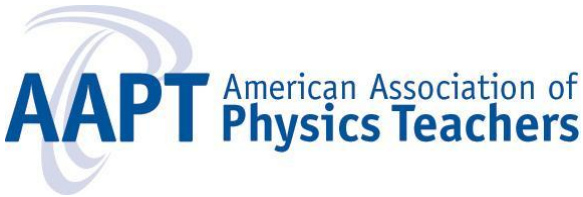
2019 PHYSICS EDUCATION RESEARCH CONFERENCE

Provo, UT, USA July 24 – 25, 2019

EDITORS

Ying Cao
Steven Wolf
Michael Bennett



Editors

Ying Cao
Drury University
School of Education and Child Development
Lay Hall 204
Springfield, MO 65802
USA
E-mail: ycao@dury.edu

Steven Wolf
East Carolina University
Department of Physics
SciTech 508
Greenville, NC 27858
USA
E-mail: wolfs15@ecu.edu

Michael Bennett
University of Colorado – Boulder
Department of Physics
440 UCB,
Boulder, CO 80309
USA
E-mail: michael.bennett@jila.colorado.edu

© 2019 American Association of Physics Teachers and the article authors

Published under the terms of a Creative Commons Attribution 3.0 license:
https://creativecommons.org/licenses/by/3.0/

You are free to:

- Share — copy and redistribute the material in any medium or format
- Adapt — remix, transform, and build upon the material for any purpose, even commercially.

provided you give attribution (include the original article's title, author(s), proceedings citation, and DOI), provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

ISSN (Print): 1539-9028
ISSN (Online): 2377-2379
ISBN: 978-1-931024-36-5

2019 Physics Education Research Conference

Table of Contents

Preface 1

Conference Overview 4

Conference Program 5

Introduction 7

PLENARY PAPERS

Informal STEM education: From personal to professional 9
Jamie Bell

Reflections on informal physics education 15
Shane D. Bergin

PEER REVIEWED PAPERS

Types of explanations students use to explain answers to conceptual physics questions 21
Anne T. Alesandrini and Paula R. L. Heron

Introductory physics students' insights for improving physics culture 26
Acacia Arielle Evans, Kai S. Bretl, Amad Ross, and Abigail R. Daane

Benefits of a student-led astronomy club: lessons to inform instructional design 32
Daniel F. Barringer, Alice R. Olmstead, and Audiel Maldonado

Students' use of conceptual resources for understanding superposition 38
Lauren C. Bauman, Lisa M. Goodhew, and Amy D. Robertson

Improving STEM self-efficacy with a scalable classroom intervention targeting growth mindset and success attribution 44
Ian D. Beatty, Stephanie J. Sedberry, William J. Gerace, Jason E. Strickhouser, Maha A. Elobeid, and Michael J. Kane

What factors influence pedagogical methods in informal learning spaces? 51
Michael B. Bennett, Brett L. Fiedler, and Noah D. Finkelstein

Student-identified themes around computation in high school physics 57
Theodore E. Bott, Daniel P. Weller, Marcos D. Caballero, and Paul W. Irving

Social positioning correlates with consensus building in two contentious large-group meetings 63
David T. Brookes, Brant E. Hinrichs, and Jacob L. Nass

How do previous coding experiences influence undergraduate physics students? 69
Jacqueline N. Bumler, Patti C. Hamerski, Marcos D. Caballero, and Paul W. Irving

Assessing problem-solving in science and engineering programs 75
Eric Burkholder, Argenta M. Price, Michael Flynn, and Carl E. Wieman

Students' conversion from electric field line diagrams to other representations 81
Esmeralda Campos, Genaro Zavala, Kristina Zuza, and Jenaro Guisasola

Emergent explicit group regulation in small group scientific activities 87
Ying Cao, Aikaterini Mari, Pierre-Philippe A. Ouimet, Amreen Nasim Thompson, and Jenay R. Sermon

A comparison study of pre/post-test and retrospective pre-test for measuring faculty attitude change 93
Stephanie V. Chasteen and Rajendra Chattergoon

