

# Overview of PER, then Reflection in Quantum Mechanics

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- What is PER?
- Paper: Do QM students reflect?
  - Rationale
  - Rubric for analysis
  - Results
  - Interview follow-up
- Discussion

# Physics Education Research: What Is It?

- Overall goal: Develop pedagogy to improve student learning
  - Traditional coursework (lecture, lab, recitation) did not seem to benefit students
  - Call for a “scientific approach to science education” (Reif 1981)

# Who's been driving PER?

- Physics faculty who researched something else first and/or simultaneously (formed first groups, e.g. U. Washington, Kansas State, Maryland)
- Educational, cognitive psychologists (e.g. U. Pittsburgh, Carnegie Mellon)
- High school science teachers
- Funding and curriculum development (Dept. of Ed, NSF, postsecondary administrators, private-industry education companies)
- Students and postdocs - field has grown into dissertation topics and careers in or related to PER

# Some topics of interest

- Student assessment tools (surveys, e.g. FCI, CLASS, BEMA; online intelligent tutors)
- Investigative research (e.g. misconceptions, tutorials)
- Course-specific topics (undergraduate physics, K-12, graduate physics)
- Section-specific topics (recitations, laboratories, lectures; implementation)
- Cognitive psychology-related (**expert-novice, problem solving**, learning transfer, epistemology)
- Teacher Training (PhysTEC programs, laboratory training)
- Physics and Society (Physics outreach, citizen science, etc.)

# Types of PER University Research Groups

- Where can you find them?
  - Very large research universities (e.g. U. Minnesota)
  - Medium-to-large-sized research universities
  - Four-year colleges and universities
- In what departments?
  - Physics departments
  - Education departments
  - Cognitive psych departments
  - A mix of the above

# Resources

- comPADRE: All kinds of resources for physics and astronomy education
  - Collaboration by AIP (“a society of societies”), AAPT, APS, AAS, and SPS
  - <http://www.compadre.org>
- American Association of Physics Teachers (AAPT)
  - <http://www.aapt.org>
  - Two meetings a year
- PERticles (run by M. Wittmann)
  - <http://www.citeulike.org/group/10888> (2009-present)
  - <http://perticles.blogspot.com/> (2007-2009)

# Frequent PER publications

- American Journal of Physics (AAPT – need to be member)
  - <http://www.aapt.org/ajp/>
- The Physics Teacher (also AAPT – need to be member)
  - <http://tpt.aapt.org/>
- Physical Review Special Topics – PER (APS – free!)
  - <http://prst-per.aps.org/>
- Proceedings from Physics Education Research Conferences (AIP; PERCs are coupled with AAPT summer meetings)
  - Difficult to find one, but can be found using library, Google Scholar or PERticles
- Outside journals in science and education (e.g. Science, International Journal of Science Education, Journal of the Learning Sciences, Curriculum and Instruction)



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# Paper background

- Reflection and Metacognition
  - Thinking about thinking
- Here, evaluating one's problem-solving processes
  - Usually a vital part of heuristics
  - Often overlooked!
- Why we did this
  - Intervention studies on introductory students (e.g. Mason et al. 2008, Cohen et al. 2008, Yerushalmi et al. 2008)
  - wanted to see if upper-level undergraduates needed such intervention

# QM Experiment: Setup

- Treatment group: 14 students, honors-level Quantum Mechanics 1, fall 2007
- 4 problems given on 2 midterms (pretest)
  - Relevant material covered in lecture, homework and text via “standard” teaching approach
  - 3 selected by difficulty: students struggled with these on the midterms (roughly 50% combined average)
- These four problems are also part of the final exam verbatim (posttest)

# Analysis

- Self-diagnosis rubric (Mason et al. 2008, Cohen et al. 2008, Yerushalmi et al. 2008)
  - Developed in another study on introductory physics with Yerushalmi and Cohen was adapted for use with QM problems
- Because upper-level undergraduates are more advanced:
  - Do they perform better if asked the same question a second time?
  - Have they voluntarily reflected upon what they did incorrectly the first time?
  - Do they check their work with TA solution automatically?

