#### Summer Reading Group for Economists Interested in Physics Education Research<sup>1</sup>

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#### Introduction

Physicists have devoted substantial resources to understanding how their students learn and how to best teach them. Economists are likely to be impressed by their pedagogical research "inputs:"

- 92 physics departments in the U.S. report they have a physics education research group.<sup>2</sup>
- An estimated 516 physicists at PhD granting institutions are active in this area and they have 156 PhD students.<sup>3</sup>
- The program of the Summer 2019 American Association of Physics Teachers conference lists 900 physicists.<sup>4</sup>
- One study found 144 advertised postdoc positions in physics education research over a recent seven-year span.<sup>5</sup>

More interesting than these inputs are the research outputs – there are entire areas of inquiry that are missing in economics education research, while other areas we economists study have been explored much more intensively by physics education researchers. This research by physics education researchers has had a considerable influence on teaching in that discipline – they have created guides for novice instructors on the many misconceptions students bring to the classroom<sup>6</sup>. Further, this research has helped train 40% of new physics and astronomy faculty in a series of four-day teacher-training workshops (Henderson, 2018).

Thus, a study of the physics education research (PER) literature might be of interest to economics educators. It will likely suggest new research opportunities, deepen insights into how our students learn, and generate new ways to improve our students' understanding of economics. To facilitate this exploration, in the summer of 2021, there will be an online virtual reading group on a representative set of PER papers (the schedule is below). Each paper covers one or two of the six categories of physics education research identified in a survey of PER by Docktor and Mestre (2014): conceptual understanding, problem solving, curriculum and instruction (teaching), assessment, cognitive psychology, and attitudes and beliefs about teaching and learning. An additional paper will illustrate recent research on diversity, equity, and inclusion.<sup>7</sup> We will meet every two weeks on Zoom (details below) to discuss one of the seven selected papers.

<sup>&</sup>lt;sup>1</sup> I would like to thank the following for help with this project: Jeff Adams, Cynthia Bansak, Stephanie Chasteen, Rebecca Lindell, Mark Maier, Alex Reinhart, Chandra Anne Turpen, and Carl Wieman. Also, I would like to thank Mark Maier and Scott Simkins for introducing me to PER. All errors remain mine.

<sup>&</sup>lt;sup>2</sup> Retrieved from <u>https://www.compadre.org/per/programs/</u> on May 18, 2021.

<sup>&</sup>lt;sup>3</sup> Barthelemy, Mohamed, and Henderson (2020).

<sup>&</sup>lt;sup>4</sup> See <u>https://www.aapt.org/Conferences/SM2019/upload/AAPT\_program\_sum19\_4.pdf</u>. The 2019 program was chosen as the pandemic might have had uncertain impact on the 2020 conference. While high school instructors participate in this conference, they appear to be a distinct minority.

<sup>&</sup>lt;sup>5</sup> See Knaub, Jariwala, Henderson, and Khatri (2018). These postdoc positions were advertised from 2008 to 2015.

<sup>&</sup>lt;sup>6</sup> In <u>https://www.youtube.com/watch?v=IKZ6HBY3tHo</u> a novice instructor describes how he used this literature and found "it was a little disconcerting how accurate the literature was." In part, this instructor was referencing Knight (2004).

<sup>&</sup>lt;sup>7</sup> Besides matching the categories in Docktor and Mestre (2014), other criteria were used to select these papers: they should be accessible to economists (e.g., no heavy reliance on quantum mechanics or general relativity), they should be of reasonable length, and ideally they should have a substantial literature review or describe common PER research methods.

#### Papers We'll Read

## Paper 1: Wieman, Carl. "Why not try a scientific approach to science education?" Change: The Magazine of Higher Learning 39.5 (2007): 9-15.

*[cognitive psychology]* Carl Wieman is both a leading physics education researcher and a lab scientist.<sup>8</sup> In 2001, he was awarded a Nobel Prize for the creation of a "Bose–Einstein condensate" and after the award all his research efforts have been in PER. This paper describes the pedagogical questions he found to be sufficiently engaging to reorient his career from the lab to classroom research. While the paper describes his research journey, which involves extensive use of the cognitive science literature, it also mirrors the journey of PER in general and serves as a useful introduction to the field.