Evaluating the effectiveness of two methods to improve students' problem solving performance after studying an online tutorial 99
Zhongzhou Chen, Kyle M. Whitcomb, Matthew W. Guthrie, and Chandralekha Singh

Instructors' justifications regarding curricular design: Assumptions about life sciences students and their role in physics courses 105
Mary K. Chessey, Adrian M. Madsen, and Chandra Turpen

Meaning and purpose in the pursuit of physics teaching careers 111
Hunter G. Close

Characterizing active learning environments in physics: network analysis of Peer Instruction classroom using ERGMs 117
Kelley Commeford, Eric Brewe, and Adrienne L. Traxler

Investigating the mechanisms of peer review 123
Robert Dalka and Timothy McKay

Student perspective of GTA strategies to reduce feelings of anxiousness with cold-calling 129
Constance M. Doty, Ashley A. Geraets, Tong Wan, Erin K. H. Saitta, and Jacquelyn J. Chini

All aboard! Challenges and successes in professional development for physics lab TAs 135
Danny Doucette, Russell Clark, and Chandralekha Singh

Preliminary model for student ownership of projects 141
Dimitri R. Dounas-Frazer, Laura Ríos, and H. J. Lewandowski

Do I belong here?: Describing identities of participation and non-participation in a contentious "board" meeting 147
Jared L. Durden and Brant E. Hinrichs

Student reasoning about multivariable covariation in thermodynamics 153
Paul J. Emigh, Reese R. Siegel, Jonathan W. Alfson, and Elizabeth Gire

Coordinating epistemic frames in informal physics: Agency, support, and technology 159
Brett L. Fiedler, Michael B. Bennett, Nicole E. Johnson, and Emily B. Moore

How is students' online learning behavior related to their course outcomes in an introductory physics course? 165
Geoffrey Garrido, Matthew W. Guthrie, and Zhongzhou Chen

Categorizing mathematical sense making and an example of how physics understanding can support mathematical understanding 172
Julian D. Gifford and Noah D. Finkelstein

Strong preference among graduate student teaching assistants for problems that are broken into parts for their students overshadows development of self-reliance in problem-solving 178
Melanie Good, Emily Marshman, Chandralekha Singh, and Edit Yerushalmi

Students' context-sensitive use of two kinds of conceptual resources for mechanical wave reflection 184
Lisa M. Goodhew, Amy D. Robertson, Paula R. L. Heron, and Rachel E. Scherr

Comparing student behavior in mastery and conventional style online physics homework 190
Matthew W. Guthrie and Zhongzhou Chen

Sensemaking in special relativity: developing new intuitions 196
Kelby T. Hahn, Paul J. Emigh, and Elizabeth Gire

Museum-based physics education research through research-practice partnerships (RPPs) 202
Danielle B. Harlow and Ron K. Skinner

Student response to a careers in physics lesson 208
T. Blake Head, Robynne M. Lock, Raina Khatri, Zahra Hazari, and Geoff Potvin

A longitudinal exploration of students' beliefs about experimental physics 214
Rachel Henderson, Kelsey Funkhouser, and Marcos D. Caballero

The effect of similar surface features on students' understanding of the interaction of charges with electric and magnetic fields 220
Eder Hernandez, Esmeralda Campos, Pablo Barniol, and Genaro Zavala

Differences in the predictive power of pretest scores of students underrepresented in physics 226
Dona Sachini Hewagallage, John Stewart, and Rachel Henderson

Changing the notation that represents a force changes how students say it 233
Brant E. Hinrichs and Dayna M. Swanson

Impact of industry experience on faculty teaching practices in STEM 239
Dehui Hu, Benjamin M. Zwickl, and Carmen Carusone

Using cueing from question pairs to engage students in reflective thinking: An exploratory study 245
Joss Ives and Jared B. Stang

Developing an organizational framework for informal physics programs 251
Dena Izadi, Julia Willison, Kathleen A. Hinko, and Claudia Fracchiolla