# Sample Problem

- This is “Problem 2” in paper (p. 766):
  - “For an electron in an infinite square well potential, measurement of position yields the value  $x = a/2$ . Write down the wave function immediately after the position measurement, and without normalizing it show that if energy is measured immediately after the position measurement, it is equally probable to find the electron in any odd-energy stationary state.”
- Rather different from introductory student problem

(p. 762, Table I has problem 3, more detail)				midterm	Final	R-SD
Physics	Invoking	Appropriate concepts	Dirac delta function, energy eigenstates, $\Psi(x) = \sum c_n \psi_n$ , $E_n$ prob.			
		Inappropriate concepts?	e.g. confusing position, energy eigenstates			
	Applying	Appropriate concepts	Delta function, orthogonality, etc.			
Presentation (strategy)	Desc-ription	Drawings Givens	Square well, initial state, labels			
	Solution cons-truction	Target and intermediate variables Surplus principles Plan	$P(E_n) =  c_n ^2$ , $c_n$ , summation of eigenstates  (can be omitted)			
	Check-ing	Units (proof) Check ans.	Completes proof  In terms of $\langle \psi_n   \psi \rangle$ or $c_n$			
Total Scores (Phy. Score, Pres. Score)						

# Results (more detail in Table II, p. 762)

Physics scores						
Problem	1	2	3	4	All	1,2,3
Midterm mean	69	60	43	93	66	57
Final exam mean	58	54	46	80	60	53
Presentation scores						
Problem	1	2	3	4	All	1,2,3
Midterm mean	59	51	44	84	60	51
Final exam mean	54	47	44	72	54	48

- No improvement!
- Same results between physics and presentation ( $p > 0.5$ , all cases)

## Sample: Student 3, Problem 1

$$\begin{aligned}
 \langle \psi | \hat{Q} | \psi \rangle &= \langle \psi | \hat{Q} \sum_{j=1}^N \phi_j \rangle \langle \phi_j | \psi \rangle \\
 &= \sum_{j=1}^N \langle \psi | \hat{Q} \phi_j \rangle \langle \phi_j | \psi \rangle \\
 &= \sum_{j=1}^N \langle \psi | q_j \phi_j \rangle \langle \phi_j | \psi \rangle \\
 &= \sum_{j=1}^N q_j \langle \psi | \phi_j \rangle \langle \phi_j | \psi \rangle \\
 \therefore \langle \psi | \hat{Q} | \psi \rangle &= \sum_{j=1}^N q_j \langle \phi_j | \psi \rangle^* \langle \phi_j | \psi \rangle \\
 &\text{in terms of } \langle \phi_j | \psi \rangle
 \end{aligned}$$

Midterm:

Answer is correct

Final exam:

