Student Perspectives in Quantum Physics

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Introduction

There are good reasons to believe that introductory courses in **classical physics are promoting** in students a perspective **that we call *local realism***. A realist perspective would be deterministic, where all physical quantities describing a system can be simultaneously specified for all times. Having had their commitment to a realist perspective reinforced through **prior instruction may be problematic for students of modern physics**, who must then learn that, from a *quantum perspective*, physical observables are indeterminate outside the context of measurement, and subject to the laws of probability[1]. We are therefore concerned with **how students' perspectives change** as they make the transition from learning classical physics to learning quantum physics. We conclude from the available data that **specific attention paid to the ontological interpretation of quantum processes during instruction may aid in the cultivation in students of a suitable quantum perspective.**

Introductory Physics Courses at University of Colorado

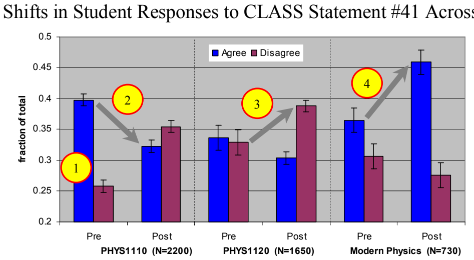
A Three Semester Sequence of Calculus-Based Introductory Physics:

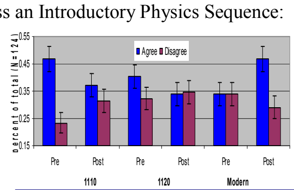
Physics 1110	Classical Mechanics	N=300-600
Physics 1120	Classical Electromagnetism	N=300-450
Physics 2130 Physics 2170	Modern Physics	N~75

Students' Views of Measurement Change Over Time

CLASS[2] Statement #41: "It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct."
& "Why? (Optional)"

Shifts in Student Responses to CLASS Statement #41 Across an Introductory Physics Sequence:





A longitudinal study of 124 students (above) reveals trends similar to those seen in the aggregate data (at left), but without the effect of student filtering between semesters.

1. Many **students agree** with statement #41 **prior to instruction** in classical physics.
2. **Following instruction** in classical physics, the **number in agreement decreases** significantly, and…
3. …the number of **those who disagree increases** significantly.
4. **After a single semester of modern physics**, the number of students who **agree with #41 increases** dramatically, with an even with an even greater percentage in agreement than at the beginning of instruction in classical physics.

Instruction in modern physics causes the **reasons** behind student responses to **change**:

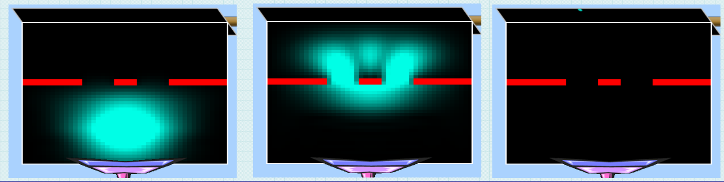
		PRE-MODERN PHYSICS INSTRUCTION (N=507)		POST-MODERN PHYSICS INSTRUCTION (N=83)	
	CATEGORIZATION OF REASONING OFFERED BY STUDENTS IN RESPONSE TO CLASS#41	Disagree w/ #41	Agree w/#41	Disagree w/ #41	Agree w/ #41
A	Quantum theory/phenomena Relativity, different frames of reference	5% (1%)	13% (1%)	32% (5%)	48% (5%)
B	There can be more than one correct answer to a physics problem Experimental results are open to interpretation	5% (1%)	28% (2%)	6% (3%)	10% (3%)
C	Experimental/random/human error Hidden, unknown variables, chaotic systems	21% (2%)	59% (2%)	19% (4%)	42% (5%)
D	There is only one correct answer to a physics problem Experimental results should be repeatable	69% (2%)	0% (0%)	42% (5%)	0% (0%)

Interpretations of Quantum Processes

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.



Three students discuss the PhET Quantum Wave Interference Simulation[3]:

Student A: That blob represents the probability density, so it tells you the probability of where the electron could have been before it hit the screen. We don't know where it was in that blob, but it must have actually been a tiny particle that was traveling in the direction it ended up, somewhere within that blob.
REALIST

Student B: No, the electron isn't inside the blob, the blob represents the electron! It's not just that we don't know where it is, but that it isn't in any one place. It's really spread out over that large area up until it hits the screen.
QUANTUM

Student C: Quantum mechanics says we'll never know for certain, so you can't ever say anything at all about where the electron is before it hits 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?*

Variations in Student Responses from Two Semesters of Modern Physics

- **2170A** –"Transformed" using research-based reforms, taught by a Physics Education Research (PER) Professor
- **2170B** – "Traditional"

	2170A (N=71)	2170B (N=42)
Quantum Perspective	78% +/-5%	11% +/-5%
Realist Perspective	18% +/-4%	75% +/-7%
Mixed/Other	4% +/-2%	14% +/-5%

Sample "Quantum" Response

"The blob is the electron and an electron is a wave packet that will spread out over time. Therefore, the electron acts as a wave and will go through both slits and interfere with itself. This is why a distinct interference pattern will show up on the screen after shooting out electrons for a period of time."

Sample "Realist" Response

"We just can't know EXACTLY where the electron is and thus the blob actually represents the probability density of that electron. In the end, only a single dot appears on the screen, thus the electron, wherever it was in the probability density cloud, traveled in its own direction to where it ended up."

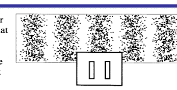
Differences in Specific Learning Goals

For the question at right:

- Students from **2170A** were instructed that choice '**D**' is correct.
- Students from **2170B** were instructed that choice '**B**' is correct.

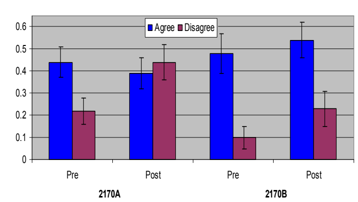
[We note that the correctness of each answer is a question of interpretation.]

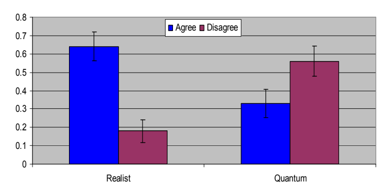
You shoot a beam of photons through a pair of slits at a screen. The beam is so weak that the photons arrive at the screen one at a time, but eventually they build up an interference pattern, as shown in the picture at right. What can you say about which slit any particular photon went through?



A. Each photon went through either the left slit or the right slit. If we had a good enough detector, we could determine which one without changing the interference pattern.
B. Each photon went through either the left slit or the right slit, but it is fundamentally impossible to determine which one.
C. Each photon went through both slits. If we had a good enough detector, we could measure a photon in both places at once.
D. Each photon went through both slits. If we had a good enough detector, we could measure a photon going through one slit or the other, but this would destroy the interference pattern.
E. It is impossible to determine whether the photon went through one slit or both.

Quantum Attitudes Statement #16: "An electron in an atom has a definite but unknown position at each moment in time."





Combined responses to QA#16 grouped by how students responded to the essay question

- Students from both semesters who had preferred a **quantum perspective** in the essay question tended to **disagree with QA#16**, while the majority of **those preferring a realist perspective agreed**.
- The results shown here appear to reflect the specific learning goals of each instructor.

Conclusions

- Instruction in classical physics promotes and reinforces a realist perspective
- Students develop a quantum perspective through instruction in modern physics
- These perspectives are not robust concepts, and are sensitive to context
- Student learning can be significantly impacted by an instructor's choice of learning goals[4,5]

Acknowledgements

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