# Physics Education Research Conference (PERC) 2019

## 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**

# At-a-glance Schedule

| Wednesday, July 24, 2019 | | |
|---|---|---|
| 3:00pm | **Bridging Plenary Talks -- Shane Bergin, Paula Hooper** | Ballroom C |
| 4:30pm | Break, Poster Session I Setup | |
| 4:45pm | Poster Session I (First Timer / Undergraduate – refreshments provided, two 45-minute groups odd/even) | Exhibit Hall C |
| 6:15pm | Dinner / Poster Session II setup (on your own, or sign up for a Dine & Discuss) | |
| 8:15pm | Poster Session II (dessert, two 45-minute groups odd/even) | Exhibit Hall C |

| Thursday, July 25, 2019 | | |
|---|---|---|
| 8:00am | Juried Talks I | Cascade A |
| | Discussion Space for People of Color | Cascade B |
| **Parallel Sessions Cluster I** | Learning by analyzing more than just correct answers | Cascade C |
| | Representing student reasoning about math in physics | Cascade D |
| | Bright approaches to informal physics | Cascade E |
| 9:45am | Poster Session III (coffee, 1 group of posters, 45 minutes) | Exhibit Hall C |
| 10:45am | Critical Theory as a Research Framework for Addressing Injustice in Physics Education | Cascade A |
| **Parallel Sessions Cluster II** | Blending Physics and Other Interests (In and Out of the Classroom) | Cascade B |
| | Museum-based physics education research through research-practice partnerships (RPPs) | Cascade C |
| | Teaching 3D Physical Concepts Using Virtual and Augmented Reality | Cascade D |
| | Video Analysis of Student Thinking in Labs | Cascade E |
| | Juried Talks II | Soldier Creek |
| 12:15pm | **Lunch Plenary -- Jamie Bell** | Ballroom C |
| 1:30pm | Understanding and Assessing Problem-solving in introductory physics | Cascade A |
| **Parallel Sessions Cluster III** | Measuring the conceptual development of teachers: A data analysis workshop | Cascade B |
| | Conceptual Design of Informal Physics Programs | Cascade C |
| | Using Social psychological intervention to make STEM classrooms inclusive and improve learning | Cascade D |
| | PERC 20/20: A Sneak Peak at "Insights, Reflections, & Future Directions" | Cascade E |
| 3:15pm | Closing Session | Ballroom C |
| 4:00pm | End of PERC | |

## Wednesday, July 24, 3:00pm Ballroom C
## Plenary Session

### Paula Hooper, Northwestern University

### Making through a lens of culture, power, & equity: Visions for Learning and Teaching in Informal Settings

Physics education in informal settings often happens in places that are described as makerspaces or tinkering settings. Claims are made by the branded maker community that the creation of objects with physical and digital tools will provide equitable access for children of all ages, cultural and socioeconomic backgrounds to STEM learning that will open career paths in which they are underrepresented. But these broad claims need a lot of conceptual and pedagogical work to help educators design spaces and activities that shift the nature of learning and teaching within informal settings to be responsive to the needs of all children.

This presentation will consider the questions -What allows the physics of sound to be a material for exploration/investigation within a makerspace that is designed to be equitable and inclusive? How can educators come to think about learning and teaching where equity and science ideas are intertwined?

We will discuss four principles from equity-oriented and making/tinkering research: critical analyses of educational injustice, historicized approaches to making as cross-cultural activity, ongoing inquiry into the sociopolitical values and purposes of making, and explicit attention to pedagogical philosophies and practices (Vossoughi, Hooper, Escude 2016). We will examine two cases that embody some of these principles that can help this community to recognize and design for equitable informal STEM learning environments. One case is a teaching interaction within an after school program where students are engaged in exploring sound with physical and digital tools. The other is an example of a professional development design that engages both formal and informal educators in grappling with how inquiry-oriented pedagogical structures can become tools for valuing multiple paths of sense making about science ideas.

**About Paula**

Paula K. Hooper is an Assistant Professor of Instruction in the School of Education and Social Policy at Northwestern University. Her research and teaching addresses uses of computational tools to support STEM learning in both informal and formal settings from a hybrid of ecological and sociocultural perspectives. She particularly enjoys developing professional development experiences that help educators to come to understand computational ideas as materials for creating equity and inquiry oriented learning environments. She holds a PhD in Media Arts and Sciences from the Media Lab at MIT with a focus on epistemology and learning. She is a former elementary classroom teacher and worked with youth in informal settings on robotics and the use of digital design fabrication for creative activism.

## Wednesday, July 24, 3:00pm Ballroom C
## Plenary Session

### Shane Bergin, University College Dublin

### A Collective Exploration of Physics Beyond the Classroom.

This talk will explore learning physics beyond the classroom, laboratory, and lecture hall. Grounded in our collective experience of running, or participating in, informal physics programmes, and scholarship from this emerging sub-discipline, I hope to construct, with your help, goals and questions that we might engage with over the PERC meeting. To that end, the session will be an active one.

In advance of this session, you may like to reflect on informal physics programmes you have participated in, or led. In doing so, consider your motivations, the practices and community of people involved. Think, too, about how they may have affected you. During the session, you'll be invited to discuss, in small groups, your experiences of those programmes. I hope we can build on these to co-construct community-level ideas, concerns, goals, etc. around informal learning.

**About Shane**

Dr. Shane Bergin is a physicist and a lecturer in science education at the School of Education, University College Dublin (UCD), Ireland. Shane and his research group are interested in informal teaching and learning in physics (and STEM more broadly). Our research sees us create, run, and reflect upon informal physics education initiatives. Recent projects include i) Quavers to Quadratics, where children play with ideas common to physics and music; ii) City of Physics – sparking city-wide conversations by placing 'physics adverts' in public spaces, and iii) Community Challenge – a co-teaching project that sees school children pose questions of their local community. This research is/has been supported by grants from Science Foundation Ireland (SFI), Marie Curie Actions, and the Irish Research Council. Shane's interest in informal learning sees him contribute to regular radio slots on Today with Sean O'Rourke (RTE) & Futureproof (Newstalk).

## Thursday, July 25, 12:15pm Ballroom C
## Plenary Session

### Jamie Bell, CAISE

### Informal STEM Learning and Science Communication: An Expanding Landscape of Resources, Research and Collaborators

Since the founding of the Exploratorium, the Ontario Science Center and Lawrence Hall of Science 50 years ago, the landscape of organizations, institutions, networks and professionals who design, study and evaluate informal STEM learning and science communication experiences and settings has continued to expand and mature. With technological development has come an increasing variety of platforms and channels through which people of all ages can engage with and learn about the physical and natural world. And through advances in the social and learning sciences educators, communicators and researchers have become increasingly knowledgeable about inclusive, culturally responsive approaches to designing activities and environments, and to the measurement of their impact.

Within this context, and through the investment of the National Science Foundation and other federal and private funders over the past dozen years, the availability of and access to evidence-based resources, tools and potential partners has never been greater. Knowledge about the rich variety of strategies that those developing curricula and events can tap into to address their goals and objectives isn't as widely shared as it might be. I will provide an overview of what is sometimes called an "invisible infrastructure" of support for informal STEM learning and communication and invite attendees to share their own discoveries and what's in their toolboxes.

**About Jaime**

Jamie has been Principal Investigator and Project Director for CAISE, at the Association of Science-Technology Centers (ASTC) in Washington, D.C. since 2010. As a National Science Foundation-funded resource center for the Advancing Informal STEM Learning (AISL) program, CAISE provides a repository of project abstracts, related scholarship and evaluation reports for designers and researchers of informal STEM learning settings and experiences including museums and science centers, media and cyberlearning, citizen and community science programs and science festivals and events. Before joining CAISE, Jamie held a variety of leadership roles in STEM education and cultural institutions including at the Exploratorium in San Francisco where he led the High School Explainer Program and managed a renovation of the museum's physics exhibits and the Center for Astrophysics Science Media Group where he served as content developer for the Essential Science for Teachers: Physical Science video professional development series. Mr. Bell holds degrees from Carnegie Mellon and Harvard Universities where his worked focused on educational and developmental experiences for youth outside of the formal classroom.

## Poster Session I
## Wednesday, July 24, 4:45pm

**Exhibit Hall C**

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|---|---|---|
| AlFiky, Mohammad | Investigating Students' Difficulties in Calculus-Based EM Using MCQ Tests: Preliminary Study | A52 |
| Alesandrini, Anne | Types of explanations introductory students use to explain their answers to conceptual physics questions | A68 |
| Archibeque, Benjamin | STEP UP: Analyzing Discussions of Underrepresentation | A14 |
| Arielle, Acacia | Introductory Physics Students' Insights for Improving Physics Culture | A10 |
| Barringer, Daniel | First steps towards building curriculum around student interests in astronomy | A24 |
| Bauman, Lauren | Students' use of conceptual resources for understanding superposition | A62 |
| Bhansali, Aesha Piyush | First year students' emotional engagement with Physics | A48 |
| Bott, Theodore | Preliminary Analysis of Student-Identified Themes around Computation in High School Physics | A5 |
| Brunk, KC | Student activist strategies for creating a welcoming physics culture | A16 |
| Bumler, Jacqueline | How do previous coding experiences influence undergraduate physics students? | A1 |
| Charpentier, Lucas | Understanding student pathways in a physics degree with network analysis | A40 |
| Coon, Alexander | Assessing Motivations to Engage In Responsible Conduct of Research | A81 |
| Corpuz, Aileen | Students' motivation in a student-centered learning environment | A60 |
| Cwik, Sonja | Understanding motivational characteristics of students who repeat algebra-based introductory physics courses | A69 |
| Dalka, Robert | Investigating the Mechanisms of Peer Review | A36 |
| Das, Kushal | Learning About Teacher Recruitment and Retention from Our Math Department | A83 |
| Descamps, Ian | A Critical Assessment of General Physics | A41 |
| El-Adawy, Shams | Faculty as Learners and Educators: Interactions between Community of Practice, Individual Experience and Teaching Philosophy | A33 |
| Eriksson, Urban | -Where are the stars? - A citizen science project on light pollution | A19 |
| Fadaei, Azita Seyed | Comparing the Effects of Cook Book and Non-Cook Book Based Lab Activities | A75 |
| Faletic, Sergej | Using Rutgers Scientific Ability Rubrics to Improve Student Learning and Reduce Instructor Workload | A86 |
| Fuller, Elizabeth | Polaris: Outreach Initiatives for Retention and Sustainability of Underrepresented Minorities and Women in a Competitive Climate | A12 |
| Fung, Anderson | An Exploration of Students' Concept Images of Ordinary Differential Equations | A87 |
| Gambrell, Justin | Identifying important research questions involving computation in physics | A3 |
| Garrido, Geoffrey | How are students' online learning behavior related to their course outcomes in an introductory physics course? | A50 |