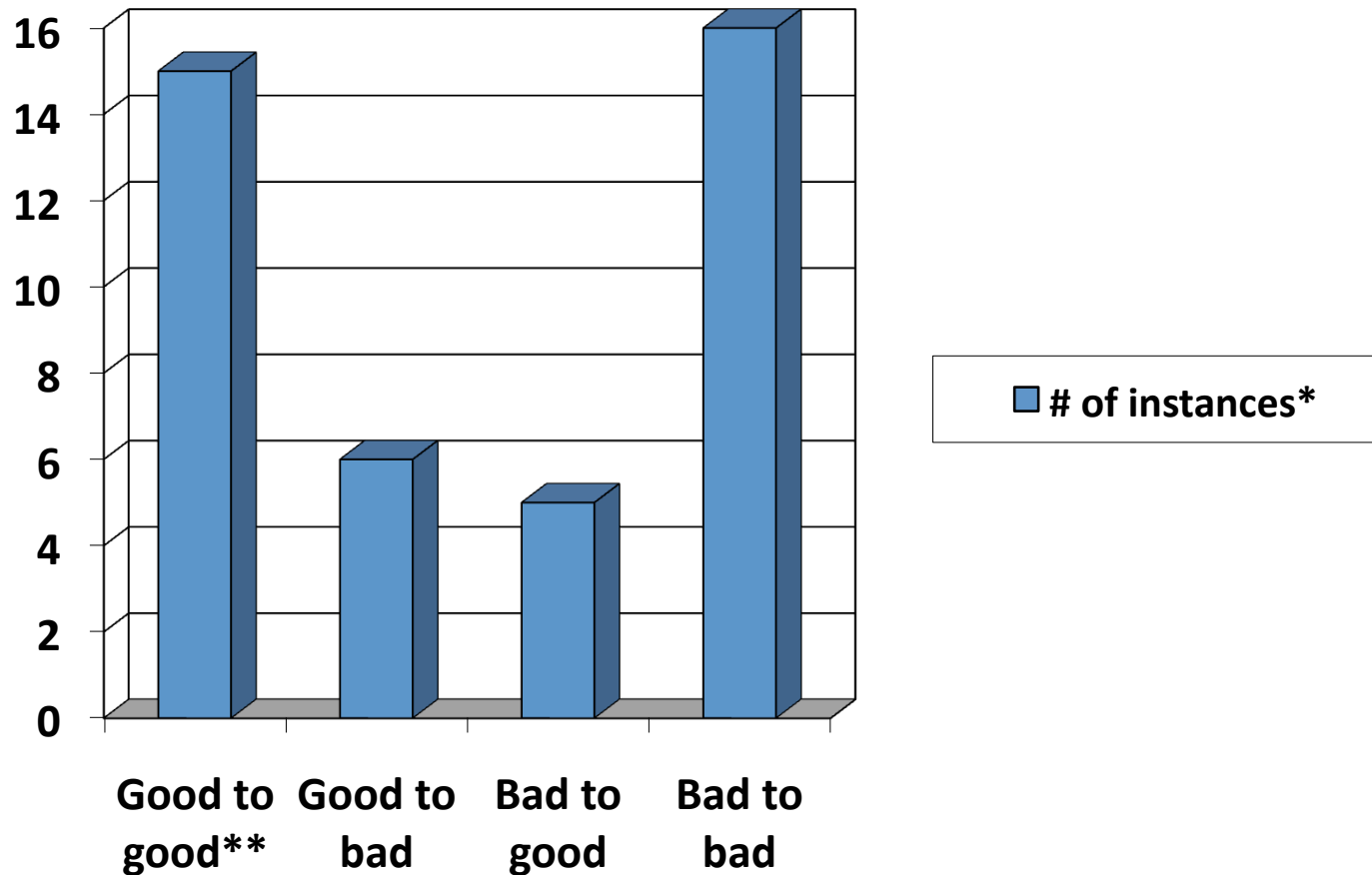
Not so correct

$$\begin{aligned}
 C_n &= \langle \psi | \psi \rangle & \langle \hat{H} \hat{Q} \psi | \psi \rangle - \langle \psi | \hat{Q} \hat{H} \psi \rangle \\
 \langle \psi | \hat{Q} | \psi \rangle &= \langle \psi | \hat{H} \hat{Q} - \hat{Q} \hat{H} | \psi \rangle \\
 &= \langle \hat{H} \psi | \hat{Q} \psi \rangle - \langle \psi | \hat{Q} \hat{H} | \psi \rangle \\
 \hat{Q} | \psi_j \rangle &= \lambda_j | \psi_j \rangle
 \end{aligned}$$