Hidden walls: STEM course barriers identified by students with disabilities 257
Westley James, Kamryn Lamons, Roberto Spilka, Caroline Bustamante, Erin M. Scanlon, and Jacquelyn J. Chini

Investigating simulation use on student learning outcomes in introductory physics 263
Manher Jariwala, Emily Allen, and Andrew Duffy

Development, validation and in-class evaluation of a sequence of clicker questions on Larmor precession of spin in quantum mechanics 269
Paul Justice, Emily Marshman, and Chandralekha Singh

Investigating the role of prior preparation and self-efficacy on female and male students' introductory physics course achievements 275
Z. Yasemin Kalender, Emily Marshman, Christian D. Schunn, Timothy J. Nokes-Malach, and Chandralekha Singh

Investigating potential influences of graduate teaching assistants on students' sense of belonging in introductory physics labs 282
Caitlin Kepple and Kim Coble

Teaching gravitational potential energy: Student interaction with surface manipulatives 288
Abigail Kimbrough, Paul J. Emigh, Jonathan W. Alfson, and Elizabeth Gire

Using student-generated content to engage students in upper-division quantum mechanics 294
Antje Kohnle

A framework for classifying opportunities to learn in Faculty Online Learning Communities: A preview with sample application 300
Alexandra C. Lau, Adriana Corrales, Fred Goldberg, and Chandra Turpen

On being a physics major: student perceptions of physics difficulties, rewards, and motivations 306
Anna E. Leak, Krystina Williamson, Daryl L. Moore, and Benjamin M. Zwickl

Using custom interactive video prelab activities in a large introductory lab course 312
H. J. Lewandowski, Benjamin Pollard, and Colin G. West

The association between sustained professional development and physics learning 318
William E. Lindsay, Sari Widman, and Matthew Garcia

Impact of the Next GEN PET Curriculum on science identity 324
Robynne M. Lock, Ben Van Dusen, Steven Maier, and Liang Zeng

GFO copywrite: development and testing of written and visual materials for recruiting STEM teachers 330
Savannah L. Logan, Richard L. Pearson III, and Wendy K. Adams

Using Conceptual Blending to model how we interpret computational models 336
Brandon R. Lunk

Magnetism, light, structures, and rotational motion: Mixed-methods study of visitors engaging with four exhibits at a science museum 342
Meghan Macias, Krista Lucas, Jasmine Nation, Erik Arevalo, Jasmine Marckwordt, and Danielle B. Harlow

Transferability and specialization: analyzing STEM students' perspectives of problem-solving 348
Vina Macias, Jacob Poirier, Benjamin M. Zwickl, and Susan Rothwell

User-centered personas for PhysPort 354
Adrian M. Madsen, Sarah B. McKagan, Linda E. Strubbe, Eleanor C. Sayre, Dina Zohrabi Alaee, and Tra Huynh

Analyzing students' reasoning about the inverse-square law through the lens of dual processing theories 360
Daniel B. Marsh and Rabindra R. Bajracharya

Learning goals and perceived irrelevance to major within life science majors in introductory physics 366
Andrew J. Mason

Supporting productive exploration in invention activities: are simulations too challenging? 372
Jonathan Massey-Allard, Ido Roll, and Joss Ives

IPER programs: a narrative framework for program development 378
Michele W. McColgan, Robert J. Colesante, and Lindsay Clark

Framing the Pursuit of a Physics Degree as a Hero's Journey 384
Gabriel R. Mestas and Hunter G. Close

Why it should be 'and' not 'or': Physics and music 390
Claire Mullen, Claudia Fracchiolla, Brean Prefontaine, and Kathleen A. Hinko

Design-based research project to develop a science and engineering education program linking field trip experiences to classroom experiences. 396
Alexandria Muller, Tarah Connolly, Ron K. Skinner, and Danielle B. Harlow

Quantifying the linguistic persistence of high and low performers in an online student forum 402
Carissa Myers, Elizabeth Fox, Adrienne L. Traxler, and Andrew Gavrin