### Paper 2: Wosilait, Karen, Paula RL Heron, Peter S. Shaffer, and Lillian C. McDermott. "Development and assessment of a research-based tutorial on light and shadow." American Journal of Physics 66.10 (1998): 906-913.

[conceptual understanding and curriculum and instruction] This paper is by the particularly influential PER group at the University of Washington. Here they probe student understanding of light to develop "tutorials," an integrated set of pretests, worksheets, homework, and exam questions on a topic.<sup>9</sup> These tutorials often use the "elicit, confront, resolve" framework. In the pretests and worksheets, students are asked their views on the topic at hand ("elicit"), which often leads to inconsistencies ("confront"). Next, through a series of questions, students resolve the inconsistencies, which leads to a deep understanding of the topic at hand ("resolve"). The authors describe the iterative process of testing and refining the tutorial to improve learning; a key component of this process is in-depth student interviews. As many as 4,000 students at several institutions participated in the development of this tutorial.

A particularly influential conceptual understanding paper that we will not read due to its inaccessibility to most economists is Halloun and Hestenes (1985). Its influence merits a mention here. It describes common misconceptions regarding motion, an essential part of the first semester of physics where highly-nonintuitive Newtonian motion is introduced. This paper led to the design of an assessment that probes students' understanding of Newton's Laws, the "Force Concept Inventory," (Hestenes, Wells, and Swackhamer, 1992). Using this assessment, Hake (1998) found that specific types of active learning lead to much more learning than lecture. These last two papers are among the most cited papers in PER (Google Scholar reports 4,520 and 7,750, respectively), but unfortunately, they are not that accessible to economists. However, "The Problem with Lecturing" in Hanford (2011) contains a popular account that is quite instructive.

### Paper 3: Beichner, Robert J. "Testing student interpretation of kinematics graphs." American Journal of Physics 62.8 (1994): 750-762.

[conceptual understanding and assessment] This paper explores 895 students' conceptual understanding of kinematics, the study of an object's motion. While it is organized around the development of a kinematics assessment, there is considerable discussion of students' understanding of the topic. One finding is that even after instruction many students still have a poor understanding of kinematics. Beyond this paper, this author also has had a considerable impact on the development of "Scale-Up" active learning classrooms in colleges and universities around the world.

This paper is one of many in PER that studies students' conceptual understanding. While a bit dated, McDermott and Redish (1999) list more than 100 studies in this area. Those interested in a more complete guide to the development of

<sup>&</sup>lt;sup>8</sup> Two of his dozen most cited papers are in PER.

<sup>&</sup>lt;sup>9</sup> Much of this group's influence comes from the development of tutorials.

assessments might wish to consult Adams and Wieman (2011). It is worth noting that the PER community has developed more than 100 assessments to measure student understanding of numerous topics.<sup>10</sup>

### Paper 4: Ogilvie, C. A. "Changes in students' problem-solving strategies in a course that includes context-rich, multifaceted problems." Physical Review Special Topics-Physics Education Research 5.2 (2009): 020102.

*[problem solving]* Ogilvie explores how students solve problems, which of course is a key aspect of most physics courses. In a study involving 300 students, the author finds that many students typically use naïve methods that are unlikely to lead to deep understanding. He also explores how students can be guided to use more sophisticated problem-solving methods that can lead to deeper understanding.

### Paper 5: Deslauriers, Louis, Ellen Schelew, and Carl Wieman. "Improved learning in a large-enrollment physics class." Science 332.6031 (2011): 862-864.

[curriculum and instruction and cognitive psychology] This paper compares learning in two sections of a second-semester physics course taught by an experienced, highly rated instructor (the control) and a novice instructor using methods from PER. The novice instructor used a specific form of active learning, "deliberate practice," which comes from studies by cognitive scientists on how experts become experts. Learning over a week of instruction was compared between two 270-student sections. The students taught by the novice instructor learned more as measured by an assessment given the following week; the effect size of the intervention was about 2.5 standard deviations. The design of the study seems rare, if not unknown, in economics education research. Two other papers that explore the impact of teaching with deliberate practice are Jones, Madison, and Wieman (2015) for a senior-level optics course and Lepage (2021) for a graduate-level course.

