning. Kober (2015, p. 95) notes that "student-centered approaches place less emphasis on the instructor transmitting factual information

Table 1.1. Reflection on Teaching Practices

Have you ever…
• taken into account the needs and prior knowledge of your particular students when planning courses or lessons?
• chosen your teaching methods based on specific learning goals, objectives, or outcomes that students should learn, including both astronomy knowledge and skills (e.g., data analysis, observational skills, critical thinking)?
• had students learn through engaging activities or exercises—in person, online, or for an assignment?
• used assessments of students' learning to adjust your teaching to better help them learn?

by lecturing and more emphasis on students building their own understanding with careful structuring and guidance from the instructor." Biggs & Tang (2007) discuss three "levels" of teaching: a focus on what students are (good, bad, smart, etc.), what teachers do, and what students do. LCT sits squarely in the third category.

In this model of teaching, the instructor serves multiple roles, not only as content expert, but also as course designer and facilitator, who works to create rich learning experiences within which "students are expected to be actively and cognitively engaged" (Kober 2015, p. 95). Other aspects of this approach that distinguish it from the teacher-centered approach are changes to the focus of the course and lesson planning, the varied roles of assessments, and the distinct purposes of learning opportunities (Weimer 2013; Kober 2015). Table 1.2 compares teacher-centered and learner-centered approaches on these various dimensions.

1.3 How Humans Learn: The Rationale for LCT

We know more about how humans learn now than at any other time in human history. In this section, we offer a very short primer into human learning. This empirical research forms the foundations of LCT and informs how it can effectively be applied in teaching astronomy.

Table 1.2. Comparison of Teacher-centered and Learner-centered Approaches

Dimension	Teacher-centered approach	Learner-centered approach
The teacher is focused on:	What the teacher teaches	What and how students need to learn
The role of the teacher is:	Expert, knowledge disseminator	Facilitator, discussion leader, the person who asks the gnarly questions, tour guide
Courses/lessons are planned to:	Deliver/Cover topics and concepts	Achieve learning outcomes (e.g., what students need to be able to do)
Assessments are intended to:	Test what learners know in order to assign grades (assessment *of* learning)	Support learning in progress and demonstrate to what extent the learning objectives were met (assessment *for/as* learning)
Assessment takes place:	At the end of a chapter, section of content, or end of course (summative assessment)	Throughout the learning process (formative and summative assessment)
Learning opportunities are designed to:	Reinforce concepts, replicate methods of the discipline, verify existing knowledge	Master concepts, apply methods of the discipline, guide exploration and inquiry, develop higher-order thinking skills (e.g., scientific and quantitative reasoning, communication, critical and creative thinking, collaboration)

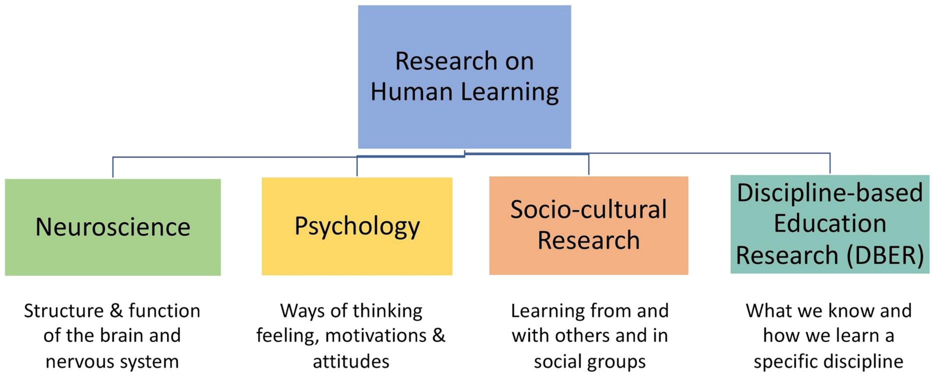

Figure 1.1. Domains informing research on human learning.

Research on human learning that informs learner-centered astronomy teaching draws from four main areas (Figure 1.1).

While highly simplified, this serves as a general overview of results from these areas of study that relate to astronomy teaching. Neuroscience research is relevant as it encompasses the physical architecture for how we detect, process, and store sensory input in and retrieve memories from neuronal networks. Psychology and cognitive science have emphasized how we think about thinking and learning, including the role our motivations, attitudes, and emotions play, which affect students' thought processes and mediate both learning and memory. Sociocultural research not only incorporates how we learn from and with other humans, including how we learn from peers, but also encompasses the role that cultural norms, social institutions, and identities play in our learning, especially among marginalized groups. Discipline-based Education Research (or DBER) offers specific results from investigations into learning concepts or skills in a discipline, such as student understandings of the cause of the seasons, stellar evolution, or quantitative reasoning (National Research Council 2000, 2012; Kober 2015; National Academies of Sciences, Engineering, and Medicine 2018). What we now know is:

> Learning is a process of actively constructing knowledge. Learning is not simply the accrual of information; rather, it involves a process of conceptual reorganization. The brain actively seeks to make sense of new knowledge by connecting it with prior knowledge and experience. Through this process, the learner "constructs" new understanding and meaning (Kober 2015, p. 57).