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| Gokuldass, Priyadarshini | Investigating Undergraduate Astronomy Students’ Ideas about Black Holes | A53 |
| Gray, Nickolas | What do Students Know about Electromagnetic Wave Generation? | A72 |
| Guthrie, Matthew | Comparing student behavior in mastery and conventional style online physics homeworks | A44 |
| Güven, Jasmin | What elements of a community help undergraduates gain confidence? | A17 |
| Her, Pachi | Students' Understanding of Matrix Algebra and Eigentheory | A88 |
| Herring, Travis | Evaluative sensemaking: frequency of student strategies and variance among instructors | A47 |
| Hewagallage, Dona Sachini | Differences in the Predictive Power of Pretest Scores of Students Underrepresented in Physics | A8 |
| House, Lindsay | Legacy of the Pale Blue Dot: Can introductory astronomy experiences impact self-concept and self-efficacy? | A27 |
| Pearson III, Richard | Faculty Perceptions of Teaching as a Profession development and validation interviews | A32 |
| Izadi, Dena | Identifying Success Markers: A Case Study of Informal Physics Efforts through Organizational Theory | A26 |
| Johnson, Kimme | Students’ beliefs about the nature of experimental physics: Part one | A58 |
| Junker, Elmar | Astronomy is the Trojan Horse for Teaching Physics Invisibly - Experiences from Star-gazing with both Students and the Public at a University Observat | A20 |
| Kamela, Martin | Lost in Translation: Newtonian Mechanics with Tibetan Buddhist Monks | A28 |
| Kepple, Caitlin | Students’ Sense of Belonging in Introductory Science Labs: Does GTA Training Matter? | A78 |
| Kimbrough, Abigail | Teaching Gravitational Potential Energy: Student Interaction with Surface Manipulatives | A63 |
| Kizito, Ndihokubwayo | Effectiveness of Teaching approaches meant to Enhance Active Learning of Optics in Physics subject in Rwandan Secondary Schools | A46 |
| Li, Yangqiuting | Understanding motivational characteristics of students who repeat calculus-based introductory level physics courses | A70 |
| Logan, Savannah | GFO Copy Write: Development of written materials for recruiting STEM teachers | A82 |
| Love, Joshua | Effectiveness of Modified Fluid Flow Diagrams for Student with and without Prior Instruction | A89 |
| Macias, Vina | Transferability and specialization: analyzing STEM students’ perspectives of problem-solving | A67 |
| Makwela, Tshiamiso | Probing student engagement of distances in astronomy | A29 |
| Marsh, Daniel | Students' Reasoning about the Inverse-square Law in Multiple Representations | A57 |
| May, Jason | Exploring Students’ Enactment of Data Analysis Practices in Interdisciplinary IPLS Laboratory Courses | A73 |
| McCauley, Austin | Is it Teaching or is it Physics? | A74 |
| Mestas, Gabriel | Framing the Pursuit of a Physics Degree as a Hero's Journey | A34 |

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| Meyer, Aurora | Topic Clustering in PER Abstracts using Computational Linguistics | A39 |
| Moore, Daryl | Growth Mindset and Agency in Learning Physics Innovation and Entrepreneurship | A49 |
| Moshfeghyeganeh, Saeed | Muslim Women Physicists' Career Choice; Investigating the Effect of Culture | A11 |
| Mullen, Claire | Why it should be and not or: Physics and Music | A31 |
| Muller, Sarah | Student Performance and Stress Level in Different Testing Environments | A56 |
| Myers, Carissa | Quantifying the Linguistic Persistence of High and Low Performers in an Online Student Forum | A79 |
| Ochoa-Madrid, Egla | Examining Students Views on Ethics and the Atomic Bomb | A22 |
| Oleynik, Daniel | Scientific Practices in Minimally Working Programs | A6 |
| Ortiz, Nickolaus | Physics Learning through Computing: An Analysis of Equity Patterns within Physics Teachers' Classrooms | A4 |
| Park, Soojin | Students' beliefs about the nature of experimental physics: Part two | A59 |
| Pina, Anthony | Presentation of integrals in introductory physics textbooks | A55 |
| Poirier, Jacob | Preventive and exploratory: two workplace problem-solving cultures | A37 |
| Profeta, Audrey | Identifying Student Conceptual and Computational Resources in Setting Up Integral Expressions for the Electric Field of Continuous Charge Distribution | A2 |
| Quealy, Erin | Rockets, Drones, and Electronic Payloads: Research Prep Curriculum Increases Interest in STEM Careers at Minority Serving Community Colleges | A13 |
| Quichocho, Xandria | Who does physics: Understanding the composition of a physicist through the lens of women of color and female LGBQ+ physicists. | A18 |
| Richardson, Connor | Were they right? Replicating IRC-based analyses using FMCE data | A71 |
| Rispler, Caleb | Understanding University Students' Identity through Engagement in Informal Physics Programs | A30 |
| Rutberg, Joshua | ISLE-Based Laboratory Reform at an Urban University | A77 |
| Sarriugarte, Paulo | Students' understanding on rigid body rotation | A61 |
| Schipull, Erin | "Success Together": Physics Departmental Practices Supporting LGBQ+ Women and Women of Color | A7 |
| Scott, Keely | STEP UP: The Impact of a Women in Physics Lesson on Students' Figured Worlds | A15 |
| Sedberry, Stephanie | Three factors that complicate self-efficacy research and affect whether self-efficacy interventions succeed or fail | A80 |
| Seese, Sydney | Hidden Value: Investigating the Physics Demonstration as Aesthetic Experience | A25 |
| Sivitilli, Alexander | Exploring Productive Modes of Engagement in the Planetarium | A23 |
| Smith-Joyner, Annalisa | Graduate teaching assistant fidelity of implementation in introductory physics laboratories | A76 |
| Staveland, Owen | Causal Statements Improve Concept Application | A43 |
| Sundstrom, Meagan | Intellectual Humility: Mindsets and Behaviors of Introductory Physics Students | A51 |

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| Tran, Khanh | The Alma Project: Cultivating Cultural Capitals in Physics through Reflective Journaling | A85 |
| Valencia, Josilyn | Studying the factors that impact the development of community of practice for educators | A38 |
| Villasenor, Armando | Evaluating Gender and Racial Gaps on the Force Concept Inventory at A Minority Serving PUI (primary undergraduate institution) | A9 |
| Walsh, Kenneth | Tracking students engagement with open educational resources and online homework | A65 |
| Waterson, Alyssa | Highlighting Earlier Time-to-Degree from Preparation through Transfer Courses | A35 |
| Webster, Christopher | Tracking the referent system to understand students' math modeling processes | A66 |
| Weinlader, Nolan | A new approach for uncovering student resources with multiple-choice questions | A42 |
| Wikowsky, Jacob | Differences between Adapted Modeling Instruction and lecture in Introductory Mechanics | A45 |
| Williams, Stephanie | Peer Support for instructors negotiating new pedagogical approaches with students | A84 |
| Willison, Julia | Developing a Methodology for Determining the Landscape of Informal Physics Programs | A21 |
| Yang, Jie | Multidimensional Item Response Theory and the Force and Motion Conceptual Evaluation | A54 |
| Zamarripa Roman, Brian | Results from the People of Color Discussion Space at the 2017/2018 PERCs | A90 |
| Zimmerman, Charlotte | Toward Understanding and Characterizing Expert Physics Covariational Reasoning | A64 |

## Poster Session II
## Wednesday, July 24, 8:15pm

**Exhibit Hall C**

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| Akinyemi, Abolaji | Linking terms to physical significance as an evaluation strategy | B70 |
| Beatty, Ian | Improving STEM self-efficacy with a scalable classroom intervention targeting growth mindset and success attribution | B8 |
| Bender, Lydia | Faculty Perceptions of Three-Dimensional Learning | B82 |
| Bennett, Michael | What Factors Influence Pedagogical Methods in Informal Learning Spaces? | B21 |
| Brewe, Eric | Instructional fingerprinting: network analysis of Framework for Interactive Learning in Lectures (FILL) data | B86 |
| Bugge, Danielle | Studying student attitudes and motivation in a first-year physics course | B45 |
| Burde, Jan-Philipp | Evaluating and improving conceptual understanding of circuits in middle schools | B64 |
| Cao, Ying | Emergent Explicit Group Regulation in Small Group Scientific Activities | B29 |
| Chang, Sheh Lit | Applying text analysis to compare student explanations in PER | B57 |
| Chasteen, Stephanie | Measuring faculty attitude change towards active learning within a professional development workshop | B89 |
| Chen, Zhongzhou | Evaluating the effectiveness of two methods to improve students' problem solving performance after studying an online tutorial | B65 |
| Cheng, Hemeng | STEP UP: Time Series Structure of High School Students’ Physics Identity Development Using Structural Equation Modeling. | B15 |
| Close, Hunter | Meaning and Purpose in the Pursuit of Physics Teaching Careers | B88 |
| Commeford, Kelley | Characterizing Active Learning Environments in Physics: Network Analysis using Exponential Random Graph Models | B60 |
| Daane, Abigail | Physics is Objective – or is it? | B12 |
| Dancy, Melissa | Survey of Physics, Mathematics and Chemistry Faculty | B47 |
| Doyle, Jacqueline | Investigating students' mixtures of expert-like and incorrect knowledge of physical science | B87 |
| Duffy, Andrew | AP Physics Results and their Implications for Diversity in Physics | B2 |
| Fiedler, Brett | Coordinating epistemic frames in informal physics: Agency, support, and technology | B20 |
| Fracchiolla, Claudia | Can we foster autonomy within Communities of Practice? | B19 |
| Goodhew, Lisa | Investigating the impact of question style on the resources that students use in written responses: an example from mechanical pulse reflection | B69 |
| Gutmann, Brianne | Supporting Math Skills in Mastery-Style Learning Exercises | B46 |
| Head, Thomas Blake | STEP UP: Analyzing Student Perceptions of Physics Following a Career in Physics Lesson | B14 |
| Hechter, Richard | The Giant, The Wintermaker, or The Hunter: Whose belt is it? (And why does that matter!?) | B92 |
| Henderson, Charles | Feedback Requested: Understanding and Humanizing the Journal Review Process | B66 |

