# Understanding and Teaching Quantum Interpretations in Modern Physics Courses

Charles Baily and Noah D. Finkelstein
Department of Physics, University of Colorado at Boulder, http://per.colorado.edu

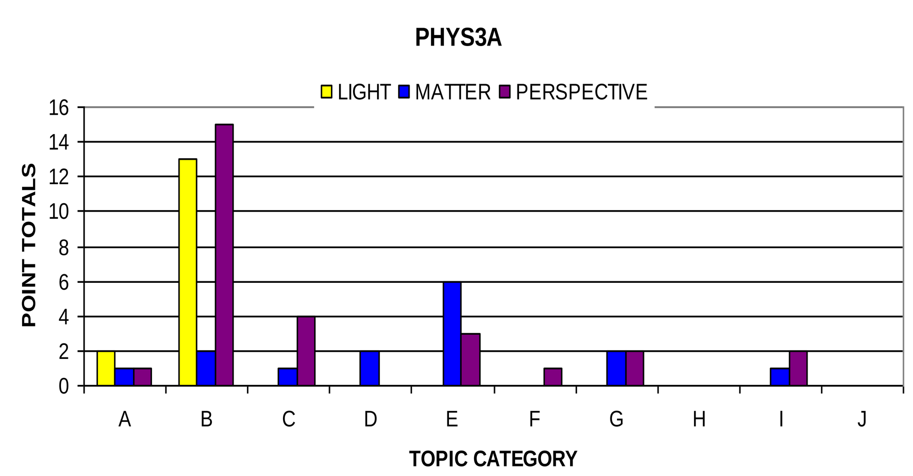
## Introduction

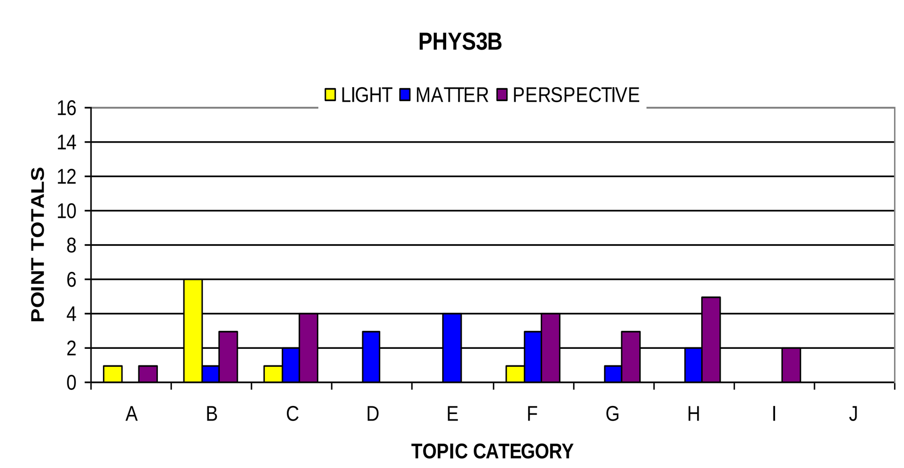
- **Physicists vary** in their personal stances **on interpretation in quantum mechanics**.
- **Instructors hold different views** on teaching (or not teaching) interpretations of quantum phenomena **in introductory modern physics courses**.
- There has been relatively little research in the physics education community on the **variation in instructional approaches** and how these choices **impact student thinking**.
- **We compare two versions of a modern physics course** taught at the University of Colorado with similar learning environments and curricula, but **where the instructors held different views** on how to teach students about quantum processes.

