Interpretation in Quantum Physics as Hidden Curriculum

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Introduction

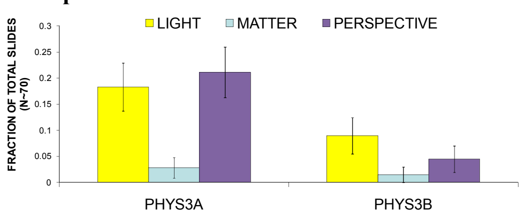
- Questions of **interpretation in quantum mechanics are often ignored** or only implicitly addressed in introductory modern physics courses.
- Many **students have developed realist perspectives** on physical systems through intuition or instruction in classical physics.
- **Instructors hold different views** on teaching interpretive aspects of quantum physics, with demonstrable effect on student thinking.[1]

Teaching practices vary…

Instructors may differ in obvious ways concerning their treatment of interpretive themes in quantum mechanics.

Compare two similar modern physics courses with instructors who differed in their emphasis on interpretive themes:

Topic Area: Photoelectric Effect and Photons.



Number of slides addressing three key interpretive themes (described below) in terms of the total number of slides used during lectures concerning the topic area *Photoelectric Effect and Photons*. Error bars represent the standard error on the proportion.

THEME	DESCRIPTION OF LECTURE SLIDE
LIGHT	Relevant to the dual wave-particle nature of light, or emphasizing its particle characteristics
MATTER	Relevant to the dual wave-particle nature of matter, or emphasizing its wave characteristics
CONTRASTING PERSPECTIVES	Relevant to randomness, indeterminacy or the probabilistic nature of quantum mechanics; explicit contrast between quantum results and what would be expected classically

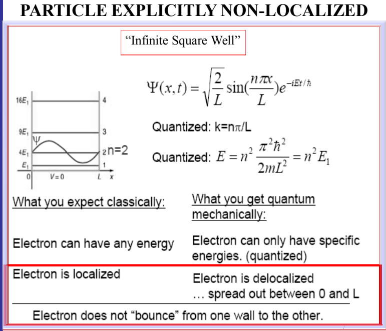
Interpretive themes may be *implicitly* or *explicitly* addressed within other course topics:

Compare two slides from these two similar modern physics courses:
Both slides list wave functions and quantized energy levels for same problem.

PHYS3A

- "Infinite Square Well" – defines problem in terms of the potential.
- Quantum mechanically, electron is described as a standing wave, and particles do not bounce back and forth.

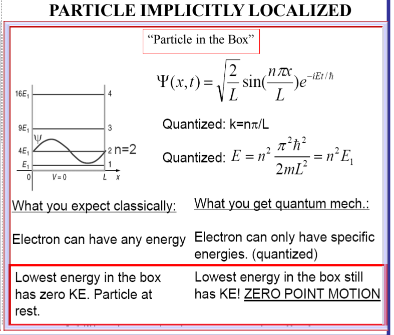
PARTICLE EXPLICITLY NON-LOCALIZED



PHYS3B

- "Particle in the Box" – evokes imagery of localized particle.
- Quantum mechanically, particles in lowest energy state still exhibit zero point motion.

PARTICLE IMPLICITLY LOCALIZED



Conclusions

- **Students express beliefs** about interpretive themes in quantum physics,[2] which are **more likely to be realist** in topic areas where instructors are less explicit in addressing student perspectives.[1]
- **Student perspectives** can (and should) be **more explicitly addressed** within a variety of topics at the introductory level. [SEE HANDOUT]

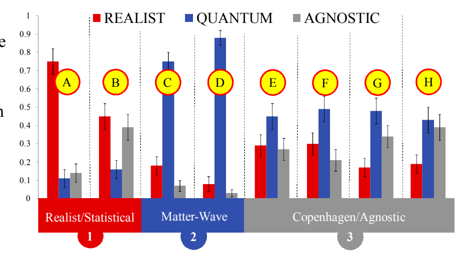
…with impact on student thinking:

- Post-instruction student responses from eight different modern physics courses (**A-H**), to an essay question on interpretations of the double-slit experiment with single quanta.
- Instructional approaches (Realist/Statistical, Matter-Wave, Copenhagen/Agnostic) are based on classroom observations, instructor interviews, and analyses of other course artifacts.
- Students from each of the…
  1. Realist/Statistical courses were most likely to prefer a Realist interpretation.
  2. Matter-Wave courses overwhelmingly preferred the Quantum interpretation.
  3. Copenhagen/Agnostic courses offered more varied responses.

REALIST Each electron is a tiny particle that went through one slit or the other.

QUANTUM Each electron went through both slits and interfered with itself.

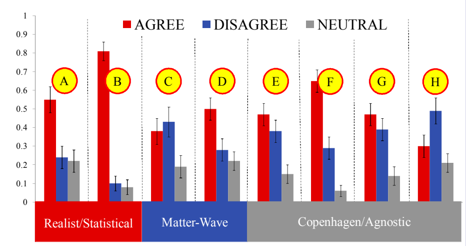
AGNOSTIC We can't know what the electron is doing between being emitted and detected.



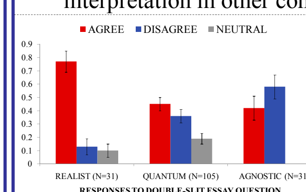
(In)Consistency of Student Responses

Post-instruction student responses to the statement:

"An electron in an atom exists at a definite (but unknown) position at each moment in time."



- Instructors were generally less explicit about interpretation at later stages of the course, e.g. the Schrödinger model of hydrogen.
- Students from most courses were most likely to agree with this statement (a realist perspective), including students from the Matter-Wave courses.
- Students develop or maintain ideas about some quantum phenomena regardless of how their instructors previously addressed themes of interpretation in other contexts.



Student responses to the statement on atomic electrons, grouped by how those students responded to the essay question on interpretations of the double-slit experiment.

- Students in the (double-slit) Realist category were most consistent, preferring realist interpretations in both contexts.
- ~50% of students who described electrons as delocalized in the double-slit experiment (Quantum) still agree that atomic electrons exist as localized particles.

Acknowledgements

This work has been supported by the National Science Foundation (REC CAREER# 0448176) and the University of Colorado; any opinions, findings and conclusions or recommendations expressed in this material are those of the authors. The authors would like to express their gratitude to the faculty and students who participated in this study, in addition to the rest of the Physics Education Research Group at the University of Colorado at Boulder.

References

1. C. Baily and N. D. Finkelstein, Teaching and understanding of quantum interpretations in modern physics courses, *PRST-PER* **6**, 010101 (2010).
2. C. Baily and N. D. Finkelstein, Refined characterization of student perspectives on quantum physics, *PRST-PER* (Submitted, March 2010).