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| Henderson, Rachel | A Longitudinal Exploration of Students' Beliefs about Experimental Physics | B22 |
| Hinrichs, Brant | Changing The Notation That Represents A Force Changes How Students Say It | B26 |
| Hinrichs, Brant | Do I belong here?: Understanding Participation and Non-participation in Whole-Class "Board" Meetings | B81 |
| Hinrichs, Brant | Social Positioning And Consensus Building In Student-Led Whole-Class Discussions | B43 |
| Hoehn, Jessica | Epistemology, sense making, and social dynamics in group work | B63 |
| Hu, Dehui | Impact of industry experience on faculty teaching practices in STEM | B83 |
| Hyater-Adams, Simone | Talking about Race: A resource for advisor-student conversations | B17 |
| Ives, Joss | Using cueing from paired questions to engage students in reflective thinking | B76 |
| Jambuge, Amali Priyanka | How can we assess scientific practices? The case of "Using-Mathematics" | B32 |
| James, Westley | Hidden walls: STEM course barriers identified by students with disabilities | B6 |
| Jariwala, Manher | Investigating Simulation Use in Algebra-Based Introductory Physics | B34 |
| Kalender, Z. Yasemin | Investigating the role of prior preparation and self-efficacy on female and male students' introductory physics course achievements | B9 |
| Khong, Hien | How can we develop assessment tasks for "planning investigations"? | B33 |
| Kuo, Eric | Using causal networks to map out the targets of resource coordination | B75 |
| Lau, Alexandra | Developing Reflective Practitioners: A Case from Faculty Online Learning Communities | B80 |
| Leak, Anne | Physics Perceptions: Challenges, Rewards, and Applicability of Innovation and Entrepreneurship | B11 |
| Lindsay, William | The Association Between Sustained Professional Development and Physics Learning | B91 |
| Little, Angela | Reflections on a Context-Dependent Beliefs Approach to Studying Mindset | B73 |
| Lock, Robynne | Impact of the Next GEN PET Curriculum on science identity | B85 |
| López Tavares, Diana Berenice | Visualizing Student Simulation Interactions: A Dashboard to Differentiate Between Instructional Approaches | B54 |
| Madsen, Adrian | User-centered personas for PhysPort | B94 |
| Mason, Andrew | Learning Goals and Belief in Lack of Relevance to Major | B35 |
| Massey-Allard, Jonathan | Learning to learn by inquiry: are simulations too challenging for novices? | B36 |
| McPadden, Daryl | Curriculum as more than content: thinking about the assumptions built into curricular materials | B61 |
| Modir, Bahar | Impact of online discussion in forming a community of practice for educators | B84 |
| Monsalve, Camila | STEP UP: Case study of teacher's changing beliefs about discrimination during the implementation of a women in physics lesson | B90 |
| Nissen, Jayson | Educational debts incurred by racism and sexism in students' beliefs about physics | B5 |

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| Nokes-Malach, Tim | How is perception of being recognized by others as someone good at physics related to female and male students' physics identities? | B7 |
| Prefontaine, Brean | Supporting Multiple Identities in Informal Spaces: Examining Design Choice | B16 |
| Price, Virginia | Determining Motivating Factors for Undergraduate Women Pursuing Physics Degrees | B4 |
| Pulgar, Javier | Contextual details, cognitive demand and kinematic concepts: exploring concepts and characteristics of student-generated problems at the university | B27 |
| Quan, Gina | The Access Network: Cultivating Equity and Student Leadership in STEM | B1 |
| Robertson, Amy | Prevalence of Impetus-Force-Like Drawings Among Contemporary University Physics Students | B39 |
| Rodriguez, Miguel | Social Interdependence Theory and Transfer in a Collaborative Learning Environment | B74 |
| Rosenblatt, Rebecca | Investigating the Effectiveness of Two Instructional Interventions for Fluid Dynamics | B68 |
| Ruggieri, Charles | Students' Perceptions and Use of Online Resources in Introductory Physics | B42 |
| Ryan, Qing | Evaluating Students' Performance on the FCI (force concept inventory) at A Minority Serving PUI (primary undergraduate institution) | B30 |
| Santangelo, Brianna | Psychometric analysis of instrument measuring student reasoning skills* | B40 |
| Scanlon, Erin | Physics Instructors' Views about Supporting Learner Variation: Modifying the Inclusive Teaching Strategies Inventory | B10 |
| Semak, Matthew Richard | An Examination of the Correlation Between Cognitive Ability and Achievement on the FCI | B25 |
| Shafer, Devyn | Predictive Modeling of Exam Performance from Mastery-Style Homework Behavior | B38 |
| Smith, Emily | Evaluating students' sense of authority when evaluating the quality of measurements | B31 |
| Smith, Trevor | Using psychometric tools as a window into students' quantitative reasoning in introductory physics | B52 |
| Southey, Philip | The Ratio Table: Making Meaning with Ratios and Units Involving "Per" | B48 |
| Speirs, J. Caleb | Network analysis of reasoning chain tasks to test theoretical perspectives* | B72 |
| Stone, Antoinette | A Team-planning and Assessment Protocol to Guide Student Group Projects | B55 |
| Strubbe, Linda | An asset-based view of faculty and their ideas about teaching | B79 |
| Thacker, Beth | A Rubric for Assessing Thinking Processes in Free-Response Exam Problems | B24 |
| Topdemir, Zeynep | Identity Development Comparison of Physics Majors with Different Career Goals | B67 |
| Valente, Diego | Effects of group interactions on student cognitive load in vector tests | B28 |
| Vieyra, Rebecca | A Survey of Teachers' Integration of Earth and Space Science Contexts for Teaching Physics | B77 |
| Wagner, DJ | Perceived Effect on Buoyancy of Weight vs. Gravitational Force | B37 |
| Walsh, Cole | Assessing the assessment: mutual information between response choices and factor scores | B58 |
| Walter, Paul | Transition Matrices Applied to the Force Concept Inventory | B50 |

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| Wells, James | Modelling Student Collaborations Using Valued ERGMs | B71 |
| Whitcomb, Kyle | An examination of gender differences in self-efficacy and academic performance in different STEM domains | B3 |
| Wilson, Michael | Visualizations of E&M Plane Waves Designed for Better Student Understanding | B53 |
| Wood, Laura | Developing a Coding Scheme for Self-Efficacy Opportunity Experiences | B62 |
| Wu, Xian | Adapting differentiated cognitive load measurement in physics classroom | B56 |
| Young, Nicholas | Using Machine Learning to Understand Physics Graduate School Admissions | B18 |
| Zamarripa Roman, Brian | Attending to Emotion in a Metaphor for Success in Physics with Poetic Analysis | B59 |
| Zamarripa Roman, Brian | Results from the People of Color Discussion Space at the 2017/2018 PERCs | B13 |
| Zavala, Genaro | Students' conversion from electric field line diagrams to other representations | B44 |
| Zavala, Genaro | The effect of similar surface features on students' understanding of the interaction of charges with electric and magnetic fields | B49 |
| Zeng, Liang | Using Skateboarding Experiential Learning to Teach Introductory College Physics Course | B51 |
| Zhang, Muxin | Realistic Exam Practice Study | B41 |
| Zich, Raymond | A Revision of a Traditional Astronomy Course through Active Learning | B23 |
| Zisk, Robert | The quality of instructional artifacts and teachers' content knowledge for teaching energy | B93 |
| Zwickl, Benjamin | Agile, Scrum, Fishbones: Teaching Structured Problem-Solving in STEM Workplaces | B78 |

## Poster Session III
## Thursday, July 25, 9:45am

**Exhibit Hall C**

| | | |
|---|---|---|
| Aiken, John | Supporting Future Educational Data Miners through a Summer Research Internship | C7 |
| Alfson, Jonathan | Explicitly Prompting Covariational Reasoning in a Thermodynamics Context | C43 |
| Arruda, Anthony | Student use of Quantum Notations – Dirac Notation as a Template | C53 |
| Barooni, Amin Bayat | Designing lab activities by using research-based activities | C31 |
| Beverly, Nancy | Categorizing stages of students' sustained inquiry in self-chosen projects | C20 |
| Chessey, Mary | Physics faculty's reasoning about life science students pursuing professions | C22 |
| Close, Eleanor | Designing Learning Assistant Program Structures to Create Resilient Community | C27 |
| Conlin, Luke | A framework for recognizing debugging in students computational model building | C1 |
| Corbo, Joel | Connecting facilitation to outcomes in the Departmental Action Team model | C9 |
| Corpuz, Edgar | The physics motivation of life science and engineering majors | C23 |
| Doty, Constance | Student perspective of GTA strategies to reduce feelings of anxiousness with cold-calling | C30 |
| Doucette, Danny | All Aboard! Challenges and Successes in Training Lab TAs | C25 |
| Dounas-Frazer, Dimitri | Preliminary model for conditions and processes that facilitate project ownership | C48 |
| Emigh, Paul | Student Reasoning about Multivariable Covariation in Thermodynamics | C50 |
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| Lo, William | Developing a concept inventory for statistical mechanics | C42 |
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## Thursday, July 25, 8:00am Cascade A
## Parallel Session Cluster I: Juried Talk Session

### Juried Talks I

### Organizing Committee, PERC

This session consists of four juried talks.

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Juried Talk 1

### A framework for classifying learning opportunities in Faculty Online Learning Communities: A multipurpose tool with practical applications

**Primary Contact: Alexandra C Lau, University of Colorado Boulder**
**Co-authors: Adriana Corrales, Fred Goldberg, Chandra Turpen, and the Next Gen PET FOLC Research Team**

Faculty Online Learning Communities (FOLCs) are a unique professional development environment for physics and astronomy instructors where they engage in sustained pedagogical reflection and growth. FOLC participants meet via a video conferencing platform to discuss their teaching. In order to capture the breadth and depth of learning that can occur by participating in a FOLC, we developed a taxonomy to characterize the opportunities to learn (OTLs) in a FOLC meeting. In this talk, we will present the taxonomy and discuss its development based on meetings from two different FOLCs: one centered around the Next Generation Physical Science and Everyday Thinking curriculum and another serving new physics and astronomy faculty. In order to accurately characterize OTLs, we consider both the content of the conversations and how participants engage in the conversations. We will present how our taxonomy captures these two dimensions. We will also discuss the broader utility of this framework.

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Juried Talk 2

### Breaking with Tradition: How Informal Learning Experiences in Physics Contribute to Physics Identity Development

**Primary Contact: Zahra Hazari, Florida International University**
**Co-authors: Remy Dou, Gerhard Sonnert, Philip M Sadler**

While research exists on the effect of informal science experiences on students' broader science identities, little is known about how informal science education generally affects students' development of physics identities--a construct strongly associated with physics career choice. We administered a national survey to students from 27 different colleges and universities across the country (N = 15,847). The survey captured participants' engagement in a variety of informal learning experiences across their elementary, middle, and high school years, including talking with friends and family about science, mixing chemicals, tinkering, reading science fiction, and others. Using multiple regression, we tested linear models that reveal a positive relationship between traditional informal learning experiences in physical science (e.g., tinkering) and respondents' physics identity. We also find a negative relationship between life science experiences and physics identity. We use this evidence to suggest developing interdisciplinary experiences that better engage participants with diverse interests.