## Teaching Practices Vary

| | | Instructor Approach |
|---|---|---|
| PHYS3A Instructor A | Modern Physics (for Engineers) | "Quantum" (ascribe physical reality to wave function) |
| PHYS3B Instructor B | Modern Physics (for Physics Majors) | Copenhagen/Agnostic/Less Explicit |

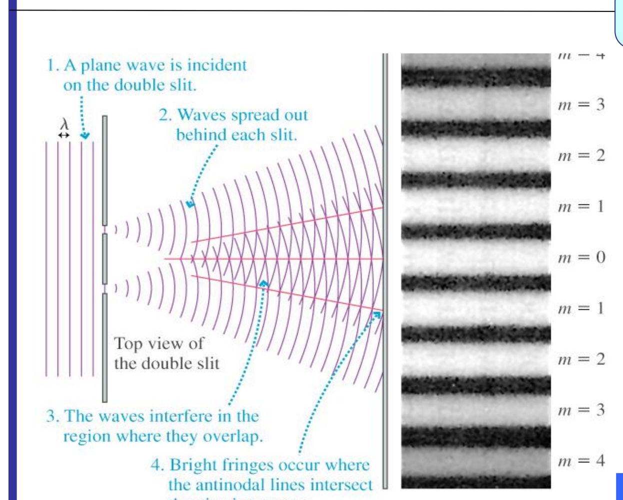
| CODE | TOPICS FROM QUANTUM PHYSICS |
|---|---|
| A | INTRODUCTION TO QUANTUM |
| B | PHOTOELECTRIC EFFECT, PHOTONS |
| C | ATOMIC SPECTRA, BOHR MODEL |
| D | DE BROGLIE WAVES/ATOMIC MODEL |
| E | MATTER WAVES/INTERFERENCE |
| F | WAVE FUNCTIONS, SCHRODINGER EQUATION |
| G | INFINITE/FINITE SQUARE WELL |
| H | TUNNELING, ALPHA DECAY, STM |
| I | 3-D SCHRODINGER EQUATION, H-ATOM |
| J | MULTI-ELECTRON ATOMS, SOLIDS |
| **THEME** | **DESCRIPTION OF LECTURE SLIDES** |
| LIGHT | Relevant to the dual wave/particle nature of light, or emphasizing the particle characteristics of light. |
| MATTER | Relevant to the dual wave/particle nature of matter, or emphasizing the wave characteristics of matter |
| PERSPECTIVE | Relevant to randomness, indeterminacy or the probabilistic nature of quantum mechanics; explicit contrast between quantum results and what would be expected classically. |




- **Key slides** are highlighted that **address quantum interpretations**.
- **Instructor A** spent a greater proportion of lecture time at the outset of the course addressing indeterminacy in quantum physics and non-classical descriptions of light.
- **Both courses spent** relatively **little time at later stages** of the course **addressing themes** relevant to **student perspectives.**

### e.g., The Double-Slit Experiment




**With Single Quanta**

- The intensity of the beam can be tuned down to the point where only single quanta at a time pass through the apparatus.
- Individual quanta are detected as localized particles on the screen, yet an interference pattern still develops over a period of time.

Instructors vary in how to explain this result:

**Instructor A**

- Particle is delocalized as it propagates through space…
- …passes through both slits…
- …interferes with itself…
- …becomes localized when interacting with detector.

"If you don't take into account [the distance between] both slits and the electron as a delocalized particle, then you will not come up with the right observation."

**Instructor B**

- One *might* say the particle interfered with itself.
- The Copenhagen Interpretation says a particle doesn't have a definite position until measured.
- But…

"Most physicists today say: We don't go there. I don't care as long as I can calculate what I need."