This learning theory is known as "constructivism." Neurologically, neurons build networks and in so doing encode and "store" everything we think, feel, and remember, such as sensory information, ideas, beliefs, attitudes, emotions, and other experiences. This means that each individual has a highly individualized set of mental models (or schemas), beliefs, and attitudes based on their prior experience and thinking that they bring into any situation. We also now understand "memory involves reconstruction rather than retrieval of exact copies" (National Academies of Sciences, Engineering, and Medicine 2018, p. 4). In other words, human memory is less like a computer that can be simply overwritten, and more like a building that is constructed and remodeled over time (National Research Council 2000).

Other key research findings from the fields of study mentioned above have informed the shift in teaching to an LCT focus on learners and learning:

1. "Each learner develops a unique array of knowledge….as they navigate through social, cognitive, and physical contexts…. A person's brain will develop differently depending on her experiences, interpretations, needs, culture, and thought patterns" (National Academies of Sciences, Engineering, and Medicine 2018, pp. 2–3, 59).
2. "Decisions about how to teach should be based in large part on goals for what students should learn. These outcomes address the specific knowledge and skills, as well as the more general habits of mind and professional conduct, that students are expected to learn" (Kober 2015, p. 90).
3. "Interactions with others can promote learning. The evidence is very strong that collaborative activities enhance the effectiveness of student-centered learning over traditional instruction and improve retention of content knowledge. When students work together on well-designed learning activities, they can help each other solve problems by building on each other's knowledge, asking each other questions, and suggesting ideas that an individual working alone might not have considered" (Kober 2015, p. 62).
4. "Educational assessment does not exist in isolation, but must be aligned with curriculum and instruction if it is to support learning" (National Research Council 2001, p. 3). "Student-centered approaches to teaching and learning call for different methods of assessment. In a student-centered undergraduate class, many of the learning activities themselves are a form of assessment that provide instructors with richer information about students' understanding than they could obtain from traditional assessments" (Kober 2015, p. 122).

You may recognize these four key findings as the same themes from the "Have you ever…" questions in Table 1.1.

Learning, especially when dealing with mental models that people have held for a long time, can be as much about deconstruction as it is about construction. Part of the difficulty is that our beliefs, attitudes, and emotions serve to protect important information we may have learned that is key to our survival or sense of identity. When a new experience challenges our current knowledge, to protect the existing structure, we often disbelieve or discount the new idea. This happens most often when the topic is tied to a belief system that defines one's sense of identity, and also includes self-confidence and self-image. When students respond confrontationally about the Big Bang Theory or Evolution by Natural Selection, that is a clear expression of feeling that their identity is threatened. Similarly, when a student cries or becomes angry over an exam or assignment grade, this is an expression that their self-confidence or self-image has been threatened (National Research Council 2001).

Even when students do not experience a psychological "threat" from what they are learning, what we learn is built on top of an imperfect mental model. Depending on how much the mental model differs from the scientific understanding, more or less "reconstruction" may be necessary. For example, students can come into classes with mistaken ideas about the cause of the seasons, moon phases, and other commonly taught topics in our courses. If that is the case, then much more work is required to re-construct a more accurate model, a process called "conceptual change" (Posner et al. 1982). This is often accomplished by creating experiences where students are able to engage with and think through believable evidence that counters their existing model (also called "cognitive conflict" or "cognitive dissonance") in a way that does not threaten their beliefs or sense of identity. Therefore, knowing, planning, teaching, and assessing learning with students' knowledge, skills, and attitudes in mind is crucial for effective learning.

While beliefs and attitudes can stymie learning, they can also have a positive influence, serving to support or accelerate the "construction" process. Motivation, interest, and excitement about a topic can help students not only focus attention for longer periods of time, but also help improve characteristics such as determination, persistence, and learning in general (e.g., Pintrich 2003; Lazowski & Hulleman 2016). Table 1.3 below has several strategies for supporting students' motivation.

Other ways of generating interest include asking students about their interests and then incorporating these topics into a course, as well as expressing your own enthusiasm for astronomy in general, as well as particular topics. Capitalizing on curiosity by encouraging and answering students' questions, or creating opportunities for students to pursue and answer their own questions through inquiry-based learning is another way to engage motivation and interest. Relating topics to real-world examples or issues that students care about, incorporating gamified learning (e.g., games, competitions, simulations, role plays), and using creative or service-based projects can also harness students' prior knowledge, skills, and attitudes to help them learn in the present (e.g., Clark et al. 2016). Another powerful boon to learning is helping students find value in what they are learning and how it might help them in their future work or life (more on how LCT can serve as a motivational tool later in this chapter).

Table 1.3. Ways to Support Students' Motivation

A few ways of supporting learners' motivation:
- Helping students to set desired learning goals and appropriately challenging goals,
- Creating learning experiences that students value,
- Supporting students' sense of autonomy,
- Helping students to recognize, monitor, and strategize about their learning progress, and
- "Creating an emotionally supportive and nonthreatening learning environment where learners feel safe and valued" (National Academies of Sciences, Engineering, and Medicine 2018, p. 6)