# Results: Overall Change

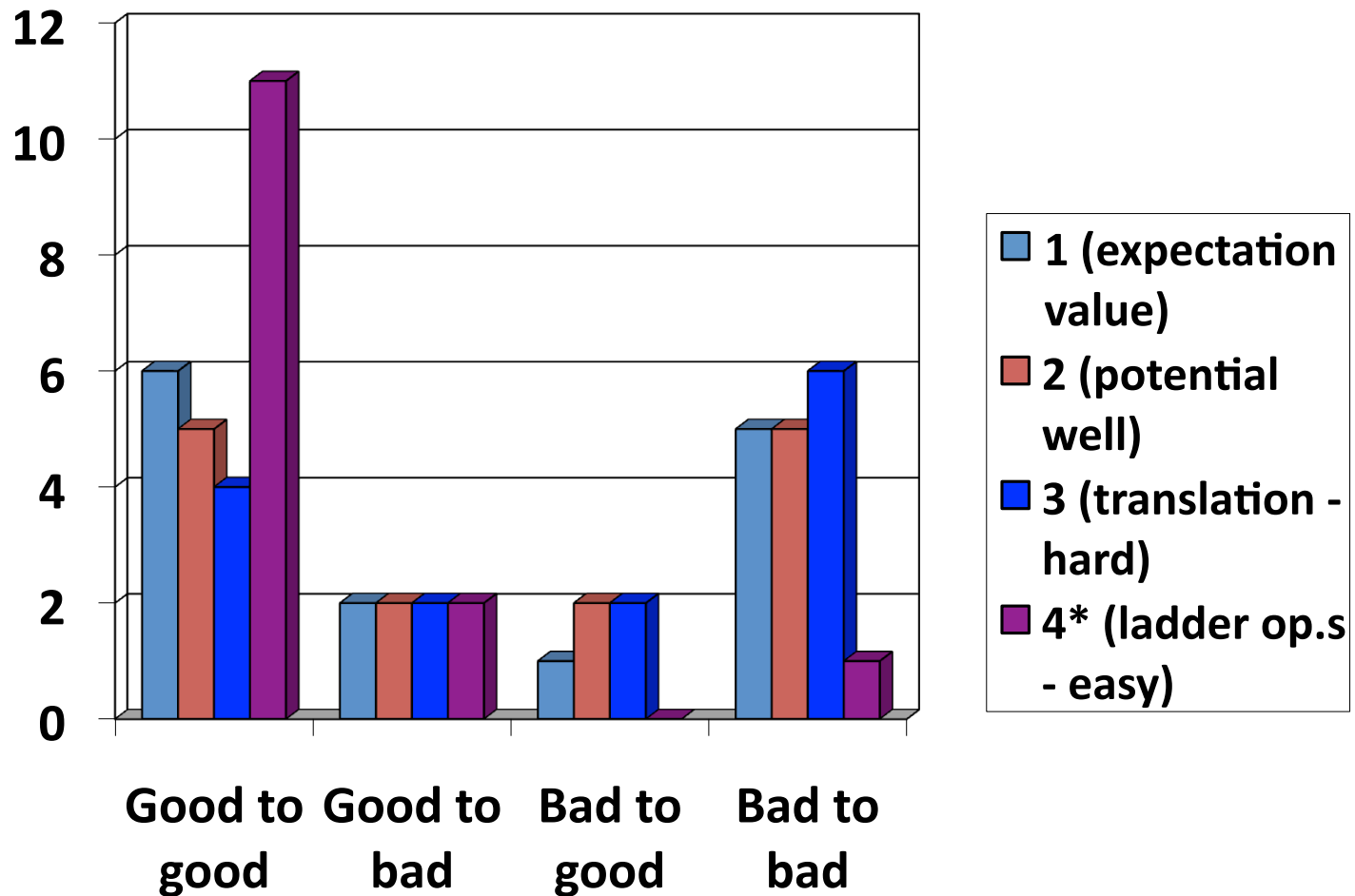
(3 hard problems only; see Table III, p. 763)



\* "Instance" = 1 attempt on 1 problem (problem 4 not included - too easy)

\*\* "Good" = at least 60% score with our rubric, "Bad" < 60%

# Results: Change Per Individual Problem



\* "Instance" = 1 attempt on 1 problem (problem 4 not included - too easy)

"Good" = at least 60% score, "Bad" < 60%

## Results: Considerations

- Some students do reflect on their mistakes and improve on some problems (or get them right both times), but **this is not always the case!**
  - Some don't figure a problem out on either attempt
  - Some do well on midterm but regress on final
  - Some fluctuate in performance between problems
  - Why is this?