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Juried Talk 3

## Longitudinal analysis of a student’s identity trajectory within the physics community

**Primary Contact: Gina M. Quan, San José State University**
**Co-authors: Chandra A. Turpen; Andrew Elby**

We study how undergraduate physics majors develop identities within the physics community. In this talk, we present a longitudinal case study of a single student, Cassidy. As a white woman and older transfer student, Cassidy held multiple intersecting nondominant identities in undergraduate physics which contributed to her unique experiences of marginalization. We analyzed Cassidy's experience through two constructs: 1) her perception of "normative identities," the accepted and valued roles within physics, and 2) her personal identity as it plays out in the physics community. We found that Cassidy experienced shifts in both her personal identity and her perceptions of normative identities. Because these shifts resulted in greater alignment between personal and perceived normative identities, they contributed to her deeper participation in the physics community. Finally, we discuss implications for future research and programmatic design.

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Juried Talk 4

## Student activist strategies for creating a welcoming physics culture

**Primary Contact: Mary Chessey, University of Maryland**
**Co-authors: KC Brunk et al.**

Connections between physics students' strategies of resistance and experiences outside the classroom are not well-documented. We carried out a 16-month critical ethnographic study centered around a cohort of transfer student physics majors by observing formal and informal learning spaces, interviewing, and participant-researchers autoethnographic memoing. Data were analyzed for emerging themes using a constant comparative method through a critical lens to understand power dynamics. During the study, participants created an equity and inclusion group, whose discussions and actions embodied students' resistance against marginalization. For example, a prevalent perception that instructors expected majors to sacrifice other parts of their lives in order to succeed in physics inspired participants to create an open mic night to celebrate talent in music and comedy. By documenting students' efforts to upend dominant ideas about the physics community and subsequent pushback they faced, we present key factors that shaped student activist experiences in a traditional physics department.

## Thursday, July 25, 8:00am Cascade B
## Parallel Session Cluster I: Custom Format

### Discussion Space for People of Color

**Brian Zamarripa Roman, University of Central Florida**
**Co-authors: Geraldine Cochran, Rutgers University;**
**Alexis Knaub, Michigan State University;**
**Simone Hyater-Adams, University of Colorado Boulder**

Building off the 2018 PERC People of Color (POC) Discussion Space, we plan to use this parallel session in two ways. First we will continue to form community among POC. Safe spaces are important because they often provide an opportunity for individuals in the group to vocalize shared experiences and utilize their agency to act and speak on their own behalf. Safe spaces also aid in creating solidarity among the group. Thus, this intimate session is intended for individuals who identify as a Person of Color. Second, we will take the discussion further by planning how to distribute the paper created from the 2017 and 2018 sessions in addition to collectively deciding on the next action items of the group.NOTE: People of Color is a term with many different interpretations. We do not want to impose our own ideas of race on individuals' identity. We ask that participants make every effort to arrive within 10 minutes of the start time to cover the rules of engagement for the discussion.

## Thursday, July 25, 8:00am Cascade C
## Parallel Session Cluster I: Poster Symposium

### Learning by Analyzing More Than Just Correct Answers

**Dave Pritchard, MIT**
**Co-authors: Benjamin Van Dusen, John Stewart, T. Smith, A. Traxler, Nasrine Bendjilali,**

The great majority of quantitative work in PER is based on students correct answers (raw score) - for example when analyzing concept tests or classroom grades. However the distractors on concept tests often represent commonly held alternate conceptions of physics. Thus the particular distractors selected, and by extension students' textual responses, symbolic responses, and discussion posts contain additional information about their state of mind beyond 'not correct'. This session showcases some research analyzing responses to each distractor as well as analysis of student's free response writing. Analyzing it can reveal specific student misconceptions and other knowledge that could help instructors tune instruction to address specific misunderstandings. This session highlights the power of modern analytics to reveal new educationally relevant insight, but also deals with the new tools and their potential pitfalls.

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Symposium Poster 1

### Modernizing use of regression models in physics education research: a review of hierarchical linear modeling

**Primary Contact: Ben Van Dusen, CSU Chico**
**Co-authors: Jayson Nissen**

Physics education researchers (PER) often analyze student data with single-level regression models (e.g., linear and logistic regression). However, education datasets can have hierarchical structures, such as students nested within courses, that single-level models fail to account for. The improper use of single-level models to analyze hierarchical datasets can lead to biased findings. Hierarchical models (a.k.a., multi-level models) account for this hierarchical nested structure in the data. In this presentation, we outline the theoretical differences between how single-level and multi-level models handle hierarchical datasets. We then present analysis of a dataset from 112 introductory physics courses using both multiple linear regression and hierarchical linear modeling to illustrate the potential impact of using an inappropriate analytical method on PER findings and implications. Research can leverage multi-institutional datasets to improve the field's understanding of how to support student success in physics. There is no post hoc fix, however, if researchers use inappropriate single-level models to analyze multi-level datasets. To continue developing reliable and generalizable knowledge, PER should use hierarchical models when analyzing hierarchical datasets.

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Symposium Poster 2

### Network Analysis of Students Descriptions of Scientific Research

**Primary Contact: Adrienne Traxler, Wright State University**
**Co-authors: Carissa Myers, Jason Deibel, Meredith Rodgers**

This work analyzes students' talk about their expectations and experiences of undergraduate research. The Applying Scientific Knowledge (ASK) program at Wright State University takes science and math majors in their second year, builds a cohort through a shared research methods class, then places students with faculty-mentored research projects. Students' accounts of their experiences are examined using epistemic network analysis, which focuses on connections between different conceptual elements in their responses. Here we give preliminary results from two physics majors, one early and one late in the program. We describe the conceptual elements present and the network structures that emerge from how they link ideas in their responses. The long-term goal of the analysis is to compile trajectories of how students in various disciplines think about and experience scientific research.

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Symposium Poster 3

## The Second Dimension of the FCI is Mostly Medieval

**Primary Contact: John Stewart, MIT**
**Co-authors: Angel Perez Lemonche, John Stewart, Byron Drury, Rachel Henderson, Alex Shvonski**

In order to measure students' physics beliefs prior to instruction, we applied two-dimensional Item Response Theory (2DIRT) to all 150 pre-instruction responses to the Force Concept Inventory (FCI) with N = 17000. Examination of Item Response Curves (fraaction selecting a response vs raw score) showed an absence of random guessing because students scoring below chance overall coalesced on only one or two distractors. One dimension of 2DIRT corresponded to Newtonian ability. The second dimension corresponds closely to the number of frequently selected responses whose response curves maximized at intermediate raw score, over a dozen in total. These responses embodied known commonsense physics ideas, most frequently the Medieval concept of impetus. The lowest Newtonian skill students selected a wider range of "wronger" responses. The ability to measure the detailed misconceptions of individual students or classes will allow development and application of instructional interventions for those specific misunderstandings. In general classes with intermediate FCI scores believe in impetus in one or more of its guises.

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Symposium Poster 4

## Using IRT to rank incorrect responses FMCE questions

**Primary Contact: Trevor I. Smith, Rowan University**
**Co-authors: Nasrine Bendjilali**

Research-based assessment instruments (RBAIs) have been standard tools for measuring student learning in physics for decades. The prevalence and power of using RBAIs hinge on the incorrect "distractors" being designed to correspond with students' intuitive ideas, and typical analyses yielding a single number that is straightforward to calculate and easy to understand. Unfortunately, by (implicitly) considering all incorrect responses to be equivalent, these analyses throw away much of the rich information that students provide when they select responses corresponding with particular intuitive ideas. We present analyses of more than 7,000 students' responses to the FMCE. Using item response theory (IRT), we show that students' likelihood of selecting particular responses may be correlated with their overall understanding of Newtonian mechanics. We use IRT correlation parameters to rank incorrect responses and develop a scoring method that values what students know rather than focusing primarily on what they don't yet know.

Symposium Poster 5

## Using Multidimensional Item Response Theory to Understand the FCI, the FMCE, and the CSEM

**Primary Contact: John Stewart, West Virginia University**
**Co-authors: Cabot Zabriskie, Jie Yang, Seth DeVore**

Constrained Multidimensional Item Response Theory (MIRT) is a powerful tool to understand the detailed structure of a multiple-choice instrument. A detailed model of the conceptual solution of the instrument developed by experts in the field can be mapped onto the MIRT model and the degree to which the expert solution models student thinking can be evaluated. Small, theoretically motivated, changes to the model are then explored to find an optimal model of student thinking. This process was applied to the FCI, FMCE, and CSEM. The structure of each instrument was dramatically different. This analysis suggested that the FCI was largely one-dimensional, while the FMCE contained multiple sub-facets. The CSEM models for two institutions were compared showing that the optimal models selected by MIRT were very similar but not identical across institutions.

## Thursday, July 25, 8:00am Cascade D
## Parallel Session Cluster I: Talk Symposium

### Representing student reasoning about math in physics

**Gina Passante, CSU Fullerton**
**Co-authors: Co-moderators: Homeyra Sadaghiani and Steven Pollock**
**Presenters: Steven Jones, Suzanne White, Benjamin Schermerhorn, and Kevin Watson**

Much of the teaching and learning of physics involves incorporating mathematical reasoning and principles. This extends beyond the use of math as a computational tool to how it contributes to interpreting physical systems and shapes our thinking in physics. Over the past decade, physics education researchers have made strides towards understanding this connection with the development of several frameworks to help analyze student responses to questions that involve mathematics. In this session we invite a group of researchers to advance our understanding of the interactions between math and physics in our curriculum and how students' nuanced understanding of mathematics affects their ability to do physics. This session will have a focus on the frameworks used in research to represent students' use and understanding of math in physics. The session will bring together researchers from the Research in Mathematics Education (RUME) community with researchers in PER to share their findings on the interface of math and physics. The session will conclude with extended time for a broader discussion and questions of all speakers.

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Symposium Talk 1

### Adapting the structural features framework to address computation: Exploring student preferences when calculating expectation value

**Primary Contact: Benjamin Schermerhorn, Cal Poly Pomona**

A common activity in undergraduate quantum mechanics (QM) involves calculating expectation values. Analysis of written exam data given at three universities (teaching spins-first QM) showed students had a tendency to use matrix or integral calculation in situations where it is much simpler to use the summation method. To investigate students' use of and preferences for the various methods, interviews were conducted at two universities in the middle and end of the semester. Adapting Gire and Price's framework for categorizing structural features of different quantum mechanical notation, we analyze student responses to expectation value problems to highlight specific areas of difficulty and features of the methods which led to students' choices of one method over another.