1.4 Knowing, Engaging, and Assessing Students

As discussed in the previous section, each individual constructs their own knowledge, beliefs, and attitudes based on their experiences. How then can LCT help students learn in astronomy courses? Fundamentally, LCT is about *knowing, engaging, and effectively assessing students*. Because engaging students' individuality is key to what they will learn, it is crucial to get to know students as individuals. However, there are general characteristics in any group of people that can be assumed. For example, there always will be disparate levels of interest, knowledge, and skill levels. Some individuals will be highly motivated, while others will be more passive and uninterested. Some may come into a course very knowledgeable about the topic or with advanced study skills, while others may struggle with learning challenges or have divided priorities that can interfere with focus or time for study (e.g., part- or full-time jobs, parenting or other caregiving responsibilities). In addition, students' own views about themselves relative to learning astronomy (or learning in general) affect their willingness to engage. Helping empower students "by providing them with opportunities to have some control over their learning" (Osborne & Jones 2011, p. 144), such as making choices about projects or assignments, can help support more learning-centered views about themselves (Weimer 2013). Similarly, asking students to reflect on or articulate how what they are learning is relevant or of value to them can also help break them out of their own negative mindset about a particular subject or topic; this is often heard when students say things like, "I'm just not a science person" or "I can't do math" (Osborne & Jones 2011).

Another common first step in getting to know students, for example, is by asking them to complete a start-of-term or start-of-topic survey, quiz, or exam. This can provide valuable information on students' knowledge, skills, attitudes, and other attributes, which can be useful "data" for tailoring your planning and instruction for specific groups or individual students. It can also serve as a pre-assessment, which could be matched with a similar survey, quiz, or exam as a post-assessment following teaching to compare what students have learned. The survey could include not only tests of astronomy knowledge, but attitudes and interests in specific topics, particular skills they bring to the class, or challenges they face. As will be discussed later in this chapter, another important attribute of LCT is the planning of clear instructional objectives or outcomes, which combined with the knowledge of the learners, forms the basis for the planning of the curriculum, teaching practices, and assessment (Angelo & Cross 1993; Weimer 2013). A number of validated astronomy content tests and concept inventories exist, which can be used to measure students' learning of astronomy in general and in key areas, such as the cause of Moon phases, light and spectroscopy, and stellar evolution (see Bailey 2011 for a review). In taking a scholarly approach to measuring learning, whether through a quiz, exam, laboratory report, research, observation project, or something else, "a fair assessment is one that yields comparably valid inferences from person to person and group to group" (National Research Council 2001, p. 176). We will expound on this idea later in the chapter.

As revealed by the scholarship on teaching and learning, humans learn better through active engagement. In a class setting, this means "learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work" (Freeman et al. 2014, pp. 8413–8414). These results have been rigorously tested across disciplines, including astronomy (e.g., Prather et al. 2009) and for science majors and non-majors alike (e.g., Springer et al. 1999; Freeman et al. 2014; Kober 2015). As specific examples of active learning in astronomy teaching are discussed throughout the rest of this book, we will not reiterate them here, but there are many astronomy-specific active-learning tools that have been developed and are ready to use, either by individual students, pairs, or small groups.

In a general sense, how might you determine if your course or specific teaching practices are learner-centered? There are a number of useful tools that, while not astronomy specific, are very useful for planning and assessing your class. On the course level, Palmer et al. (2014) have developed a rubric for assessing the extent to which a syllabus reflects a learner-centered course. As for assessing particular lessons, a number of validated observation protocols exist for examining the use of a learner-centered (or evidence-based) teaching approach in face-to-face undergraduate courses. While not exhaustive, three that were developed with science courses in mind include the Reform Teaching Observation Protocol (RTOP; Piburn & Sawada 2000), Teaching Dimensions Observation Protocol (TDOP; Hora et al. 2013), and the Classroom Observation Protocol for Undergraduate STEM (COPUS; Smith et al. 2013). For assessing online courses, the most commonly used tool in higher education is the membership-based Quality Matters Rubric, which has been adopted by over 850 colleges and universities in the U.S., the standards of which are "based on best practices that are well established in online education" (Legon 2015).

1.5 Learner-centered Teaching, Universal Design for Learning, and Inclusive Excellence

Education has seen the simultaneous rise of several models of teaching that share much of the same research foundations and similar goals, i.e., to optimize learning by accounting for students' needs, and tailoring courses and learning environments accordingly. The three most common models used in higher education are LCT, Universal Design for Learning (UDL), and Inclusive Excellence. While each of these other models could also encompass their own chapter, we will describe them briefly here and discuss how they can be used in coordination with LCT.

1.5.1 Universal Design for Learning

UDL originated in the 1990s to address the needs of students with disabilities who encountered barriers to learning in school and the possibilities that developments in technology offered to remove at least some of these barriers. Similar to the shift in focus from teachers to learners in LCT, UDL applied results of neuroscientific and education research, especially disability studies, as well as the movement toward barrier-free design in the field of architecture, to "shif[t] the focus from 'fixing' kids to fixing the curriculum" and "to design learning environments that from the outset offered options for diverse learner needs" (Meyer et al. 2014, p. 5). The term "Universal Design" in fact originated in the field of architecture (Story et al. 1998). The UDL guidelines (CAST 2018) expand on LCT's commitment to consider students' individual characteristics when planning, instructing, and assessing learning by offering a variety of means and options for *student engagement* (e.g., "provide tasks that allow for active participation, exploration and experimentation"), *representations of knowledge* (e.g., "offer ways of customizing the display of information"), and *means of expression* (e.g., "solve problems using a variety of strategies"). Many of these principles have been incorporated into the architectural design of individual institutions and into multimedia and other instructional technologies, such as built-in ramps in physical classrooms, websites that are compatible with screen readers for visually impaired students, or online videos that are closed captioned. This makes it much easier for individual instructors to reduce learning barriers for all students.