Educational debts incurred by racism and sexism in students' beliefs about physics 408
Jayson M. Nissen and Ben Van Dusen

How is perception of being recognized by others as someone good at physics related to female and male students' physics identities? 415
Timothy J. Nokes-Malach, Z. Yasemin Kalender, Emily Marshman, Christian D. Schunn, and Chandralekha Singh

Characterizing physics students' ethical reasoning after a unit on the development of the atomic bomb 423
Egla Ochoa-Madrid, Alice R. Olmstead, and Brianne Gutmann

Computational Essays: An Avenue for Scientific Creativity in Physics 429
Tor Ole B. Odden and Marcos D. Caballero

Scientific Practices in Minimally Working Programs 435
Dan P. Oleynik and Paul W. Irving

Identifying qualities of physics graduate students valued by faculty 441
Lindsay Owens, Benjamin M. Zwickl, Scott V. Franklin, and Casey W. Miller

Presentation of integrals in introductory physics textbooks 446
Anthony Pina and Michael E. Loverude

Preventive and exploratory: two workplace problem-solving cultures 452
Jacob Poirier, Vina Macias, Benjamin M. Zwickl, and Susan Rothwell

Methodological development of a new coding scheme for an established assessment on measurement uncertainty in laboratory courses 458
Benjamin Pollard, Robert Hobbs, Dimitri R. Dounas-Frazer, and H. J. Lewandowski

A controlled study of virtual reality in first-year magnetostatics 464
C. D. Porter, Jonathon R. Brown, J. R. Smith, Erik M. Stagar, Amber Simmons, Megan Nieberding, Abigail Ayers, and Christopher Orban

Supporting multiple identities in informal spaces: Examining design choice 470
Brean Prefontaine and Kathleen A. Hinko

Contextual details, cognitive demand and kinematic concepts: exploring concepts and characteristics of student-generated problems in a university physics course 476
Javier Pulgar, Alexis Spina, Carlos Ríos, and Danielle B. Harlow

The Access Network: Cultivating Equity and Student Leadership in STEM 482
Gina M. Quan, Brianne Gutmann, Joel C. Corbo, Benjamin Pollard, Chandra Turpen, and Access Network

Who does physics? Understanding the composition of physicists through the lens of women of color and LGBTQ+ women physicists 488
Xandria R. Quichocho, Jessica Conn, Erin M. Schipull, and Eleanor W. Close

Faculty survey on upper-division thermal physics content coverage 494
Katherine D. Rainey and Bethany R. Wilcox

Understanding university students' identity through engagement in informal physics programs 500
Caleb Rispler, Brean Prefontaine, and Kathleen A. Hinko

Impact of ISLE-based labs in courses with traditional lecture 506
Joshua Rutberg, Marina Malysheva, and Eugenia Etkina

Evaluating students' performance on the FCI at a minority serving institution 512
Qing X. Ryan, Darwin Del Agunos, Armando Villasenor, Homeyra R. Sadaghiani, and Alexander Small

Experiences of departmental supports by physics graduate students: results from 20 research-intensive institutions 518
Ntiana (Diana) Sachmpazidi and Charles R. Henderson

Physics instructors' views about supporting learner variation: Modifying the Inclusive Teaching Strategies Inventory 524
Erin M. Scanlon and Jacquelyn J. Chini

Student perceptions of math-physics interactions throughout spins-first quantum mechanics 530
Benjamin P. Schermerhorn, Armando Villasenor, Darwin Del Agunos, Homeyra R. Sadaghiani, Gina Passante, and Steven J. Pollock

"Success Together": Physics departmental practices supporting LGBTQ+ women and women of color 535
Erin M. Schipull, Xandria R. Quichocho, and Eleanor W. Close

Three critical issues that shape and complicate STEM self-efficacy intervention research: Reflections and analysis from an interdisciplinary research team 541
Stephanie J. Sedberry, Ian D. Beatty, William J. Gerace, Maha A. Elobeid, and Jason E. Strickhouser