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Symposium Talk 2

### Assessing the math+physics conceptual blend: A new mathematical reasoning inventory for introductory physics

**Primary Contact: Suzanne White Brahmia, University of Washington**

Mathematical reasoning flexibility across physics contexts is a desirable learning outcome of introductory physics, where the "math world" and "physical world" meet. Physics Quantitative

Literacy (PQL) is a set of interconnected skills and habits of mind that support quantitative reasoning about the physical world. We present the PIQL, Physics Inventory of Quantitative Literacy, which is currently under development in a multi-institution collaboration. PIQL assesses students' proportional reasoning, co-variational reasoning, and reasoning with signed quantities in physics contexts. Unlike concept inventories, which assess conceptual mastery of specific physics ideas, PIQL is a reasoning inventory that can provide snapshots of student ideas that are continuously developing. Item distractors are constructed based on the different established natures of the mathematical objects in physics contexts (e.g. the negative sign as a descriptor of charge type and the negative sign as indicator of opposition in Hooke's law). An analysis of student responses on PIQL will allow for assessment of hierarchical reasoning patterns, and thereby potentially map the emergence of mathematical reasoning flexibility throughout the introductory sequence. (NSF DUE-IUSE # 1832836)

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Symposium Talk 3

## How many calculus concepts are grounded in meanings in math classes that do not align well with how those same concepts are used in science

**Primary Contact: Steven Jones, Brigham Young University**

Beginning in the mid 1900's, the academic departments of mathematics and natural sciences have been drifting apart, leading to the following problem. Because many mathematical concepts can have multiple meanings associated with them, it is possible for certain meanings to be developed and focused on within mathematics classes in a way that does not align well with how those same concepts are used or reasoned about in science. This appears to be true for several calculus concepts, including the derivative, the integral, and Taylor series, among others. I use pieces of frameworks on "centers of focus," "ways of thinking," and "concept projection" to briefly illustrate (a) the conceptual grounding given to these concepts within typical calculus classes, (b) the resulting types of meanings many students may develop for these concepts in their calculus classes, and (c) why that can lead to difficulty for students in using these concepts in science coursework. The hope is that by knowing what kinds of meanings their students have developed within their calculus classes, science instructors would be in a better position to work with students' current understanding -- and to develop that understanding -- in ways that can better help those student in using calculus concepts in science classes.

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Symposium Talk 4

## Student Meanings for Eigenequations in Mathematics and in Quantum Mechanics

**Primary Contact: Megan Wawro, Virginia Tech University**
**Co-authors: John Thompson and Kevin Watson**

Students encounter advanced mathematical concepts in both mathematics classes and physics classes. What meanings do they develop about the concepts across the various contexts? Our research project investigates students' meanings for eigentheory in quantum mechanics and how their language for eigentheory compares and contrasts across mathematics and quantum physics contexts. We present results regarding students' interpretations of a canonical mathematical 2x2 eigenequation, a spin-½ operator eigenequation, and a spin-½ operator equation in which the operation "flips" the spin state. The data consist of video, transcript, and written work from individual, semistructured interviews with 9 students from a quantum mechanics course. Students were asked to explain what the first two equations meant to them and then to compare and contrast how they conceptualize eigentheory in the two contexts. They were then asked to discuss the third equation. Using discourse analysis and symbolic form analysis, results characterize students' nuanced imagery for the various equations and highlight instances of both synergistic and potentially incompatible interpretations.

## Thursday, July 25, 8:00am Cascade E
## Parallel Session Cluster I: Workshop

### Bright Approaches to Informal Physics Education for New Audiences

**Jessamyn Fairfield, NUI Galway**
**Co-authors: Shane Bergin, University College Dublin**

Informal learning initiatives need to engage with a diverse range of communities. While well-intentioned, a large number of informal physics programmes are 'preaching to the converted'. Finding formats that achieve diversity of engagement provides both challenges and opportunities for practitioners and researchers of informal learning. This workshop will see participants actively engage with strategies and pedagogies that broaden the reach of informal learning opportunities in physics. Grounded in the experiences and research activities of Dr Jessamyn Fairfield and Dr Shane Bergin, the workshop will ask 'how can your informal physics programmes engage hard-to-reach communities?'. The practical session will blend evidence-based approaches with the informal learning goals of those who attend. Drs Bergin and Fairfield will draw upon experiences with projects like: i) Bright Club: a research/comedy variety night that spans disciplines and brings researchers into informal pub environments in high-production value events across Ireland, ii) Soapbox Science: an international event bringing science to the streets, capturing passers-by and highlighting the active role of female researchers in STEM fields, iii) City of Physics: a 'hack the city' campaign across traditional and new media that sparked conversations on physics in Dublin Ireland This workshop will also include active components drawn from the training for these projects, where participants will learn how to craft written and oral communication about physics to engage diverse communities. Positive outcomes for this workshop might include i) making connections with other PERC attendees who share your goals and wish to grow the potential of their own projects (or ideas for a project), ii) learning about strategies and pedagogies that have engaged broad audiences, iii) a community-level discussion around establishing research norms for best practice.

## Thursday, July 25, 10:45am Cascade A
## Parallel Session Cluster II: Talk Symposium

### Critical Theory as a Research Framework for Addressing Injustice in Physics Education

**Jayson Nissen, U. Maine**
**Co-authors: Ben Van Dusen, Katemari Rosa, Jackie Chini, and Adrienne Traxler**

While chemistry, mathematics, and biology have made consistent progress toward gender equity, advancements in equity for physics have largely stagnated over the last thirty years. Far less attention has focused on the representation of Communities of Color in physics than on gender inequities, and there is little indication of systemic progress in this area. Most studies in Physics Education Research are not designed to address the role of gender/sexism, race/racism, class/classism, and disability/ableism in student learning and attitudinal development. Most studies in Physics Education Research are also conducted at research-intensive, primarily White institutions. Adopting theoretical frameworks explicitly created to address these inequities may provide physics educators and physics education researchers the perspective required to begin improving equity in physics. Critical Theories, such as Critical Race Theory, are one set of theories that focus on the role of power in the lived experiences of students and educators. As such, Critical Theories support research that looks at inequities in power between and within institutions and classrooms to inform the systemic power structures that drive inequities. Critical Theories stand in stark contrast to the objective, distant, and cold scientific stance central to physics because Critical Theories have an open and activist agenda. Critical Theorists seek not simply to enumerate inequities but to address those inequities. This session will include talks from scholars on their use of Critical Theory to address racism, sexism, and ableism in physics instruction with both qualitative and quantitative studies. We invite participants to question the underpinning ideologies in their own research and to consider the systemic power dynamics at their own institution that support or harm the success of students from marginalized groups.

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Symposium Talk 1

### Asking different questions: Critical Theory lessons for physics education

**Primary Contact: Adrienne Traxler, Wright University**

The work of Critical Race Theory (CRT) has been taken up and expanded in various fields including education. One key CRT theme is racism as "normal science," the idea that it is ordinary and embedded in society. Another is interest convergence, the idea that advances in civil rights only happen when they also favor white people. I will argue that both of these themes can be observed in many physics departments today. They are also influential in physics education research. I will discuss examples using tenets from two related Critical Theory areas: Critical Disability Studies and DisCrit (Dis/Ability Critical Race Studies). Because racism and related power structures are so embedded in our academic institutions, it takes equally powerful tools to frame research studies that disrupt rather than support these hierarchies. Critical Theory is one place to find these tools.

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Symposium Talk 2

## Equity in College Physics Student Learning: a Critical Quantitative Intersectionality Investigation

**Primary Contact: Ben Van Dusen, CSU Chico**
**Co-authors: Jayson Nissen**

We investigated the intersectional nature of race/racism and gender/sexism in broad scale inequities in physics student learning using a critical quantitative intersectionality framework. To provide transparency and create a nuanced picture of learning, we problematized the measurement of equity by using two competing operationalizations of equity: Equity of Individuality and Equality of Learning. These two models led to conflicting conclusions. The analyses used hierarchical linear models to examine student's conceptual learning as measured by gains in scores on research-based assessments administered as pretests and posttests. The data came from the Learning About STEM Student Outcomes' (LASSO) national database and included data from 13,857 students in 187 first-semester college physics courses. Findings showed differences in student gains across gender and race. Large gender differences existed for White and Hispanic students but not for Asian, Black, and Pacific Islander students. The models predicted larger gains for students in collaborative learning than in lecture-based courses. We discuss the implications of these mixed findings and identify areas for future research using critical quantitative perspectives in education research.

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Symposium Talk 3

## Exploring Assumptions of Dis/Ability in Physics Education

**Primary Contact: Jacquelyn J. Chini, University of Central Florida**
**Co-authors: Erin M. Scanlon**

One goal of many physics education researchers is to broaden the participation in the physics community. However, even socially just and radical teaching perspectives often center "an inherently able-bodied (or as we would term ableist) soldier: a guerrilla fighter physiologically and psychologically tooled up for action" (Goodley, Lawthorm, Liddiard & Runswick Cole, 2017). Our research agenda explores the impacts of ableism along several dimensions of physics participation, including instructional and mentoring practices. I will discuss how we use critical frameworks to: 1) question how we categorize impairments and situate disability as an individual problem of the "disabled person" versus barriers constructed through organizational attitudes, processes and practices; 2) inform our inclusion of research team members; and 3) connect research and practice.

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Symposium Talk 4

## Research, practice, and activism: when Critical Race Theory meets the classroom

**Primary Contact: Katemari Rosa, Universidade Federal da Bahia**

I have been researching Physics Education through the lenses of Critical Race Theory and Methodology, teaching undergraduate courses for physics majors, and working with graduate students in a Science Education program. At the same time, I gather with anti-racist grassroots groups and people trying to fight systemic inequalities in Brazil. In this presentation, I will discuss

how CRT intertwines my research, teaching practices, and activism. Besides, I argue that CRT perspectives can be helpful to decolonize academia. The discussion is an invitation for us to think, collectively, about what does it mean (or what it looks like) to be a CRT researcher in physics education.

## Thursday, July 25, 10:45am Cascade B
## Parallel Session Cluster II: Talk Symposium

### Blending Physics and Other Interests (In and Out of the Classroom)

**Brean Prefontaine, Michigan State University**
**Co-authors: Katie Hinko**

In this session we will explore the intersection of physics with musics, sports, hobbies, the arts, and the many other areas of interests that are experienced by physicists and how to bring this into an informal or classroom setting. Many examples of these blended spaces exist, for instance, music and physics classes, cooking and physics workshops, "Physics of XYZ" books and media, summer camps blending art and physics, etc. This session will start with a 10-15 minute, non-traditional activity from a physics lesson, such as a yoga/physics activity, to give all attendees a shared experience of thinking about physics within a context outside of the discipline. This will be followed by a quick round of introductions from all attendees so that we can get a sense of their interests for discussion. We will then have three distinct talks, each 5-10 minutes in length, that explore 1) the theories that inform the design of these spaces, 2) the diverse contexts that already exist where physics and other topics are being explored (including examples of real informal programs and classrooms), and 3) the ways learners can make meaning and build identity from these activities. The second half of the session will start with a 30 minute discussion that we will tailor to the interests of the attendees. Each small group will be tasked with creating an artistic (drawing, skit, performance, etc) representation of their discussion that will be shared out during the final fifteen minutes of the session. We will share output from this session with the attendees including notes taken during this session, documentation of the artistic products created, and any design considerations discussed.

