“Classical-ish”: Negotiating the boundary between classical and quantum particles

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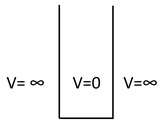
Developing quantum ontologies

- Developing a conceptual understanding of quantum mechanics includes developing ontologies for quantum entities (models for what kind of thing something is). [1-3]
- A quantum “particle” is different from both a classical particle and a classical wave, but we bring in classical intuitions with us when we learn quantum mechanics.
- What does it look like when students are negotiating the boundaries between classical and quantum ontologies while trying to make sense of a quantum system?

Context: Particle in a box tutorial

- 5 physics undergrads (Al, Bob, Chad, Dan, Ed) taking 1st-semester quantum mechanics, and near the end of the semester
- Focus group setting (outside of class)
- Tutorial on the particle in a box (infinite square well)



Data analysis

- Identifying ontologies through gesture analysis [4-5] and predicate analysis [6]
- Metacognitive utterances about the relationship between quantum and classical physics

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References
[1] K. Mannila, I.T. Koponen, & J.A. Niskanen, “Building a picture of students' conceptions of wave- and particle-like properties of quantum entities,” *Eur. J. Phys.* **23**, 45 (2002)
[2] G. Kalkanis, P. Hadzidaki, & D. Stavrou, “An instructional model for a radical conceptual change towards quantum mechanics concepts”, *Sci. Educ.* **87**, 257 (2003)
[3] C. Baily & N.D. Finkelstein, “Ontological flexibility and the learning of quantum mechanics,” arXiv:1409.8499 [physics.ed-ph] (2014)
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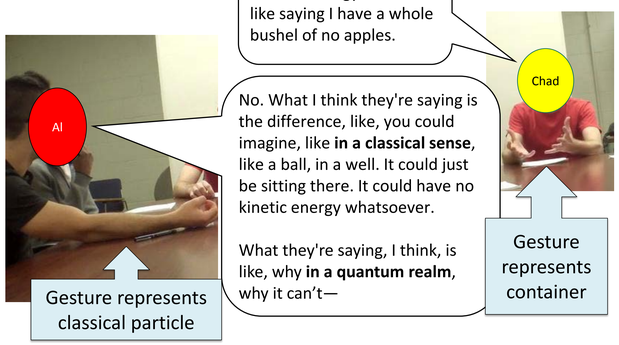
[6] J.D. Slotta, M.T.H. Chi, & E. Joram, “Assessing students’ misclassifications of physics concepts: An ontological basis for conceptual change,” *Cogn. Instr.* **13**, 373 (1995)

Acknowledgments
This work is supported by NSF-DUE 1323129. We thank the focus group participants, the University of Maryland Physics Education Research Group, and our collaborators at the University of Colorado (Noah Finkelstein, Katie Hinko, Jessica Hoy, and Skip Woody).

Question 3:
Why isn’t the ground state $n = 0$? That is, why isn’t it possible for the particle to have zero energy?

It’s not classical, it’s quantum

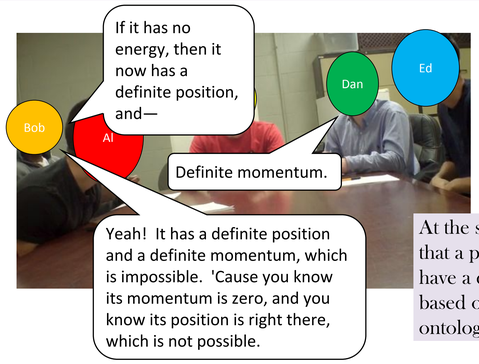


Chad suggests that the question is trivial.

Al explains why it isn’t trivial: a classical particle **could** have zero energy. But a quantum particle is different.

Hybrid classical/quantum ontology

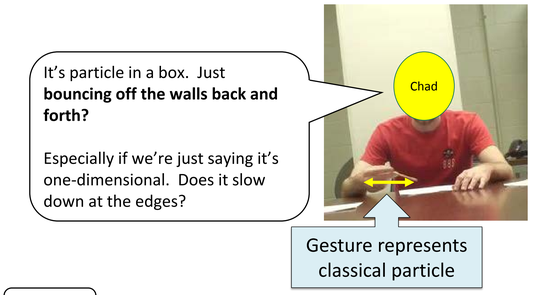
Bob’s argument is based on the uncertainty principle: a particle can’t have both a definite position and a definite momentum. This is a property of a quantum particle.