# Interviews (pp. 763-765)

- Survey about student's opinion of the course and performance in the course
- spring 2008: 4 students (3 in QM2) interviewed, 2 more partially interviewed
- Same 4 problems in study were given once more (think-aloud protocol)
  - Can student remember how to do the problem?
  - Another opportunity to reflect on material – student asked afterwards about problem performance

# Interviews: Study Habits

- Some work alone, some work in groups
  - Student 11 feels his math major helps his physics major
  - Several students (e.g. 8, 9, 10) don't bother with studying midterm exams for the final
    - Student 8's comments, p. 764
  - Student 3 focuses on practice problems, reading book
    - Explicitly looks at midterm exams before final
  - Student 6 studied with student 10
    - Focus on studying equations

## Interviews: Interesting Quotes (struggles, problem 1)

- “I remember doing it, I remember seeing it, I remember thinking, ‘oh, it’s not really that bad,’ so I know it’s not bad. It’s just... I’m not remembering how to manipulate with bra and ket. Basically that’s all it is.” (student 3, p. 765)

# Interviews: Interesting Quotes (struggles, Problem 3)

- “...yeah, I totally forget...I haven’t touched translator of space since the final...it’s just not ringing a bell right now.” (student 6, problem 3, p. 765)
- “It was just one of the problems in the homework. It was never mentioned previously or after, so I didn’t assign much importance to it in my head as far as studying goes to it.” (student 10, problem 3, p. 765)

# Interviews: Interesting Quotes (struggles, problem 3)

- “...sometimes problems like this just seem like ‘oh, this is just a math thing.’...at the time I thought it was just something to make me stay up another hour and a half. And then, you know, it was on the test and I thought, ‘I should’ve paid more attention to it,’ and then it was on the final and I thought, ‘jeez, I really should’ve paid attention to it.’ ” (student 3, problem 3, p. 764)



## Interviews: Interesting Quotes ("A" students)

- "When I make mistakes I always look back at the work to see where I erred. In most cases I will be more careful in looking over homework than past exams as far as studying purposes go." (student 9, study habits)
- "Well, we learned that {derivation} in particular. It was proven to us in like, three different ways. I remember the page in Griffiths now..." (student 11, problem 1)

# Interview Results

- Observations:
  - “A” student showed ideal tendencies
    - Also, math major plus physics major seemed to help student 11
  - Students that showed regression displayed less-than-ideal tendencies
  - Some difficulty with Dirac notation during course
    - Students 3 and 6 may be cramming (p. 765)
  - All four fully interviewed students complained about “difficult” problem (#3)
    - Unexpected – topic only approached once during semester

# Summary

- Upper-level undergraduate students are not necessarily learning from their mistakes on exams
  - Material not retained in many cases
  - Possible need for explicit intervention (e.g. self-diagnosis)
- Some evidence of study habits
  - Not all students pick up conceptual understanding of QM
  - Evidence of trying to “psych out” the test
    - Most difficult problem generally unexpected

# Discussion

- Thanks!
- U of M PER seminar this semester: Fridays, 2pm, 157 Tate Laboratory of Physics
- My current group's website:
  - <http://groups.physics.umn.edu/physed/>

# Why Quantum Mechanics?

- Material (both math and concepts) tends to be very new to students
  - Compare to intro-level students with introductory physics
- Hope is that seniors have learned reflection process as they've advanced through curriculum