1.5.2 Inclusive Excellence

Similar to LCT and UDL, Inclusive Excellence (sometimes used alongside Diversity and Inclusion, and/or Equity) shares the goal of optimizing learning for all (e.g., Williams et al. 2005; American Association of Colleges and Universities 2015). This model originates in sociocultural research, including sociology, social psychology, anthropology, and cultural and gender studies. The aim of inclusive excellence is to advance culturally-responsive teaching (Gay 2000) in order to reduce bias, prejudice, and oppression, which serve as barriers to learning, to reduce achievement (and opportunity) gaps between student groups, and to reduce underrepresentation in specific majors and professions, especially in STEM fields (Considine et al. 2017). One of the central tenets of Inclusive Excellence or culturally responsive pedagogy is

> that teachers need to incorporate the experiences and perspectives of students…being responsive to diverse racial, ethnic, language, and social class backgrounds in designing curriculum, learning activities, classroom climate, instructional materials, teaching strategies, and assessment procedures" (Gay 2000 as cited in Considine et al. 2017, p. 173).

In astronomy classes, this can mean small gestures, such as learning and using students' names, inviting students to share and use appropriate gender pronouns and reducing or eliminating microaggressions,[1] as well as larger ones, such as deliberately including historical and current contributions of individuals of diverse genders, cultures, backgrounds, disabilities, etc., and bringing in guest speakers who represent diversity in astronomy and STEM. Another important mechanism for

[1] "[B]rief and commonplace daily verbal, behavioral, or environmental indignities, that communicate hostile, derogatory, or negative racial slights and insults toward people of color of which the perpetrators are often unaware" (Sue et al. 2007, p. 237).

breaking down biases and promoting inclusion is to have students work in diverse groups to achieve success together. Research has also revealed that teacher "behaviors such as eye contact, gesture, movement, smiling, and a relaxed body position" (Considine et al. 2017, p. 177) can all impact learning and motivation, as well as intentions to persist in college. Mentoring and creating opportunities to increase visibility of these issues within a course or department, as well as setting the tone for the learning environment in your course to one in which diversity is not only respected but desired, can also be effective ways to particularly encourage members of underrepresented and marginalized groups (e.g., Ong et al. 2018).

There is another element of culturally responsive pedagogy that extends beyond the classroom. As Astro 101 is so often a terminal science course for students, it is a (last) vehicle to talk about how science, society, and culture interact. We can use astronomy, with its broad popular appeal, to highlight and discuss issues of equity, inclusion, and global citizenship, and the role astronomy and science can play in that effort (e.g., IAU's Office of Astronomy for Development, http://www.astro4dev.org/). Another element of culturally responsive pedagogy deals with curriculum design, in particular around decisions on topics and concepts to include, and how to include them. Culturally responsive pedagogy also means giving voice to astronomers who are not consistently part of the traditional Western narrative, such as contributions from non-Western societies, women in astronomy, and the rich and beautiful indigenous astronomy traditions (e.g., https://www.maoriastronomy.co.nz/; http://www.aboriginalastronomy.com.au/; Cajete 1994; Holbrook et al. 2008; Antonellis 2013). Despite the brief descriptions of these other approaches here, the overlap and complementarity between LCT, UDL, and Inclusive Excellence work in tandem to achieve better learning outcomes for all students. In the next section, we look toward specific aspects of the LCT approach and how they can play out in an astronomy course.

1.6 Learner-centered Teaching as a Motivational Tool

LCT requires students to be more active in their learning. The popular appeal of astronomy, which captures the imagination, makes students on average more likely to want to engage with the materials in the course, giving us an advantage as astronomy teachers when using LCT techniques. It is important to realize that in Astro 101 courses, this higher intrinsic motivation on one hand is usually met with some trepidation on the other hand. In particular, when teaching non-science-major students, we must be aware as teachers that a good fraction of our students will have science and math anxiety (e.g., Tobias 1978; Mallow 1986; Udo et al. 2004), especially around the manipulation of (algebraic) equations. Regardless of its cause, science and math anxiety will consume a certain amount of student mental resource, meaning that there is less mental resource available for the task at hand, and inhibit engagement in certain types of activities, due to fear of (public) failure (e.g., answering direct questions from the instructor). However, while these students may lack self-confidence in their science and math abilities, this does not mean that they are not capable of engaging with mathematical concepts. For example, when comparing brightnesses of stars, one can plug the numbers in the Stefan–Boltzmann equation, or one could use proportional reasoning that shows appropriate conceptual understanding of the material without doing the detailed math (both temperature and size matter, and temperature matters more than size). The approach taken should match the target audience, and both can be considered academically rigorous (Brogt & Draeger 2015). LCT techniques, in particular peer discussions and group work, can also help engage students with math and science anxiety (as well as others) as the power distance between students is much lower than the power distance between teacher and students. In addition, representing the opinion of the group is far less daunting than representing your own individual opinion; in essence, the responsibility is divided by N, with N being the number of people in the group.