Hidden value: Investigating the physics demonstration as aesthetic experience 548
Sydney Seese, Megan Halpern, and Kathleen A. Hinko

Context of authority may affect students' evaluations of measurement 554
Emily M. Smith, Nicole Chodkowski, and Natasha G. Holmes

Using psychometric tools as a window into students' quantitative reasoning in introductory physics 560
Trevor I. Smith, Philip Eaton, Suzanne White Brahmia, Alexis Olsho, Andrew Boudreaux, Chris DePalma, Victor LaSasso, Christopher Whitener, and Scott Straguzzi

The Ratio Table: a tool for understanding ratios 567
Philip Southey

Student interpretations of uncertainty in classical and quantum mechanics experiments 573
Martin M. Stein, Courtney White, Gina Passante, and Natasha G. Holmes

Visualizing student engagement with simulations: a dashboard to characterize and differentiate instructional approaches 579
Diana Berenice López-Tavares, Michael Kauzmann, and Katherine K. Perkins

Criteria for collapsing rating scale responses: A case study of the CLASS 585
Ben Van Dusen and Jayson M. Nissen

Perceived effect on buoyancy of weight vs. gravitational force 591
Doris J. Wagner and Samuel Harryman

Assessing the assessment: Mutual information between response choices and factor scores 597
Cole Walsh and Natasha G. Holmes

Tracking student engagement with open educational resources (OER) and online homework 603
Kenneth C. Walsh, Michael Dumelle, and Katy Williams

Characterizing graduate teaching assistants' teaching practices in physics "mini-studios" 609
Tong Wan, Constance M. Doty, Ashley A. Geraets, Erin K. H. Saitta, and Jacquelyn J. Chini

Tracking the referent system to understand students' math modeling processes 615
Christopher Webster and Benjamin M. Zwickl

A new approach for uncovering student resources with multiple-choice questions 621
Nolan K. Weinlader, Eric Kuo, Benjamin M. Rottman, and Timothy J. Nokes-Malach

Teachers' intended learning outcomes around computation in high school physics 627
Daniel P. Weller, Marcos D. Caballero, and Paul W. Irving

Modeling student collaborations using valued ERGMs 633
James E. Wells

Inconsistent gender differences in self-efficacy and performance for engineering majors in physics and other disciplines: A cause for alarm? 639
Kyle M. Whitcomb, Z. Yasemin Kalender, Timothy J. Nokes-Malach, Christian D. Schunn, and Chandralekha Singh

Student behavior and test security in online conceptual assessment 645
Bethany R. Wilcox and Steven J. Pollock

Challenges in study design for characterizing the informal physics landscape 651
Julia Willison, Dena Izadi, Issac Ward, Kathleen A. Hinko, and Claudia Fracchiolla

Introductory physics laboratory practical exam development: Investigation design, explanation, and argument 657
Steven F. Wolf, Mark W. Sprague, Feng Li, Annalisa Smith-Joyner, and Joi P. Walker

Adapting differentiated cognitive load measurement in physics classroom 663
Xian Wu and Diego Valente

Using machine learning to understand physics graduate school admissions 669
Nicholas T. Young and Marcos D. Caballero

Attending to emotion in a metaphor for success in physics with poetic analysis 675
Brian Zamarripa Roman, Amy Vary Schwandes, and Jacquelyn J. Chini

Effect of online practice exams on student performance 682
Muxin Zhang, Andrew Engel, Timothy Stelzer, and Jason W. Morphew

A revision of a traditional astronomy course through active learning 687
Raymond Zich, Amber Sammons, and Rebecca Rosenblatt

Toward understanding and characterizing expert physics covariational reasoning 693
Charlotte Zimmerman, Alexis Olsho, Suzanne White Brahmia, Michael E. Loverude, Andrew Boudreaux, and Trevor I. Smith

List of Contributed Poster Presentations 699

Index 708

Preface

The theme of the 2019 Physics Education Research (PER) Conference was Physics Outside of the Classroom: Teaching, Learning, and Cultural Engagement in Informal Physics Environments.