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Symposium Talk 1

### Performing Physics: An Analysis of Design-Based Informal STEAM Education Programs

**Primary Contact: Simone Hyater-Adams, University of Colorado Boulder**

Informal educational programs that integrate the arts with sciences technology engineering and mathematics, or STEAM, are growing in prominence, including within informal physics. There are learning and social benefits that can come from blending physics with arts through STEAM education. One benefit that drives this work is the ability of STEAM programs to shift the exclusive culture of typical science learning environments, which is especially relevant to typical physics settings. However, there is room in the literature to understand the different ways we can integrate arts and STEM. This work presents two models for a design-based informal STEAM program that integrates performance art and physics content. We analyze artifacts, video and interview data from a "performing physics" program that was designed and run in the fall of 2015. We use this analysis to inform a second model of the program that will run at the end of this summer.

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Symposium Talk 2

### The Art Lab Project: The Schrodinger’s Cat is in Town!

**Primary Contact: Dena Izadi, Michigan State University**

Physics seems to be intimidating for the general public and art is a powerful medium that can be used to visualise physics. We organized the first session of 2-hour public workshop series that brought together physicists, artists and the public in a venue that physics phenomena was communicated through art. Guest physicists present one or several physics concepts briefly and broadly via a short (5-10 minute) ignite talk/presentation.The audience, with the help of both artists and physicists in the room, are encouraged to use words/figures/cardboards/printed pictures/paint/other media in order to create visual posters of the concepts presented.The activities take place in several groups and the best work is selected by the public. These events are co-hosted and sponsored by the The Eli and Edythe Broad Art Museum at MSU.

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Symposium Talk 3

## We Are Not Only Physicists: Creating Spaces That Support Students in Many Ways

**Primary Contact: Brean Prefontaine, Michigan State University**

Creating informal physics experiences that support students by integrating personal interests with physical concepts can provide a unique opportunity for students to cultivate multiple identities. These blended spaces present activities that allow learners to make meaning in ways that might not otherwise be possible and build meaningful interest in physics. Informal physics programs that intentionally blend physics learning with other areas of interest (art, music, sports, etc.) allow for supportive of more than just the student's physics identity, including their racial, cultural, and gender identities. Considerations for program design and implementation will be discussed as well as current efforts to research and understand existing informal programs intentionally blending physics and other interests. Finally, work that is aiming to create new programs and frameworks for understanding program design and identity support will be discussed.

# Thursday, July 25, 10:45am — Cascade C
# Parallel Session Cluster II: Poster Syposium

### Museum-based physics education research through research-practice partnerships (RPPs)

**Danielle Harlow, University of California Santa Barbara**
**Co-authors: Ron Skinner, Alexandria Hansen, Alexandria Muller, Meghan Macias, Jasmine McBeath, Jasmine Marckwordt, Javier Pulgar, Alexis Spina, Erik Arevalo, Krista Lucas**

MOXI is an interactive science center focused on physical science topics. MOXI's exhibits and education program are informed by Physics Education Research and the Next Generation Science Standards (NGSS). MOXI is an outstanding laboratory for research on how people learn physics through interactive experiences and how best to support this learning. However, conducting research in public spaces with diverse audiences differs from classroom based research. These differences provide both opportunities and challenges. Effective research and program design requires multiple types of expertise including content, research design, and informal environments. In MOXI's first two years of operation, we have conducted research across a wide variety of participants and topics through a research-practice partnership (RPP) model. This session will focus on establishing RPPs and methodological considerations when conducting research in informal science education settings such as interactive science centers.

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Symposium Poster 1

### Design-based research project to develop a science and engineering education program linking field trip experiences to classroom experiences.

**Primary Contact: Ali Muller, UCSB**
**Co-authors: Ron Skinner, Danielle Harlow**

The Next Generation Science Standards have incorporated engineering standards, requiring K-12 teachers to teach engineering. Unfortunately, teachers are ill-prepared and have little comfort to introduce these unfamiliar complex topics into their classrooms. The University of California at Santa Barbara and MOXI, The Wolf Museum of Exploration + Innovation partnered up to tackle this problem and bring physics-related engineering activities to teachers through the MOXI Engineering Explorations program. This poster will explore the development process and the research methods used to evaluate the programming including key challenges that arose from working with a museum outreach program. These include the collection of permission from multiple institutions, tracking program effectiveness over different facilitators, time constraints, and more.

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Symposium Poster 2

### Developing interactive activities about complex topics for all ages: Quantum ideas in interactive science centers

**Primary Contact: Jasmine Marckwordt, UCSB**
**Co-authors: Ali Muller**

Quantum computers, which depend on quantum properties to solve complex problems, have the potential to transform the way we solve problems as diverse as data encryption, finding cures for cancer, and solving world hunger. The goals of the NSF-funded research project EPiQC include activities and resources to help the public develop ideas related to quantum computing. As part of this goal, we developed interactive activities to introduce ideas that will help the public grapple with concepts that will build a foundation for thinking about quantum computing. These activities are appropriate for museums, science nights, and other outreach events that serve an audience of varied ages and backgrounds. These activities developed through designed-based research by an interdisciplinary team that includes computer scientists, education researchers, and museum staff. Iterative development of each activity was informed by the trials with visitors of various ages and educational backgrounds at an interactive science center.

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Symposium Poster 3

### Educating informal educators to facilitate learning through practice-based facilitation.

**Primary Contact: Ron Skinner, MOXI, The Wolf Museum of Exploration + Innovation**
**Co-authors: Danielle Harlow, University of California, Santa Barbara**

Interactive science centers are moving towards focusing on the visitor experience rather than on disseminating information. Moving from the expected content-based learning to the less directed learning through exploration requires changing visitors' mindsets not just about the role of a museum, but also about science - from viewing science as a collection of facts and ideas to viewing science as a way of thinking and engaging with phenomena that can be developed and practiced. Through a Research-Practitioner partnership, we developed a year-long museum educator training and certificate program designed to train floor staff to engage visitors in facilitation that engages visitors in the practices of science and engineering. Continuous research on the museum educators' learning and visitor experience informs iterative program development. We discuss the methods of researching museum educators facilitation and impact on the visitor experience.

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Symposium Poster 4

### Fabricating fidgets with special education students. Study of middle school students with disabilities designing, fabricating, and testing fidget tool

**Primary Contact: Alexandria Hansen, CSU Fresno**

This poster describes the design process of 5 middle school students diagnosed with Attention-Deficit/Hyperactivity Disorder (ADHD). Students were tasked with designing and fabricating a personalized fidget-a small hand-held object to use in a classroom with the goal of increasing focus-by following the process of engineering design described in the Next Generation Science Standards. Students teamed with a local science museum to access tools and expertise. Analysis of student interviews and recorded design sessions revealed that students accurately defined the problem and design constraints. Further, despite issues in measurement precision, students successfully optimized their design solution over time through multiple rounds of revision.

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Symposium Poster 5

### Introducing Children to Computer Coding in Virtual Reality in an Interactive Science Center

**Primary Contact: David Sanosa, UCSB**
**Co-authors: Jim Gribble**

We developed and tested a virtual reality coding environment intended to provide a new way to engage children in learning computer coding. In order for meaningful learning to occur in a virtual reality (VR) environment, designers and facilitators must pay special attention to the learner's understanding of how to interact with a VR application. This environment was tested in the interactive science center. We investigated facilitation techniques and children's interactions. The research design and methods are applicable across other content areas such as VR experiences to develop physics understanding.

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Symposium Poster 6

### Magnetism, light, structures, and rotational motion: Mixed-methods study of visitors engaging with four exhibits at a science museum

**Primary Contact: Meghan Macias, UCSB**
**Co-authors: Jasmine Nation, Jasmine Marckwordt, Krista Lucas, Erik Arevalo**

This poster describes mixed-methods research conducted at four exhibits by four teams of graduate students and museum practitioners through a research practice partnership (RPP) model at an interactive science museum in southern California. Two projects modified or manipulated the exhibits or facilitation strategies to assess the impact on guest stay time at the exhibit. These focused on Keva planks, which small wooden planks guests can use to make structures and Turn Tables, a rotating table that visitors place objects on. Two other projects used mixed methods including qualitative observations to analyze guest behaviors when interacting with each exhibit. One focused on ways that visitors engaged with Magnetic Islands, a small magnetic structure guests can attach magnetic washers to and the other focused on early childhood interactions with Light Patterns, a life-sized color peg board.

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Symposium Poster 7

### Math and Making. Study of visitors exploring mathematics through knot tying, string art, tessellations, and minimal surface bubbles.

**Primary Contact: Alexis Spina, UCSB**
**Co-authors: Javier Pulgar, Jasmine Nation**

The Math and Making poster describes an innovative workshop held at a local science museum in southern California, featuring four week-long maker activities designed for children grades K-8. Throughout the workshop, students were introduced to the behind-the-scenes mathematics of real-world experiences, such as concepts in geometry through string art and understanding surface area by creating bubbles. Student participation in these activities was through open exploration instead of a guided lesson, although facilitators were there to assist when needed. We examined how students interacted with the maker math activities, and the connection these activities had to the Eight Mathematical Practices established by the Common Core State Standards for Mathematics.

Preliminary results show how the math practices were present in the design and student uptake of the activities, providing insight into how to structure and implement math lessons that are interactive and relevant to children's everyday lives.

# Thursday, July 25, 10:45am Cascade D
# Parallel Session Cluster II: Talk Symposium

## Teaching 3D Physical Concepts Using Virtual and Augmented Reality

**Jared Canright, University of Washington**
**Co-authors: Rebecca Vieyra**

Physics education researchers have begun to explore the impact virtual and augmented reality (VR and AR) tools can have on student understanding of three-dimensional concepts, such as electromagnetic fields and forces and the motions of celestial bodies. This session proposal means to bring these research efforts and their associated VR and AR experiences together in the same room to share insights into virtual environment design practices, classroom implementation, and assessment strategies. Further, it is meant to showcase to the physics education research community the current state of VR and AR applications for physics education in enhancing student understanding of 3D concepts. The first half of the session will consist of ~10-minute oral presentations in a rotating symposium format, describing the VR/AR application(s) each presenter is studying, their PER goal(s) for said application, and the findings of their project. The latter half of the session will consist of a demonstration showcase. Every presenter will have VR/AR equipment set up, ready for any participants to experience the presenters' applications for themselves, learning by example how VR and AR technologies can improve student understanding in ways previously impossible. Participants will be able to ask questions of the presenters during the demo showcase, digging deeper into the unique challenges presented in the development, implementation, and assessment of VR and AR teaching tools. To facilitate lasting impact and conversation around this topic, a write-up describing each presenter's application, research goals, current results, and (where possible) a link to a current build of their application will be collected and disseminated following the session.

