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 effects 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.

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

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

**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**
  - \( \psi(x,t) = \frac{1}{\sqrt{2aL}} \sin\left(\frac{n\pi x}{L}\right) e^{-i\omega t} \)
  - Quantized: \( E_n = \frac{n^2\pi^2\hbar^2}{2mL^2} \)
  - What you expect classically: Electron can have any energy.
  - What you get quantum mechanically: Electron can only have specific energies (quantized).
  - Electron is 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**
  - \( \psi(x,t) = \frac{1}{\sqrt{L}} \sin\left(\frac{n\pi x}{L}\right) e^{-i\omega t} \)
  - Quantized: \( E_n = \frac{n^2\pi^2\hbar^2}{2mL^2} \)
  - What you expect classically: Electron can have any energy.
  - What you get quantum mechanically: Electron can only have specific energies (quantized).
  - Electron is delocalized; spread out between 0 and L.

Conclusions

- Students express beliefs about interpretive themes in quantum physics,[2] which are **more likely to be realist** in topics 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...
  - **Realist/Statistical** courses were most likely to prefer a Realist interpretation.
  - **Matter-Wave** courses overwhelmingly preferred the Quantum interpretation.
  - **Copenhagen/Agnostic** courses offered more varied responses.

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

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### (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.

### References


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