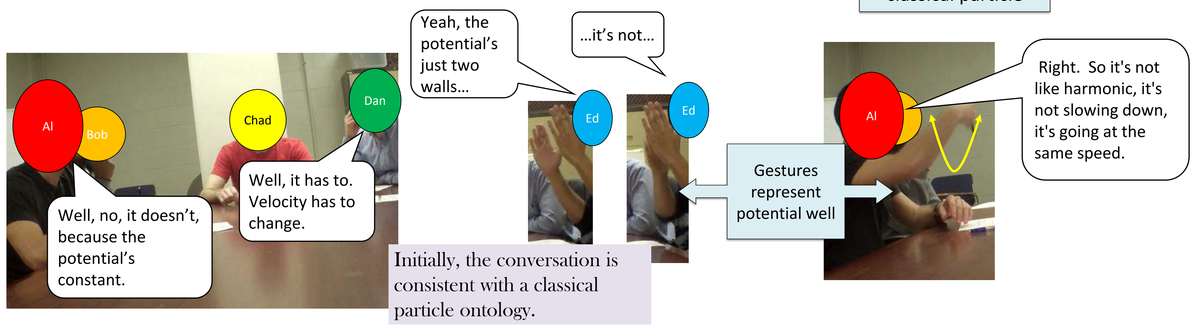


At the same time, the idea that a particle at rest must have a definite position is based on a classical particle ontology.

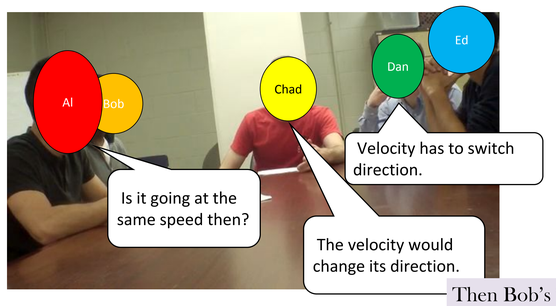
It’s not quantum, it’s classical

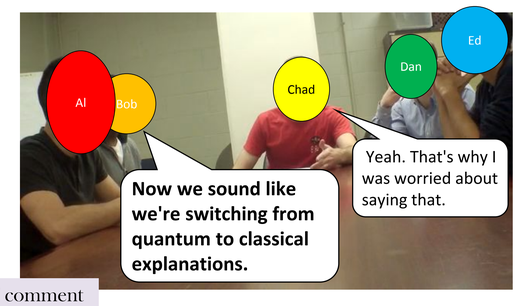
Question 6:
If you were to measure the speed of the particle at some point in time, what would you expect to measure? Why?



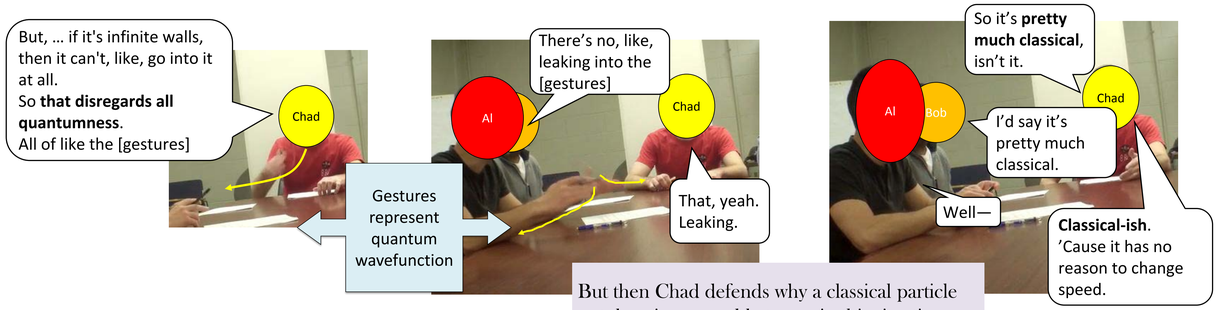


Initially, the conversation is consistent with a classical particle ontology.





Then Bob’s “meta” comment jolts the group out of this.



But then Chad defends why a classical particle ontology is reasonable to use in this situation.

What do we see?

Students are engaged in two different activities:

- Drawing on elements of various ontologies (including classical particles and quantum particles) to reason about the physical situation.
- Stepping back to label their own reasoning as classical or quantum, and reflecting on which reasoning is appropriate in the context.

The green headings above show 3 different stances toward the relationship between classical and quantum ontologies in thinking about the particle in a box. The process of building intuitions about quantum entities can include drawing analogies to classical particles, as well as making explicit contrasts with classical particles.