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Symposium Talk 1

## A controlled study of Smartphone-based Virtual Reality in Freshman Electricity and Magnetism

**Primary Contact: Chris Porter, Ohio State University**
**Co-authors: Chris Orban, Amber Simmons, and Joseph Smith**

Our group has developed a series of virtual reality apps for smartphones in Google Cardboard headsets to help students visualize electric fields, magnetic fields, and related structures, such as Gaussian surfaces. We prepared sets of highly 3D questions in these areas to function as pre- and posttests. While these sets are exploratory, we will discuss their reliability. In addition to a VR treatment group, one group worked with nearly identical material on a traditional computer screen, and a third group acted as a control, receiving only 2D static images as in a textbook. We present selected findings in student performance on the pre- and posttests, as well as student feedback on the treatments.

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Symposium Talk 2

## Cooperative Exploration of Electric Fields and Charges using AR

**Primary Contact: Steven Binz, Salisbury University**

Using modern augmented reality (AR) headsets students can create and move simulated electric charges and observe how their manipulations change the electric field in three dimensions, as well as how the charges move due to the surrounding field. All students see the same content in the same part of the room and because this is AR, the students can also see each other - allowing natural interactions between them as if the simulated fields and charges were really in the room. Research is ongoing but student feedback indicates that the experience is not only fun, but it also helps them understand the material. The overall goal is to determine if we can improve student understanding by providing them with new representations that allow them to interact with concepts in ways they could not previously.

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Symposium Talk 3

## Supporting Students' Visualization of Magnetic Fields with Smartphones and AR

**Primary Contact: Chrystian Vieyra, Vieyra Software**
**Co-authors: Rebecca Vieyra**

Using only a smartphone, we have developed an app that permits learners to anchor magnetometer measurements to 3-D space that can be viewed through the camera. We have prepared a series of exploration protocols that help users explore background and non-idealized magnetic fields. Our preliminary work with users suggests that exploration with this technology helps students to think critically about the limitations of idealized field models and recognize the complexity of environmental fields.

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Symposium Talk 4

## Teaching Gauss's Law using Virtual Reality: Motivation and Implementation

**Primary Contact: Jared Canright, University of Washington**

Virtual reality (VR) laboratory and tutorial exercises hold promise for enhancing student understanding of 3D concepts and phenomena, especially those that are otherwise difficult or impossible to experience directly. Gauss's Law poses difficulties for students that have proven resilient to many forms of instructional intervention. This work presents data that highlight particular student difficulties with the concepts underlying correct understanding and application of Gauss's Law and provide a backdrop
to motivate the development of a VR learning environment on this topic. Further, we describe, from instructional and software development perspectives, the design and implementation of virtual exercises and tools to elicit and confront these difficulties in the virtual learning environment.

## Thursday, July 25, 10:45am Cascade E
## Parallel Session Cluster II: Workshop

### Video Analysis of Student Thinking in Labs

**Luke Conlin, Salem State University**
**Co-authors: Natasha Holmes, Emily Smith, Anna Phillips, Diana Sachmpazidi, Katie Ansell**

Labs are an important component of learning physics. They can provide students with hands-on experiences to help them learn experimental methods and/or empirical ways of thinking. Many instructors are shifting away from traditional overly-structured, verification labs, focusing instead on supporting students in taking up more agency during experimentation. But little is known about how students develop the various skills or engage with these more open-ended activities. How do students learn to design their own experiments? How do students learn to quantitatively assess whether their data answer their question, or support their hypothesis? How do students work together productively in groups to accomplish the goals of lab? What barriers to participation exist in lab, and how can they be addressed?

Video analysis of student interactions during lab can be a powerful research tool to address these questions by uncovering the processes by which student groups learn to think critically together. In this workshop, various research teams who are currently analyzing video data of students in lab will each present a video clip for collaborative analysis. Participants will break into small groups to collectively view and discuss the clips. A subsequent whole-group discussion will synthesize lessons learned about specific student interactions as well as insights into the process of conducting video analysis of student thinking in physics labs. This workshop will highlight innovative approaches to researching students' thinking in reformed labs. It will also provide participants with opportunities to learn about video analysis methods through conducting some preliminary analyses and discussing the process.

## Thursday, July 25, 10:45am — Soldier Creek
## Parallel Session Cluster II: Juried Talk Session

### Juried Talks II

### Organizing Committee, PERC

This session consists of four juried talks.

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Juried Talk 1

### Analyzing the role of evidence in the model revision process.

**Primary Contact: Sarah K. Braden, Utah State University**
**Co-authors: Lauren Barth-Cohen**

The Next Generation Science Standards promote modeling as an important scientific practice. However, instruction often leads students to create models of phenomena that lack mechanistic thinking and explanatory power. To better understand how students develop scientific models and how they use evidence to revise their models, this study compares cases of model revision from a 7th grade a unit on magnetism. Audio and video recordings of small groups and copies of student work were collected across multiple phases of instruction and coded using an existing framework for mechanistic reasoning with additional codes for students' uses of evidence. Results indicate that the individual and group models were pervasively mechanistic but that students used evidence to support their reasoning during unexpected moments in instruction. This presentation includes the analysis, instructional materials, and copies of student work for the audience to examine and discuss.

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Juried Talk 2

### Impact of Group Work on Cognitive Load and Conceptual Test Performance

**Primary Contact: Tianlong Zu, Purdue University**
**Co-authors: N. Sanjay Rebello**

We investigated the effect of group work on students' conceptual test performance from a cognitive load perspective. Half students completed a conceptual test and a cognitive load survey both individually and in a group in the beginning and end of the semester. The other half complete all tests individually at all time. We found that group testing significantly improved test performance. More importantly, we found a significant interaction between the time the test is taken (beginning or end) and test format (individual or group) indicating that the performance improvement from individual to group testing is significantly larger at the end of the unit than that at the beginning. Furthermore, working on the same test individually twice revealed no significant difference in testing performance. Cognitive load survey results showed working in groups could maintain a high level of germane load even though it may increase the extraneous load experienced by students.

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Juried Talk 3

## Square Peg Thinking, Round Hole Problems

**Primary Contact: Brian Farlow, North Dakota State University**
**Co-authors: Marlene Vega, Alden Bradley, Chaelee Dalton, Ruby Kalra, Jordan Brainard, Michael Loverude, Warren Christensen**

Our research team seeks to develop research-based curriculum to aid students in translating across the math-physics interface in the upper division, specifically in the areas of basic vector concepts within various spatial coordinate systems. We developed an interview protocol and conducted 7 interviews with subjects at the junior undergraduate level and higher with analysis guided by Resource Theory. A case study and analysis of a common response type – making curvilinear-coordinate position vector expressions look like those of Cartesian coordinates – revealed a tendency for students to inappropriately activate resources productive in Cartesian coordinates in curvilinear coordinate situations. Analysis of Calculus textbooks revealed Cartesian-coordinate-based instruction comprised 95% of the content of those texts. Calculus III students also showed combinations of productive and non-productive ideas about these vector ideas at the end of their courses. We report in more detail and outline how our findings will inform future instructional material development.

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Juried Talk 4

## Student Reasoning about Eigenvectors and Eigenvalues from a Resources Perspective

**Primary Contact: Megan Wawro, Virginia Tech University**
**Co-authors: Warren Christensen, Kevin Watson**

**Eigentheory is an important concept for modeling quantum mechanical systems. Research findings indicate that eigentheory is conceptually complex for students to deeply understand. The focus of this research is students' reasoning about eigenvectors and eigenvalues of 2x2 matrices as they transition into quantum mechanics. The data consist of video, transcript, and written work from individual, semi-structured interviews with 17 volunteer students enrolled in a quantum mechanics course from one of two universities. Responses were analyzed using a Resources (Hammer, 2000) framework, which allowed us to characterize nuances in how students understand various aspects of an eigentheory problem. We share three subthemes of results: interpreting the equations graphically, interpreting the equals sign, and determining solutions. These results are consistent with and extend previous research findings regarding not only how students reason about eigenvectors and eigenvalues but also about how students make sense of an equation, its components, and its solutions.**

## Thursday, July 25, 1:30pm Cascade A
## Parallel Session Cluster III: Talk Symposium

### Understanding and assessing problem-solving in introductory physics

**Eric Burkholder, Standford University**
**Co-authors: Argenta Price**

Expert-like critical thinking and problem-solving skills are often lauded as outcomes of an undergraduate STEM education, and are highly sought-after by potential employers of physics graduates. While many heuristics for problem-solving and some research on expert problem-solving exists, there is little evidence showing that we are training students to become good problem-solvers or critical thinkers. Moreover, previous work on expert versus novice problem-solving has two important limitations: 1) The experts used are often graduate students, and may not be fully-developed experts in their field. 2) The "problems" used in these studies are not authentic--for the true expert these are merely exercises that one might find in a normal introductory textbook. In this session we will discuss recent work to advance our knowledge of how experts solve problems, of how to construct authentic problems and improved assessments of problem solving in students, of how students interact with complex problems, and of instructional practices to help students improve their problem-solving skills. Current work identifying how experts--including STEM faculty and industry experts--think and solve problems they encounter in their work has shown that experts across disciplines make a remarkably consistent set of decisions when solving problems. Based on these findings, we discuss work on designing assessments of the many skills used when solving complex problems, and current work on how students interact with complex problems. The ultimate goal of these assessments is to improve instruction by providing feedback to instructors and undergraduate programs about whether their students are learning expert-like critical thinking and problem-solving skills. We will also discuss methods to teach expert-like problem solving skills in the classroom, which emphasize students practicing making the same decisions that experts make when solving problems along with formative feedback from the instructors.

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Symposium Talk 1

### Assessing adaptive expertise in undergraduate engineering curricula

**Primary Contact: Eric Burkholder, Stanford University**

Engineering programs frequently claim that they teach undergraduate students how to be good problem solvers; however, there has been no research to-date that demonstrates this, in no small part due to the fact that measuring problem-solving is quite difficult. We characterize problem-solving skills exhibited by experts as elements of "adaptive expertise," which includes critical thinking, problem-solving in novel contexts, and the ability to learn and adapt to new situations. We develop an instrument in the context of chemical process design that aims to assess elements of adaptive expertise, and how closely student thinking aligns with this framework. Preliminary investigations reveal that some students lack particular problem-solving skills; most salient is the apparent absence of a predictive framework when solving a problem. This lack of a framework leads students to make fatal errors in problem-solving, including some that they receive explicit instruction in during introductory courses. This research shows that problem-solving may not be a guaranteed byproduct of an undergraduate STEM education.

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Symposium Talk 2

## Building up to complexity: synthesizing multiple concepts to solve problems

**Primary Contact: Andrew Heckler, Ohio State University**

Since complex, authentic problems inevitably involve multiple concepts, it can be productive to investigate student solution processes for relatively simple "synthesis problems" that involve a small number of concepts. For example, we find that even simple synthesis problems require qualitatively different solution methods compared to single-concept problems that are commonly used in physics courses. Through a series of studies, our team has found a number of important factors that influence the problem solving process and can interfere with recognition of the need for multiple concepts and hinder their joint application once the relevant concept are identified. These factors can include the mathematical complexity of the solution process, whether the relevant physical phenomena are temporally simultaneous or sequential, and whether there are large differences in the cognitive availability of the relevant concepts. Further, we find that employing carefully designed worked examples and guiding students through self-explanations and analogical comparisons of the structure can significantly improve performance. Finally, we hypothesize how these insights might be used as tools to build skills for solving complex, real world problems.