In addition, as briefly described earlier, LCT can sometimes be used to increase motivation and self-efficacy (students' beliefs about their capabilities to "produce desired effects by their actions," Bandura 2010), with students who feel less confident in their abilities (see, e.g., Brogt 2009). An example is the use of Socratic dialogue, where the instructor or activity probes students to reason their way through a problem, asking questions to guide their thinking, and asking them to justify their reasoning (see e.g., Brogt 2007a). Oftentimes, students can do quite a bit of the reasoning themselves, and as teachers, we only have to intervene at those places where their thinking goes off the rails. Once they are back on track, they can usually finish their own line of thought. For students who have low math or science self-efficacy, this is a huge motivational booster, as they just did something (solving an astronomy problem) that they were convinced they could not do. In other cases, students can justify their reasoning based on criteria different from those used in science. A classic example would be an exercise where we ask students to classify galaxies without telling them the classification criteria commonly used in the profession. While students will need to come to grips with the classification scheme used in astronomy, in particular if they wish to engage in citizen science projects like Galaxy Zoo (https://www.galaxyzoo.org), having them create, use, and defend their own system can be a powerful way to reach critical thinking and science-as-a-process learning outcomes.

It is also worth noting that LCT more closely mimics the scientific process than traditional lecture. It treats the subject as something to be explored by the students (under the guidance of a teacher), rather than as a more-or-less closed body of knowledge to be transferred. It provides us as teachers with more authentic opportunities to bring (our own) research and research processes into the teaching and the learning environment (teaching–research nexus). This is of course provided that they are discussed at a level appropriate to the course and that the discussion serves a pedagogical purpose (e.g., aimed at motivating students, building rapport by showing your own enthusiasm for the subject, aligned with a particular learning objective, etc.). Bringing in the creativity of research and the sense of wonder we feel for our research into class makes the course material more relatable than when it is presented simply as a body of knowledge. It also provides an opportunity to show how, as professionals in the field, we deal with questions we do not know the answer to, or cases where the knowledge and understanding of a (sub)field is rapidly changing (e.g., the many surprising results in the last two decades and the many questions remaining around exoplanets), and that scientific knowledge is constantly evolving.

1.7 Learner-centered Teaching as a Means to an End: The Importance of Learning Objectives and Backward Design

LCT is not a goal in and of itself. Rather, it is the means to an end: to support and promote better student engagement and student learning. LCT informs the three-step process of constructive alignment (e.g., Biggs & Tang 2007) or backward design, as it is more commonly referred to in the U.S. Constructive alignment starts with the learning objectives, works backwards to assessments, and then the teaching and learning activities. In our work with faculty, we ask three questions:

1. What do the students need to know or be able to do at the end of the course/lecture/lab? [learning objectives]
    a. Bonus question: Are your learning objectives appropriate to your target audience?
2. What question can I ask for which an answer would satisfy me that the student has met that outcome? [assessment]
3. For me to be able to ask that question, what needs to happen in the class? What do I need to do as a teacher, and what do students need to do? [teaching and learning activities]

Activities only make sense if they are linked to the learning objectives of the course. Unless they serve a clearly identified pedagogical purpose, they are likely to fall flat as students (and faculty) do not really know why they are doing them. Formulating good intended learning outcomes is not as easy as many people think it is. In our experience, a first attempt often results in something like "students should understand," followed by a laundry list of topic and concepts. It is important to look at the target audience and the course in its relation to the program of study (mandatory, elective, general education, etc.). Using SMART (Specific, Measurable, Achievable, Relevant, Time-bound) strategies and taxonomies such as Bloom's (Bloom et al. 1956; Anderson & Krathwohl 2001) can help create intended learning outcomes that are realistic, achievable, and measurable. Backward design is discussed in further detail in Chapter 2.

1.8 Setting up Learner-centered Teaching in Your Class

Setting up a learner-centered classroom, online experience, or other learning environment can be a very rewarding experience. However, there are several traps along the route that are best avoided. The most common ones are

- trying to do too much at once,
- not getting student buy-in, and
- not getting teaching team buy-in.

1.8.1 Trying to Do Too Much at Once

It can be very tempting, at least at first, to try and start with a clean slate. Throw out the old, and in with the new! This approach works well if you have a lot of time to spare, know exactly what you are doing, and/or have access to considerable teaching support resources. One of us was involved in a project in the past to support one professor who wanted to do a full, radical overhaul of his introductory astronomy course (Brogt 2007b). While it was ultimately quite successful, it required substantial teaching support resources (two teaching assistants/staff developers) during the semester. These resources are not typically available at these levels or sustainable long term. An additional risk with radical overhauls is simply that there are too many free parameters. It will be difficult, if not impossible, to pinpoint causes for success or failure, meaning you may succeed or fail in the implementation without knowing how or why. Consequently, an evolutionary approach to implementing LCT is typically preferred. This will allow you to spread the teaching design over several semesters and make small incremental changes that you can evaluate one by one. Another advantage is that you get more accustomed to the LCT approach, so it becomes part of your repertoire of routine teaching, meaning that you will be less dependent on external support for your teaching (e.g., staff developers), and that there is a higher likelihood of self-sustained teaching change.

A similar argument can be made for implementing many (highly) technological and multimedia innovations in class. For those of us who remember the introduction of PowerPoint in the 1990s and the tendency among presentation makers to use every single bell and whistle available, just because something is possible does not mean it is necessarily a good idea. As a rule of thumb, all activities in class should serve a clear pedagogical purpose. As staff developers, we often ask our colleagues to explain “why this particular activity, in this format, at this place and time in the lecture/course?” LCT can be, but does not have to be, high tech. It simply depends on the goals you are trying to achieve.