### Paper 6: Elby, Andrew. "Helping physics students learn how to learn." American Journal of Physics 69.S1 (2001): S54-S64.

[attitudes and beliefs about teaching and learning] This paper explores the "epistemological beliefs" of students – that is, their views of learning and knowledge. Some students view a physics course as a small number of concepts that can be applied in different contexts (a sophisticated approach), while other see the same course as a set of isolated facts to be memorized (a naïve one). Students with different views will likely study differently. This paper measures students' epistemological beliefs with two different assessments and it describes interventions to change naïve epistemological beliefs to more sophisticated ones.

# Paper 7: Binning, Kevin R., Nancy Kaufmann, Erica M. McGreevy, Omid Fotuhi, Susie Chen, Emily Marshman, Z. Yasemin Kalender, Lisa B. Limeri, Laura Betancur, and Chandralekha Singh. "Changing social contexts to foster equity in college science courses: an ecological-belonging intervention." Psychological Science 31.9 (2020): 1059-1070.

*[diversity, equity, and inclusion]* This paper explores a low-cost intervention to boost the achievement of women and underrepresented minorities in several STEM classes. Those in the intervention group had "higher attendance, course grades, and 1-year college persistence." The intervention took the form of students writing about the challenges they face, reading testimonials from more senior students who faced challenges and surmounted them, and a discussion on these topics. About 1,800 students took part in the study. This classroom intervention is in the spirit of one applied to an entering class of college students (Yeager et al., 2016).

The authors of this paper are psychologists, biologists, and physicists. While such "mixed authorship" seems rare in PER, ideas and concepts from other disciplines are more frequently seen in PER papers than ones in economics education

<sup>&</sup>lt;sup>10</sup> See <u>https://www.physport.org/Assessment.cfm</u> . Retrieved on May 18, 2021.

research (e.g. the category of cognitive science in the review of the PER literature by Docktor and Mestre (2014)). Indeed, STEM education researchers are starting to see themselves as a set of closely related and connected "DBER" (disciplinebased education research) communities and there are efforts to formalize these connections (O'Neil, 2017). There are actually joint conferences, like one held by CIRCLE (Center for Integrative Research on Cognition, Learning, and Education) at Washington University in St. Louis.<sup>11</sup> Note that "biology, chemistry, computer science, education, engineering, geoscience, mathematics, neuroscience, occupational therapy, pharmacy, physics, and psychology" were represented at this conference while economics was not.

#### Schedule

All Zoom sessions will be on a Friday from 3:00 PM to 4:00 PM, U.S. Eastern time (if there is sufficient interest other times and dates will be added). All are welcome to attend any session or sessions that might be of interest. For the Zoom link, please contact Bill Goffe, <u>bill.goffe@psu.edu</u>.

May 28: Paper 1: Wieman, "Why not try a scientific approach to science education?" June 11, Paper 2: Wosilait et al., "Development and assessment of a research-based tutorial on light and shadow" June 25: Paper 3: Beichner, "Testing student interpretation of kinematics graphs" July 9: Paper 4: Ogilvie, "Changes in students' problem-solving strategies in a course that includes..." July 23: Paper 5: Deslauriers et al., "Improved learning in a large-enrollment physics class" August 6: Paper 6: Elby, "Helping physics students learn how to learn" August 20: Paper 7: Binning et al., "Changing social contexts to foster equity in college science courses..."

#### **Possible Outcomes**

Participants will learn about another discipline's education research. As the PER literature is broader than ours, participants will likely discover new research topics, might meet new research collaborators, and could potentially generate grant possibilities. Ultimately it should lead to a better understanding of how our students learn and how to teach them more effectively.

<sup>&</sup>lt;sup>11</sup> See <u>https://circle.wustl.edu/events/conferences/2018conference/</u>.