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Symposium Talk 3

## Development of a Practical Problem Solving Assessment Tool

**Primary Contact: Wendy K. Adams, Colorado School of Mines**
**Co-authors: Adria Brown**

Motivated by an interest to better understand student's strengths and weaknesses in problem solving and the desire to compare instruction across institution, we developed the CAPSS – the Colorado Assessment of Problem Solving. While developing the instrument, we empirically identified over 40 distinct sub-skills that affect a person's ability to solve complex problems in many different contexts. The original CAPSS is an open-ended instrument that requires either a two hour interview or, if completed as a paper and pencil assessment, an hour to grade by a trained evaluator. Therefore it is not a practical tool for an instructor to use in their teaching. Over the past year, we have been developing a forced-answer version of CAPSS with the goal of efficiently scoring as many sub-skills as possible. We will share progress to date as well as future plans for further development.

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Symposium Talk 4

## Identifying expert problem solving decisions

**Primary Contact: Argenta Price, Stanford University**

Multiple frameworks, from the "scientific method" to Chi's work on problem solving by experts vs. novices, have been used to describe how scientists solve problems. We add to this work by developing a framework, based on empirical evidence from experts solving authentic problems in their work, of detailed problem solving decisions that experts make when solving problems. We developed an initial list of decisions from interviews with faculty members and industry experts, then conducted a second, structured, set of interviews to test and refine the list. In the structured interviews we asked scientists, engineers, and doctors to think about a problem they solved in their work and walk us through the detailed decisions they made during the solution process. We were struck by how, at a high level, the decisions made by experts across STEMM fields were remarkably similar. From these interviews, we generated a list of around 40 decisions that most STEMM experts make when solving authentic problems. This list of decisions has implications for teaching and assessment, because in order to become expert-like problem solvers, students will need to practice making the decisions that experts make.

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Symposium Talk 5

## Improving Problem-solving Through Reflective Training

**Primary Contact: Shima Salehi, Stanford University**

**Effective science and engineering education goes beyond teaching content knowledge, and encompasses training problem-solvers who can use their knowledge in practice to solve complex problems. While over the past decade, the science and engineering education community (NRC 2012, NGSS) has acknowledged the significance of training good scientific problem-solvers, there remain essential questions to be addressed: "What are the characteristics of good scientific problem-solving?", and "how should we teach scientific problem-solving?" In a series of studies, we have addressed these two questions. In our previous works, we have identified major problem-solving practices used in solving complex problems. Based on the identified practices, we have designed a problem-solving training program, called reflective problem-solving. In this talk, we will describe the reflective training, and show that: 1) this training indeed improved students' problem-solving; 2) this improvement transcended specific content area, and students' problem-solving improved in a content area different than the content area of their training; and 3) the improvement resulted from the reflective training exceeded the improvement resulted from the standard educational setting of attempting multiple problems and receiving feedback only about the accuracy of their answers.**

## Thursday, July 25, 1:30pm Cascade B
## Parallel Session Cluster III: Workshop

### Measuring the conceptual development of teachers: A data analysis workshop

**Carolina Alvarado, CSU Chico**
**Co-authors: Michael Wittmann**

How should we measure teacher growth when teachers engage in professional learning opportunities? The literature often describes intensive studies of teachers, with observations, interviews, and the analysis of teaching artifacts. These methods are not feasible for teachers and administrators who, in many states, are under policy pressure to document their growth. In this workshop, we present an alternative method that relies on long time scale observations rather than intensive short time scale observations. Using a set of questions asked over several years, we studied teacher growth three areas of pedagogical content knowledge: content knowledge, knowledge of students' ideas, and understanding of productive pedagogical strategies. Workshop participants will be given teacher data to analyze. While our analysis looked at pedagogical content knowledge, we welcome other perspectives to these data. Further, while we analyzed each strand of questions individually, we plan a discussion of how, if at all, these data suggest ways that content knowledge, knowledge of students' ideas, and choice of pedagogical strategies influence each other. We end the workshop with a discussion of the strengths and weaknesses of our research and measurement tool.

## Thursday, July 25, 1:30pm Cascade C
## Parallel Session Cluster III: Poster Symposium

### Conceptual Design of Informal Physics Programs

### Michele McColgan, Siena College

Informal physics spaces often develop organically from outreach efforts of a grant or from a desire to share a STEM passion with a younger generation. Very rarely are informal physics spaces or programs developed from guiding principles or best practices. Thus, implementation of these programs varies greatly and while we know these programs have an impact on STEM interest, their diversity makes them difficult to study and evaluate. This poster session will provide an opportunity for interested parties to engage in the creation of recommendations for the conceptual development of informal physics programs. The design of these programs may include a discussion of goals of the program, community partnerships, ideal informal environments, choice of participants, choice of physics topics, program length, and selection and training of leaders and mentors. Participants may also share their research experiences in informal STEM programs and insight on topics such as program evaluation, research questions, data collection, and impact. There will be time allotted in the session for presenters and participants to work together to create conceptual designs for different types of informal physics programs.

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Symposium Poster 1

### It's not just about a physics identity: How informal programs can support multiple identities

**Primary Contact: Brean Prefontaine, Michigan State University**

Informal programs that that provide students the opportunity to interact with both physics and other interests (such as sports, hobbies, art, etc.) encourage the growth of multiple identities that are integral to a student. These programs provide support to a diverse range of students and encourage growth in many different areas of a student's identity instead of just focusing on fostering a physics identity. We have been using both the Critical Physics Identity framework and Critical Race Theory as analytical tools for understanding how students are supported within these programs. Furthermore, we are seeking to understand the design principles for creating successful informal programs that can blend student interests with physics.

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Symposium Poster 2

### PISEC: A partnership of physics, research, and youth agency

**Primary Contact: Brett Fiedler, University of Colorado Boulder**

The Partnerships for Informal Science Education in the Community (PISEC) is an informal physics program with strong conceptual foundations in the Fifth Dimension afterschool program model and design-based implementation research (DBIR) methods. PISEC is a joint collaboration between the JILA NSF Physics Frontier Center and the PER group in the physics department at the University of Colorado at Boulder. The continued success of the PISEC program, now over a decade old, can be attributed to many factors. This includes an equal focus on its growth as a physics-focused afterschool program for kids, partner of the local community, and as an active research program. We will share how foundational concepts of the program integrate to form a bi-directional benefit model, past research that has evolved the program, and how research methods are embedded in the program.

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Symposium Poster 3

## Siena Saturday Scholars: How understanding students creates valued outcomes

**Primary Contact: Michele McColgan, Siena College**
**Co-authors: Robert J. Colesante**
**Siena College**
**Education Department**

Out-of-school STEM experiences in elementary and middle school support student exploration during a time when STEM interest typically declines. Many factors are at play for students in underserved communities that may contribute to the decline. The design of our informal STEM program addresses factors to protect against this decline. Program climate and support, ever-changing class offerings, choice of classes, STEM role models, and long-term opportunities are all aspects of the program that we find to be important.  We distinguish and pursue narrative and propositional frameworks for evaluating the program. The former helps us understand students and aspects of their lives outside of the program that impact their interest and pursuit of stem classes. The later helps us examine whether the program has an impact on school outcomes of the students or to determine the characteristics of children who benefit most from the program.

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Symposium Poster 4

## The Design of Performing Physics: using the CPI framework for program structure and analysis

**Primary Contact: Simone Hyater-Adams, University of Colorado Boulder**

The Performing Physics Program integrates performance art (dance, music, spoken word, and improv) with physics content for youth of color. It's design is based off of our prior work using the Critical Physics Identity Framework (CPI) to understand Black identity in physics. In this poster, we discuss the process of our iterative design and analysis of the program using the CPI framework.

## Thursday, July 25, 1:30pm Cascade D
## Parallel Session Cluster III: Workshop

### Using Social psychological intervention to make STEM classrooms inclusive and improve learning

**Tim Nokes-Malach, University of Pittsburgh**
**Co-authors: Yasmin Kalender, Kevin Binning, Chandralekha Singh**

Despite some efforts to encourage women to pursue a career in physics, the percentage of women majoring in physics remains low. There are several frameworks that focus on the dearth of women in physics, which take into account motivational characteristics, e.g., interest in physics, self-efficacy, mindset about intelligence, sense of belonging, and identity as a physicist. We performed a longitudinal analysis of these motivational characteristics of female and male college students in large physics courses along with their performance in those courses. Among other findings, our data suggest that female students had lower physics self-efficacy than male students, even when controlling for performance. Moreover, this self-efficacy gap continued to grow throughout the college introductory physics course sequence. Based upon these findings, we implemented short in-class activities that were designed to improve the inclusivity in the physics courses and address issues related to students' sense of belonging, self-efficacy and intelligence mindset. We found that female students in physics classes who participated in these activities performed significantly better than those who did not, and they were also less likely to withdraw from the courses. These findings also have implications for mentoring a diverse group of students. This workshop will focus on the framework that underlies this type of intervention and participants will be asked to collaboratively consider how they may adapt this type of intervention in their own classroom.

## Thursday, July 25, 1:30pm Cascade E
## Parallel Session Cluster III: Discussion

### PERC 20/20: A Sneak Peek at "Insights, Reflections, & Future Directions: Emergent Themes in the Evolving PER Community

**Steve Maier, Northwestern Oklahoma State University**
**Co-authors: Alexis Knaub, Lin Ding, Beth Cunningham**

Using PERC 2019 as a springboard, we invite attendees to be a part of a dialogue as PERC 20/20 organizers begin making final preparations. To best involve participants in an open discussion, the structure of this parallel session will be an informal discussion facilitated by the PERC 20/20 organizers. In particular, we will explore emergent themes in PER as a scholarly endeavor and as a research community. For example, since its inception PER has served as a confluence of discipline, theory, research methodology, practice, and application. How has this confluence been fruitful for physics education globally, regionally, locally, or otherwise? How has this confluence influenced the very nature of PER itself (those engaged in PER and its infrastructure)? To foster continued collaboration and conversation, a shared documents folder will be made available for review in the weeks prior to the conference and through to PERC 20/20. Reviewing these documents prior to attending the session is not required. Please come to the session ready to ask questions, share ideas, offer suggestions, and contribute!

## Thursday, July 25, 3:15pm
## Closing Session

**Discussion and Reflection**

**Moderator: Mike Bennett**

This relaxed, discussion-based closing session will be led by Michael Bennett from the PERC 2019 organizing committee. During the session we invite 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.

## Utah Valley Convention Center Floor Plans