1.8.2 Not Getting Student Buy-in

Students come to our classes, in particular in their first year, with a certain set of expectations on how courses should be run that may or may not conform to the reality of how the courses are actually run. Students’ expectations naturally are based on their previous experiences in education. LCT requires students to do more in class than passively sitting and absorbing information for later regurgitation (commonly referred to as the “hidden contract”; see e.g., Slater 2003). However, this is precisely the teaching mode that students (a) are most familiar with and (b) have been successful in (or they would not be at college). Students will be (understandably) reluctant to engage in teaching and learning activities that are unfamiliar to them in the sense that it may not be clear how those activities will lead to a successful outcome (e.g., passing the course, getting a high grade).

For LCT to get buy-in from students, encourage them to engage, and change their behavior, two things need to be in place:

1. A clear research-based rationale for what you are doing. It has to be clear to students that the learner-centered approach used in the class is there for a purpose, namely to help them understand the material better and help them succeed in the course.
2. A clear "path to success." When the students know what it is they need to do to succeed in the class, they will be more likely to engage, rather than spending time and energy trying to figure out the new "rules of the game".

Critical to student buy-in is alignment between teaching and the assessments (the second piece of backward design). We can use all the learner-centered techniques we want and emphasize the importance of conceptual thinking, but if we then turn around and give a declarative knowledge-based assessment, students will (a) quickly see the misalignment between the professed relevance and assessed material, (b) feel rightfully misled, and (c) will not engage in teaching and learning activities that are not clearly advantageous to their performance on the assessment.

1.8.3 Not Getting Teaching Team Buy-in

Team buy-in has two facets to it. The first is the team teaching the course (professors, teaching assistants, lab personnel, learning assistants). It is critical that (at least publicly) all members of the teaching team are on board with LCT and are actively engaged in them in class. If this is not the case, then students can drive wedges between teaching team members, which threatens the overall classroom climate and inhibits achieving the goals for the course. Of particular relevance is the training of teaching assistants and ensuring that they are on board, take it seriously, are trained in the appropriate use of the approach, and act accordingly.

The second facet of the team is the broader department out of which the course is being taught. Being the single course that uses LCT principles is not a problem when you are teaching a non-science-major, non-advancing course. It can become a problem in larger programs of study, where the same students go through a suite of courses in the department. That makes the LCT course the odd one out, with an increased likelihood of student complaints (as it is the only course that requires them to do things differently). This is not an easy situation to solve. Student buy-in can be increased somewhat by using the same two techniques listed above, but you are likely to face increased scrutiny. Ultimately though, student performance in the course should provide good data (assuming appropriate alignment between teaching and assessment, of course) on the validity of the LCT techniques used. For example, in a study replicating the Carl Wieman Science Education Initiative (see www.cwsei.ubc.ca) in the New Zealand educational system, Kennedy et al. (2013) reported about a faculty member who was not himself entirely on board with LCT, but had nonetheless agreed to participate in the study. He ultimately became convinced about the validity of LCT after he had seen the positive impacts on student performance in his class.

1.9 Promoting the Use of Backward Design and Learner-centered Teaching at the Department Level

LCT is at its most powerful when it is done system-wide (e.g., a whole department). To make the strategic shift to department-wide implementation of LCT requires leadership at all levels, from individual teaching staff to the head of department (or even dean). For people in managerial/administrative positions like the head of department, this can be a delicate balancing act between faculty members' individual academic freedom, strategic priorities of the institution (e.g., student retention), resource (time and otherwise) investment and return on investment, and staff workload management. This balancing act is not always that visible to individual teaching staff, but it is good to be aware of these "other variables in the equation" as part of a constructive conversation about LCT at the department level. In the remainder of this section, we opted to address the head of department directly as the person in the department with formal leadership responsibilities. This is not meant to suggest that LCT at the department level is a top-down affair; most successful implementations we have been involved in as faculty developers and those reported in the educational change literature had a bottom-up as well as a top-down component, and were highly collegial in nature.

If you are a head of department, what are the merits and drawbacks of promoting and supporting the use of LCT among your teaching staff and in the courses in your department? We would argue that any department-wide discussion on the use of LCT is more meaningful within a broader (and longer-term) discussion about the department's course offerings and teaching-related objectives. In that way, LCT becomes part of a broader strategic discussion and as a means to an end, rather than an end in and of itself. We think such a discussion is also best held in conjunction with a strategy to promote backward-design principles consistently in a department. Backward design can then be used as a springboard for a discussion about LCT in a department, as devising learning and teaching activities is the final stage in the backward-design process.

1.9.1 Advantage of Backward Design across a Program of Study

Using backward design at the program level can be a very interesting and revealing exercise. More often than not, teaching staff are (understandably) focused on their own courses and do not typically look at what is happening in other courses. This means that over time, curricular overlaps, gaps, and mismatches will naturally develop. From a program cohesion point of view, it is thus advantageous to go through a (verification of the) backward-design exercise for all courses. While this process will take some time to complete, in particular in a program with a high level of student choice through elective courses, tidying up the various loose ends you will typically encounter makes for a stronger program overall, increased student experience, and better student progression/retention in the program. It will also come in handy during departmental visitations, accreditations, and other formal review processes.