The plenary talks highlighted this theme in several ways. Paula K. Hooper's talk entitled *Making through a lens of culture, power, & equity: Visions for Learning and Teaching in Informal Settings* focused on factors and ways that educators can think about where equity and science ideas are intertwined.

Shane Bergin led an interactive session demonstrating a collective experience of running, or participating in, informal physics programs. Shane also addressed the scholarship from this emerging sub-discipline.

Jamie Bell provided an overview of what is sometimes called an "invisible infrastructure" of support for informal STEM learning and communication, and invited attendees to share their own discoveries and what's in their toolboxes.

In 2019, PERC continued the breakout "Dine and Discuss" groups started in 2018. Among these groups of a variety of topics, the PERC Proceeding editors hosted a session inviting attendees to meet the editors. Steven Wolf, editor of 2019 proceedings, led the dinner discussion and addressed questions attendees asked. Juried talk papers continued in the main peer-reviewed section of the Proceedings, also a transition that happened in 2018.

PERC often ends with a plenary session or panel, and in PERC 2018 it closed with parallel discussions run by a panel of plenary speakers. This year, Mike Bennett, one of the organizers as well as a Proceedings editor, ran a relaxed, discussion-based closing session inviting attendees to reflect on their conference experiences, including the conference's interactive community engagement piece, and to discuss how the PERC 2019 themes and content might impact their own practice moving forward.

This year, the Physics Education Research Leadership and Organizing Council (PERLOC) was involved, working with the editors to improve the process of paper reviewing.

None of this could happen without a team of people every year who bring their vision, energy, and sweat. The 2019 PERC organizers were Mike Bennett, Jackie Chini, Claudia Fracchiolla, Danielle Harlow, Katie Hinko, and Katemari Rosa. They were joined by the formidable organizational powers of the American Association of Physics Teachers (AAPT).

The PERC Proceedings online submission and review process was supported by Lyle Barbato and Bruce Mason who work closely with the editors to ensure smooth functioning of the online system. We owe Lyle and Bruce a great deal of thanks.

The editors also thank the AAPT for their sponsorship of the Proceedings, allowing it to be published open-access through the comPADRE website.

As in every year, the editors wish to thank the referees for volunteering their time and expertise to give feedback to papers submitted to the Proceedings. This year we had 212 reviewers who reviewed the 151 papers submitted to the Peer Reviewed Section. The PERC Proceedings is both an important archive of findings and also a place where many new members of the field publish their first physics education research, and we are deeply appreciative of the reviewers who make this possible.