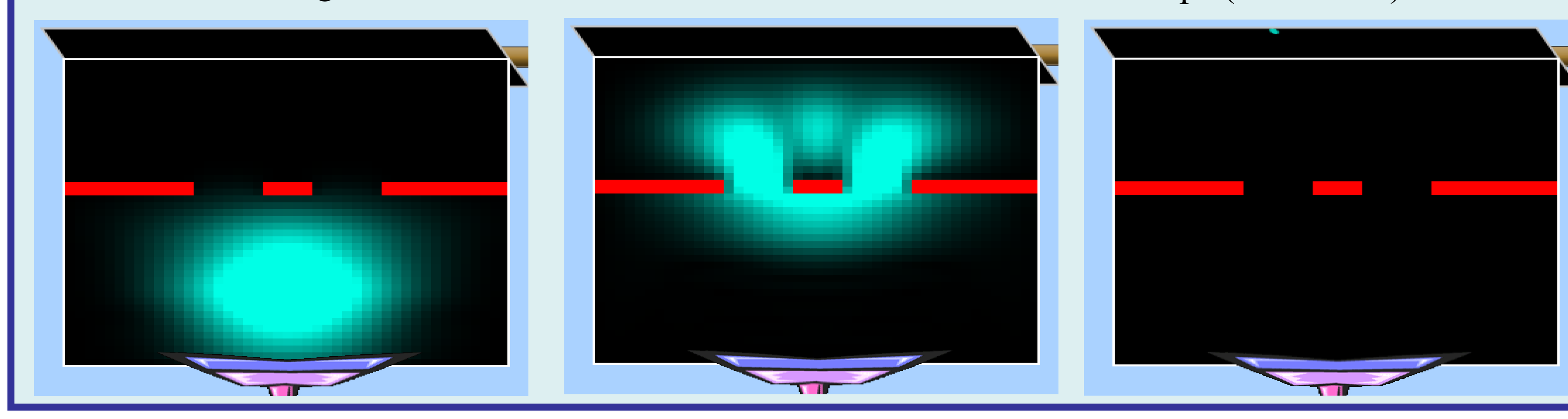
## Associated Variations in Student Perspectives

### ESSAY QUESTION ON INTERPRETATION IN THE DOUBLE-SLIT EXPERIMENT

**1.** A blob (representing the probability density for a single electron) emerges from an "electron gun".

**2.** The blob passes through the two slits

**3.** A single electron is detected on the far screen. After many electrons, an interference pattern develops (not shown).



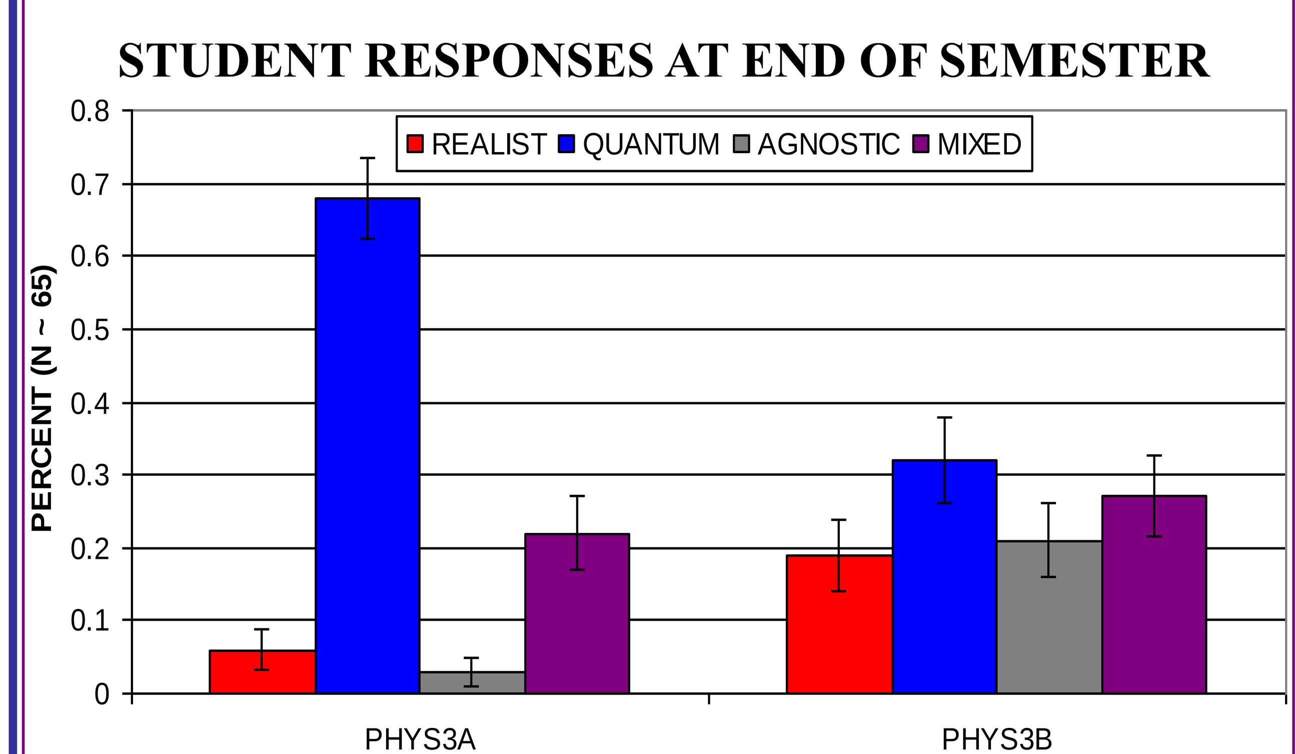
**Three students discuss the PhET Quantum Wave Interference Simulation[1] (shown above):**