1.9.2 Advantages of Backward Design at the Course Level

At the individual course level, promoting backward-design principles have three other advantages for a department. The first is that by an agreed-upon set of outcomes, the student experience in different sections of the same course will be more equitable. The individual sections may still vary based on individual teaching staff member's teaching style and academic freedom, but the outcomes should be about the same when agreed upon by all colleagues teaching the course. The second advantage from a workload and sabbatical/leave management perspective is that backward design, with clear and agreed-upon outcomes, makes portability of a course from one colleague to the next easier. Most of us have been in the situation where we "inherited" a course, with all its materials, and had no clue where to start. The learning objectives for the course will be a guide in that case, making it easier to map individual lectures/tutorials to the course outcomes, and save considerable time and stress. The third advantage is that backward design, and the various aligned teaching and learning activities, makes it easier to identify resource needs and provide a clearer justification for resource expenses (e.g., field trips).

1.9.3 Advantages of Promoting Learner-centered Teaching Techniques across a Program of Study and in Individual Courses

Each department will have its cast of characters, from gung-ho early adopters to skeptics. For LCT to be successful at the department level, it is important that it becomes normalized, i.e., the "this is just the way we work in this department" attitude among the teaching staff, and with no single course being the "odd one out." A single course using LCT is almost always considered the "odd one out," with increased student complaints about the teaching as a result. Once a whole department moves into the direction of LCT, the number of student complaints should get lower (it is the "new normal"), while at the same time seeing increased student performance, student experience, and subsequent retention in the program.

The key to normalizing LCT is to have your best teachers, who are willing and able to use LCT, teach the largest classes, bringing the "new normal" to as many students as possible, creating an expectation for LCT in follow-on courses.

1.9.4 The Head of Department as Role Model and Resource Provider

As the head of department, you have a role model function for your staff, in particular junior staff. It is important to walk the talk yourself and lead by example. Your staff will see what you truly value through your actions. Proclaiming the importance of LCT rings hollow if you are not on the journey yourself. That makes generating buy-in from your staff and colleagues much more difficult. Talking about the importance of LCT and even providing support resources are not as effective as doing that, while also engaging in LCT yourself (and sharing your journey with your colleagues).

Your priorities also come through in where and how you decide to spend the (limited) teaching support resources of the department. While LCT does not have to be resource intensive in itself, the development, the alignment with learning objectives and assessments, and getting comfortable using them take time. While this time is typically (but not always) recouped later through increased efficiencies and reduced teaching preparation time, it does provide a significant up-front investment. Recognizing this and providing workload relief for teaching staff where possible at the development stages of implementing LCT will go quite a way to generating the necessary buy-in and creating (self-initiated and sustained) engagement, rather than (performance-management-driven) compliance behavior.

For staff who have limited teaching experience and/or limited training in teaching (and most academics are hired for their content expertise, rather than their teaching expertise; see, e.g., Walczyk et al. 2007), having access to pedagogical support and other resources is critical. Engaging the equivalent of a teaching and learning center at your institution (if present) would be highly advisable. There is a myriad of resources on LCT available, of varying quality. The teaching and learning center can help you locate the (research-based) resources that would be helpful for your particular context (there are no one-size-fits-all solutions), and advise you on their use.

1.10 Evaluating Learner-centered Teaching

A good implementation of LCT is not complete without a proper evaluation to determine the effects of LCT on various constituents (students, faculty, department, etc.). Depending on the type of intervention you wish to evaluate, a variety of quantitative or qualitative research methodologies can be used. This chapter is not the place to discuss this in detail, though we would caution against relying solely on quantitative and/or statistical data. The methodology and data collection that are appropriate depend on the question you are asking, the size of the constituent populations, and the type of intervention you are evaluating, among other things. In our experience working with faculty, we have seen numerous cases where faculty insisted on using surveys and statistics (because they were reasonably comfortable with those), which when used would have led to invalid or uninterpretable results. We would strongly recommend working with colleagues with a background in educational or social science research design if you have never done this type of work before (for example in the Teaching and Learning Center, if you have one on campus). For a valid evaluation, it is important to not have changed too much in one go, as it will give you too many free parameters to make meaningful causal attributions, as mentioned earlier. Should you wish to go beyond purely internal use of these data for teaching improvement purposes and publicize the results (which is a broader term than publish, and includes conferences, posters, reports, etc.), ethics approval prior to any data collection is required. In particular, when you are investigating classes/students you are responsible for as a teacher, very careful consideration needs to be given to the ethical dimensions of the research design to ensure informed and voluntary consent from the students, and to comply with legal requirements (see, e.g., Antonellis et al. 2012; Brogt et al. 2008, Section 3.3).

1.11 Frequently Asked Questions about Learner-centered Teaching and Its Implementation

In this last section, we list and answer common questions about LCT that we have fielded both as faculty developers and from colleagues teaching astronomy over the years.

1. If I use a LCT approach, do I have to stop lecturing?
2. Doesn't LCT result in the "dumbing down" of content?
3. How can I cover all my material if I use LCT?
4. Will LCT only work for non-majors, or also for majors?
5. Will LCT work with a mathematically based course?
6. My students hate group work; how do I get them to do it?
7. Will LCT work in a large enrollment class?
8. How do I find time to design learner-centered activities?
9. Is LCT academically rigorous?