The Editors thank: Wendy Adams, Abolaji Akinyemi, Anne Alesandrini, Jonathan Alfson, Emily Allen, Rabindra Bajracharya, Pablo Barniol, Daniel Barringer, Lauren Bauman, Ian Beatty, Michael Bennett, Theodore Bott, Andrew Boudreaux, Eric Brewe, David Brookes, Jacqueline Bumler, Jan-Philipp Burde, Eric Burkholder, Danny Caballero, Esmeralda Campos, Ying Cao, Sheh Lit Chang, Stephanie Chasteen, Zhongzhou Chen, Mary Chessey, Jacquelyn Chini, Eleanor Close, Hunter Close, Robert Colesante, Kelley Commeford, Joel Corbo, Edgar Corpuz, Adriana Corrales, Sonja Cwik, Abigail Daane, Robert Dalka, Kushal Das, Ian Descamps, Richard Dietz, Constance Doty, Daniel Doucette, Dimitri Dounas-Frazer, Archana Dubey, Andrew Duffy, Jared Durden, Philip Eaton, Paul Emigh, Eugenia Etkina, Brett Fiedler, Noah Finkelstein, Thomas Finzell, Claudia Fracchiolla, Scott Franklin, Kelsey Funkhouser, Cynthia Galovich, Geoffrey Garrido, Andy Gavrin, William Gerace, Julian Gifford, Elizabeth Gire, Fred Goldberg, Melanie Good, Lisa Goodhew, Matthew Guthrie, Brianne Gutmann, Kelby Hahn, Megan Halpern, Danielle Harlow, Thomas Head, Richard Hechter, Charles Henderson, Rachel Henderson, Eder Hernandez, Paula Heron, Travis Herring, Kathleen Hinko, Brant Hinrichs, Robert Hobbs, Natasha Holmes, Dehui Hu, Tra Huynh, Paul Irving, Joss Ives, Dena Izadi, Westley James, Paul Justice, Yasemin Kalender, Christof Keebaugh, Caitlin Kepple, Raina Khatri, Abigail Kimbrough, Antje Kohnle, Eric Kuo, Alexandra Lau, Anne Leak, MacKenzie Lenz, Heather Lewandowski, Yangqiuting Li, Will Lindsay, Robynne Lock, Savannah Logan, Diana Lopez, Joshua Love, Michael Loverude, Brandon Lunk, Meghan Macias, Vina Macias, Adrian Madsen, Steve Maier, Nuraan Majiet, Tshiamiso Makwela, Alexandru Maries, Emily Marshman, Andrew Mason, Jonathan Massey-Allard, Austin McCauley, Michele McColgan, Sam McKagan, Gabriel Mestas, Daryl Moore, Emily Moore, Thomas Moore, Jason Morphew, Claire Mullen, Alexandria Muller, Sarah Muller, Carissa Myers, Kizito Ndihokubwayo, Jayson Nissen, Timothy Nokes-Malach, Egla Ochoa-Madrid, Tor Ole Odden, Daniel Oleynik, Alice Olmstead, Christopher Orban, Lindsay Owens, Gina Passante, Alanna Pawlak, Kathy Perkins, Anthony Pina, Jacob Poirier, Benjamin Pollard, Steven Pollock, Christopher Porter, Geoff Potvin, Brean Prefontaine,

Argenta Price, Javier Neira, Gina Quan, Erin Quealy, Xandria Quichocho, Katherine Rainey, Caleb Rispler, Rebecca Rosenblatt, Josh Rutberg, Qing Ryan, Diana Sachmpazidi, Paulo Sarriugarte Onandia, Ryan Sayer, Eleanor Sayre, Erin Scanlon, Benjamin Schermerhorn, Rachel E. Scherr, Erin Schipull, Christian Schunn, Stephanie Sedberry, Sydney Seese, Matthew Semak, Peter Shaffer, Chandralekha Singh, Emily Smith, Trevor Smith, Annalisa Smith-Joyner, Philip Southey, Alexis Spina, Jared Stang, Martin Stein, Tim Stelzer, John Stewart, Antoinette Stone, Meagan Sundstrom, Beth Thacker, John R. Thompson, Adrienne Traxler, Chandra Turpen, Josilyn Valencia, Diego Valente, Ben Van Dusen, Armando Villasenor, DJ Wagner, Cole Walsh, KC Walsh, Tong Wan, Aaron Wangberg, Christopher Webster, Nolan Weinlader, Daniel Weller, James Wells, Kyle Whitcomb, Suzanne White Brahmia, Carl Wieman, Bethany Wilcox, Julia Willison, Steven Wolf, Xian Wu, Nicholas Young, Brian Zamarripa Roman, Genaro Zavala, Muxin Zhang, Raymond Zich, Charlotte Zimmerman, and Benjamin Zwickl.

Finally, the Editors wish to express our special thanks to the PERC Coordination Committee chaired by Erin Scanlon, who facilitated communications and coordinated logistics among multiple parties to streamline the process for future years.

See you Summer 2020 in Grand Rapids, Michigan!

Ying Cao
Editor-in-Chief

Conference Overview: Physics Outside of the Classroom: Teaching, Learning, and Cultural Engagement in Informal Physics Environments

Physics education occurs in a multitude of contexts: in the home, afterschool, in museums, in the community, online, and in classrooms. Learning environments other than formal classroom experiences are collectively referred to as "informal learning environments" and they provide different opportunities and challenges for both researchers and practitioners. Since these programs are not typically bound by grades or standardized testing, informal physics education environments and programs can more freely focus on providing opportunities to develop interest and excitement toward physics, empowering participants of all ages and backgrounds to ask questions, be critical of information, and simply wonder at the universe, all while still engaging participants in a range of topics from introductory physics to cutting-edge research.