**Student 1:** The probability density is so large because we don't know the true position of the electron. Since only a single dot at a time appears on the detecting screen, the electron must have been a tiny particle, traveling somewhere inside that blob, so that the electron went through one slit or the other on its way to the point where it was detected. — REALIST

**Student 2:** The blob represents the electron itself, since an electron is described by a wave packet that will spread out over time. The electron acts as a wave and will go through both slits and interfere with itself. That's why a distinct interference pattern will show up on the screen after shooting many electrons. — QUANTUM

**Student 3:** Quantum mechanics is only about predicting the outcomes of measurements, so we really can't know anything about what the electron is doing between being emitted from the gun and being detected on the screen. — AGNOSTIC

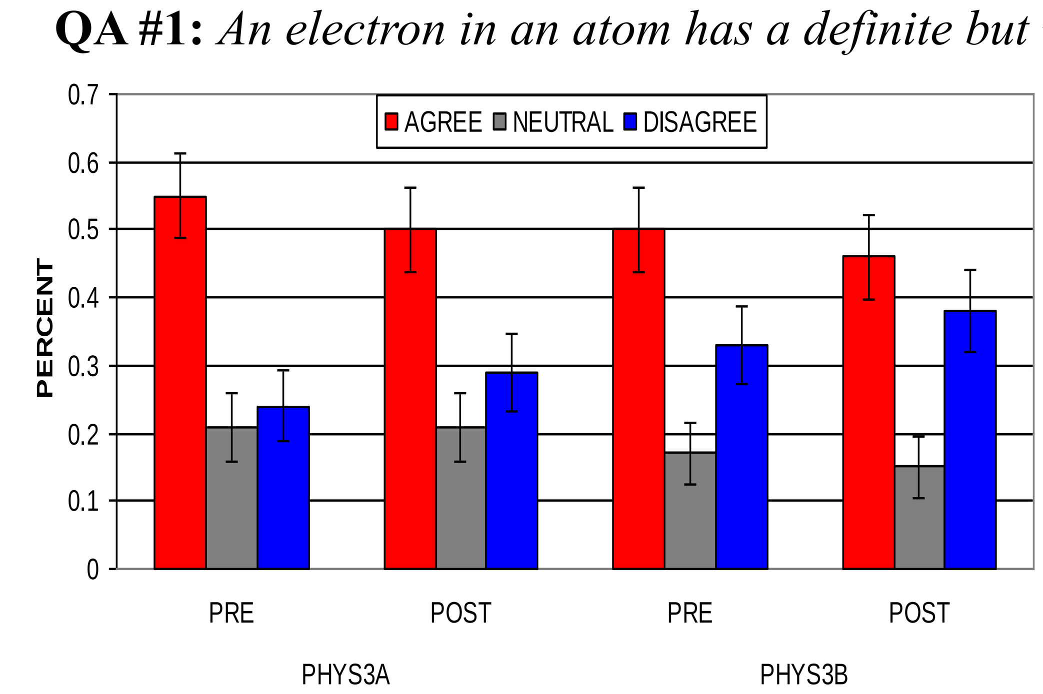
*Which students (if any) do you agree with, and why? What's wrong with the other students' arguments? What is the **evidence** that supports your answer?*