1. If I use an LCT approach, do I have to stop lecturing?

LCT is about using the appropriate teaching practice in a given context, aimed at optimizing student learning. The literature is clear that students tend to learn better using interactive techniques. That does not mean, though, that there is no place for a "traditional, stand-and-deliver" lecture in courses. In terms of information delivery, the lecture is a perfectly appropriate vehicle. Given the economy of scale and the financial constraints most institutions find themselves in, the lecture is not going to disappear any time soon. The encouragement we give to faculty as faculty developers is to explore ways in which the lecture can be made more interactive, and make informed and conscious decisions on what sort of teaching is most appropriate to achieve the goals for the lecture/class session or course. In our experience, relatively small changes in the lecture format, in particular around question-asking techniques, can have a strong positive impact on the learning environment.

2. Doesn't LCT result in the "dumbing down" of content?

LCT tends to result in higher outcomes in terms of student learning than traditional teacher-centered instruction on a variety of well-validated and standardized diagnostic tests (e.g., Hake 1998). This is in part due to the fact that LCT forces students to process and apply the course material. As such, they are actively developing their own, and more expert-like, mental models of the concepts. LCT can (and should) still be intellectually challenging for students, and it does not mean or imply hand-holding of students.

3. How can I cover all my material if I use LCT?

Learner-centered techniques take more time than traditional lecture-only instruction. However, as we argued in this chapter, LCT is a means to an end within a backward-design framework. The learning objectives are the goal, and the assessments and teaching and learning activities the means by which we endeavor to help students achieve those goals. This is different from a focus on content coverage, which is how a lot of course design is still done today. Just because something is mentioned in a lecture does not imply that it is "taught," nor does it follow that it will then be "learned." As one colleague once questioned in a research talk, "are you really teaching if no one is learning?" If you are teaching the non-science-major, non-advancing courses, it is particularly instructive to review your learning objectives. Content coverage is not necessarily the main objective of such courses. For example, making students aware of how the scientific process works in general (and how that applies to astronomy) or helping students overcome math and science anxiety might be equally relevant goals for such courses (Dokter 2008; Brogt 2009).

4. *Will LCT only work for non-majors, or also for majors?*
   LCT is a means to an end, namely to help students achieve the learning objectives for the course. Research has consistently shown LCT to lead to higher student performance. This is true for non-major students, major students, and graduate students. LCT is based on our understanding of how humans learn, and as such is not dependent on major or stage of learning.

5. *Will LCT work with a mathematically based course?*
   LCT focuses on matching teaching with how humans learn. Consequently, the topic or concepts to be learned do not matter for the overall validity of LCT. LCT approaches have been validated not only in astronomy and science fields, but also in mathematics courses required for physics and astronomy majors (e.g., linear algebra, differential equations).

6. *My students hate group work; how do I get them to do it?*
   Group work is one particular LCT technique. Research has shown that students learn more in (well-functioning) groups (see e.g., Johnson et al. 2014; Dohaney et al. 2012). Most of the issues around group work tend to be around group functionality and perceptions of unfairness (people not pulling their weight), or other issues where students perceive to be not fully in control over the outcomes (grades). While these can be quite serious concerns (in particular for those students who wish to enter limited-entry programs that have GPA targets), at the core those are logistical and implementation issues. There are a number of ways in which those can be addressed, including choice of group members, group collaboration as part of the grade, or peer review of effort. On a very practical level though, students will spend most of their careers working in (interdisciplinary) teams they do not necessarily get to pick, so learning how to navigate group dynamics is a fundamental employability skill.

7. *Will LCT work in a large enrollment class?*
   LCT is not necessarily dependent on class size. Particular teaching techniques may work better or worse in classes of different sizes or may require a slightly different logistical setup, so it is a matter of picking the right techniques for the size of the class. However, the underlying idea of LCT remains. LCT approaches have been validated across a variety of course sizes, up to 250 students and beyond as discussed in other chapters. Most resources on LCT will provide you with some

advice on how to implement it in your class, and what techniques might work well depending on the size and format of your class.

8. How do I find time to design learner-centered activities?

Designing your own activities takes time, expertise, and experience. The question to ask yourself is whether you have the time to invest and the necessary expertise to do it properly to the benefit of your students. There is little point trying to reinvent the wheel, and oftentimes there are perfectly serviceable wheels to be found that can be adapted to your needs.

There are numerous resources available on LCT techniques. The following chapters in this book provide samples of such techniques. Many of those are reasonably "off the shelf," and often come with suggestions on how to implement them in your class. In other cases, a consultation with a faculty developer or instructional designer (usually located in a Teaching and Learning Center) might be a good starting point. In case you do want to design your own, we strongly recommend working with experienced others the first time around. That will help you avoid some of the more common design and implementation problems.

9. Is LCT academically rigorous?

One commonly heard argument against LCT is that it is not as "rigorous" as traditional, content-focused teaching. As one colleague of ours, teaching a course for non-science majors, once mentioned (facetiously): "how can you reach salvation if you don't know about the forbidden oxygen transitions in planetary nebulae?" The question however is what exactly is meant by "rigor." Often in astronomy this appears to be a focus on content (facts and concepts), the use of mathematics, the language of science, and the mathematical relations between concepts. The question is whether such a conceptualization of rigor is appropriate in all circumstances. Brogt & Draeger (2015) used the definition of academic rigor by Draeger et al. (2013), which states that a course can be considered academically rigorous if it involves (a) active engagement, (b) higher-order thinking, (c) meaningful content, and (d) high expectations. They concluded that introductory astronomy classes can be considered rigorous in that sense, provided that expectations, goals, assessments, and curriculum are properly aligned.

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