Thus, as a complement to formal physics education, informal physics provides novel contexts for researching physics learning and instruction, pathways to physics identity, and other topics. Informal physics education research provides opportunities to consider the ways in which physics as a culture presents itself to the public, including to potential future physicists, especially those from under-represented groups. Informal physics can also have a strong focus on elements of inclusion and equity, often serving as the first point of contact for interested members of the public, and the experiences of informal physics practitioners and researchers can complement and even inform the way formal physics departments address these important issues. In a broader context, informal physics is the gateway through which physicists communicate with the public, making physics part of society in the process.

In PERC 2019, we seek to provide opportunities in both traditional and non-traditional ways to connect and socialize with other physicists, as well as with the local community, and we plan to provide opportunities to showcase the rigorous research being done in informal and formal fields with connections to outreach. In line with the advantages of informal learning spaces, we encourage submissions to push on the boundaries of traditional modes of presentations.

We are looking forward to conferencing with you! **Twitter: @PERC2019, #PERC2019**

PROGRAM

Wednesday, July 24, 2019	
3:00pm	Bridging Plenary Talks A Collective Exploration of Physics Beyond the Classroom Speaker: Shane Bergin Making through a lens of culture, power, & equity: Visions for Learning and Teaching in Informal Settings Speaker: Paula Hooper
4:30pm	Break, Poster Session I Setup
4:45pm	Poster Session I (refreshments, 2 group of posters, 45 minutes) First Timer / Undergraduate posters will be presented.
6:15pm	Dinner / Poster Session II setup
8:15pm	Poster Session II (dessert, 2 groups of posters, 45 minutes per group)

Thursday, July 25, 2019	
8:00am	Parallel Sessions Cluster I ● Juried Talks I ● Discussion Space for People of Color ● Learning by analyzing more than just correct answers ● Representing student reasoning about math in physics ● Bright approaches to informal physics
9:45am	Poster Session III (coffee, 1 group of posters, 45 minutes)
10:45am	Parallel Sessions Cluster II ● Critical Theory as a Research Framework for Addressing Injustice in Physics Education ● Blending Physics and Other Interests (In and Out of the Classroom) ● Museum-based physics education research through research-practice partnerships (RPPs) ● Teaching 3D Physical Concepts Using Virtual and Augmented Reality

	● Video Analysis of Student Thinking in Labs ● Juried Talks II
12:15pm	Lunch Plenary --Jamie Bell
1:30pm	Parallel Sessions Cluster III ● Understanding and Assessing Problem-solving in introductory physics ● Measuring the conceptual development of teachers: A data analysis workshop ● Conceptual Design of Informal Physics Programs ● Using Social psychological intervention to make STEM classrooms inclusive and improve learning ● PERC 20/20: A Sneak Peak at “Insights, Reflections, & Future Directions”
3:15pm	Closing Session
4:00pm	End of PERC

Introduction

Papers published in the 2019 Physics Education Research Conference Proceedings consist of two categories, two plenary papers and peer-reviewed papers.

The plenary papers were contributed by plenary speakers, Dr. Jamie Bell and Dr. Shane. D Bergin.

The peer-reviewed papers are written products of any presentation including the juried talks, parallel sessions, and poster sessions. Each paper undergoes a rigorous peer review process in order to be published in the Proceedings. This year saw 151 submitted manuscripts, of which 112 were accepted for final publication.

The readership of the Physics Education Research Conference Proceedings includes faculty, post-doctoral associates, and graduate and undergraduate students in physics education; scholars in other discipline-based science education or closely related fields, such as cognitive science; practitioners in physics or other sciences, such as teaching faculty at undergraduate and graduate levels, and high school physics teachers.