- Some students were classified as mixed because they felt two or all three of the statements had merit.
- Most students from PHYS3A preferred the wave packet description of an electron.
- ~20% of PHYS3B students preferred the realist interpretation.
- ~20% of PHYS3B students preferred the agnostic stance.
- Fewer than 10% combined of PHYS3A students chose either the realist or agnostic perspectives exclusively

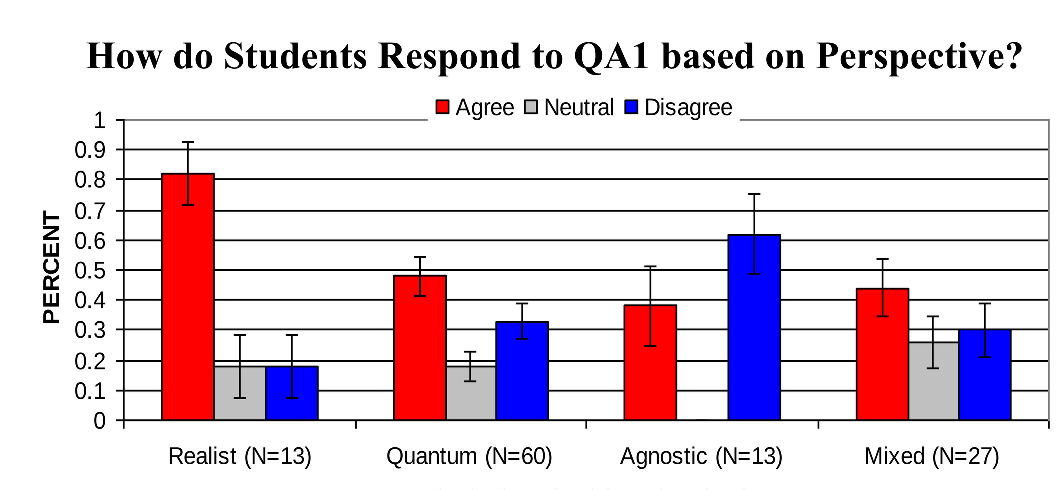
### Consistency of Student Perspectives

**QA #1:** *An electron in an atom has a definite but unknown position at each moment in time.*




- The two courses were similar in their treatment of the Schrodinger atomic model: an electron in an atom is "a cloud of probability surrounding the nucleus whose wavefunction is the solution of the Schrodinger equation."
- Agreement with this statement would be consistent with a realist perspective.
- PHYS3A just as likely to agree with this statement as students from PHYS3B, despite the emphasis in PHYS3A toward thinking of an electron as delocalized in other contexts.
- Both courses showed moderate (though statistically insignificant) increases in favorable responses.

**How do Students Respond to QA1 based on Perspective?**




- Responses to QA#1 for both courses are grouped by how students responded to the essay question on the double-slit experiment.
- ~80% of *Realist* students from double-slit experiment also take a realist stance on an electron in an atom.
- ~50% of *Quantum perspective* students from the double-slit experiment still take a realist stance on an electron in an atom.

## Conclusions

- **Instructors vary in their approach to teaching** interpretation in modern physics courses, **with demonstrable impact on student thinking**.
- **Many students** seem to **default to realist interpretations** of quantum phenomena **when instructors are not explicit** in promoting alternatives to a realist perspective. **Student perspectives** are not necessarily robust, and often **vary by context**.
- Instructors who wish to **address questions of ontology** should do so **across a range of topics**, and not assume it to be sufficient to address student perspectives primarily at the outset of the course.

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## References

1. http://phet.colorado.edu/qwi