#### **Bibliography**

Adams, Wendy K., and Carl E. Wieman. "Development and validation of instruments to measure learning of expert-like thinking." *International Journal of Science Education* 33.9 (2011): 1289-1312.

Barthelemy, Mohamed, and Charles Henderson. "Graduate programs in physics education research: A USA based survey." (2020). <u>https://www.compadre.org/PER/items/detail.cfm?ID=15454</u>

Nancy Kaufmann, Erica M. McGreevy, Omid Fotuhi1, Susie Chen, Emily Marshman, Z. Yasemin Kalender, Lisa B. Limeri, Laura Betancur, and Chandralekha Singh. "Changing social contexts to foster equity in college science courses: an ecological-belonging intervention." Psychological Science 31.9 (2020): 1059-1070.

Beichner, Robert J. "Testing student interpretation of kinematics graphs." American Journal of Physics 62.8 (1994): 750-762.

Deslauriers, Louis, Ellen Schelew, and Carl Wieman. "Improved learning in a large-enrollment physics class." Science 332.6031 (2011): 862-864.

Docktor, Jennifer L., and José P. Mestre. "Synthesis of discipline-based education research in physics." *Physical Review Special Topics-Physics Education Research* 10.2 (2014): 020119.

Hake, Richard R. "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses." *American Journal of Physics* 66.1 (1998): 64-74.

Halloun, Ibrahim Abou, and David Hestenes. "Common sense concepts about motion." *American Journal of Physics* 53.11 (1985): 1056-1065.

Hanford, Emily. "Don't Lecture Me." 2011 <u>http://americanradioworks.publicradio.org/features/tomorrows-college/lectures/</u> Retrieved May 18, 2021.

Hestenes, David, Malcolm Wells, and Gregg Swackhamer. "Force concept inventory." *The Physics Teacher* 30.3 (1992): 141-158.

Henderson, Charles, Raquib Khan, and Melissa Dancy. "Will my student evaluations decrease if I adopt an active learning instructional strategy?." *American Journal of Physics* 86.12 (2018): 934-942.

Jones, David J., Kirk W. Madison, and Carl E. Wieman. "Transforming a fourth year modern optics course using a deliberate practice framework." Physical Review Special Topics-Physics Education Research 11.2 (2015): 020108.

Knaub, Alexis V., Manher Jariwala, Charles R. Henderson, and Raina Khatri. "Experiences of postdocs and principal investigators in physics education research postdoc hiring." *Physical Review Physics Education Research* 14.1 (2018): 010152.

Knight, Randall D. "Five easy lessons: Strategies for successful physics teaching." (2004)

Lepage, G. Peter. "Active learning in a graduate quantum field theory course." *American Journal of Physics* 89.3 (2021): 317-323.

McDermott, Lillian C., and Edward F. Redish. "Resource letter: PER-1: Physics education research." American Journal of Physics 67.9 (1999): 755-767.

Ogilvie, C. A. "Changes in students' problem-solving strategies in a course that includes context-rich, multifaceted problems." Physical Review Special Topics-Physics Education Research 5.2 (2009): 020102.

O'Neil, Kathleen. "Experts Seek to Boost Knowledge and Allies for Teaching STEM." (2017). <u>https://www.aaas.org/news/experts-seek-boost-knowledge-and-allies-teaching-stem</u> Wieman, Carl. "Why not try a scientific approach to science education?." Change: The Magazine of Higher Learning 39.5 (2007): 9-15.

Wosilait, Karen, Paula RL Heron, Peter S. Shaffer, and Lillian C. McDermott. "Development and assessment of a researchbased tutorial on light and shadow." American Journal of Physics 66.10 (1998): 906-913.

Yeager, David S., Gregory M. Walton, Shannon T. Brady, Ezgi N. Akcinar, David Paunesku, Laura Keane, Donald Kamentz, Gretchen Ritter, Angela Lee Duckworth, Robert Urstein, Eric M. Gomez, Hazel Rose Markus, Geoffrey L. Cohen, and Carol S. Dweck. "Teaching a lay theory before college narrows achievement gaps at scale." *Proceedings of the National Academy of Sciences* 113.24 (2016): E3341-E3348.