



Quantum philosophy in upper secondary education

QDNL symposium: Quantum education for the younger generation (0-18)

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The quantum conundrum



2 QDNL symposium

TU/e

The central questions of this workshop

What quantum interpretation to use when teaching quantum mechanics?



Overview

- The Pedagogy of Duality
- Philosophy of Science
- Discussion



The pedagogy of duality: What is an electron?

Wikipedia: The electron is a subatomic **particle** with a negative one elementary electric charge.



three generations of matter interactions / force carriers (fermions) (bosons) П Ш =2.2 MeV/c2 =1.28 GeV/c² =173.1 GeV/c =125.11 GeV/c charge н u С t g charm top gluon higgs up ≈96 MeV/c² ≈4.7 MeV/c2 ≈4.18 GeV/c d b S γ strange down bottom photon SCALAR BO ≈0.511 MeV/c2 ≈105.66 MeV/c2 =1.7768 GeV/c =91.19 GeV/d 20 e μ τ electron tau Z boson muon EPTONS <1.0 eV/c2 <0.17 MeV/c2 <18.2 MeV/c2 ≈80.360 GeV/ Ve V electron muon tau W boson neutrino neutrino neutrino

Standard Model of Elementary Particles



The pedagogy of duality: What is an electron?



Einstein (1917)

Light has momentum



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De Broglie (1923)

Matter has a wavelength



The pedagogy of duality: What is an electron?

| Levels of understanding | Example* |
|----------------------------|---|
| Novice | <i>"The electron is like a particle because it only goes through one slit."</i> |
| Advanced beginner | <i>"The electron is a particle but behaves like a wave here."</i> |
| Proficient | "The electron goes through both slits and interferes with itself, ending in a spot that relates to the interference pattern." |

*: responses are based on work of others^{1,2}

The pedagogy of duality What is an electron?

- 1. The Copenhagen interpretation
- 2. Pilot wave interpretation
- 3. Many worlds interpretation
- 4. Pragmatic interpretation (Shut up and calculate)



The pedagogy of duality Dr.Quantum





The pedagogy of duality Dr.Quantum

What happens (3 min)?

Discuss in pairs

- 1. How is the electron depicted in this video?
- 2. What is the underlying quantum interpretation of this video?
- 3. How does this video help students to change their ideas about the nature of the electron?



The pedagogy of duality Toutestquantique





The pedagogy of duality Toutestquantique

What happens (4 min)?

Discuss in pairs

- 1. What differences have you observed?
- 2. In what ways do both videos agree?
- 3. In what ways do both videos differ?
- 4. What video would you prefer to teach waveparticle duality?



Philosophy of Science Bohr v.s Einstein





Philosophy of Science Bohr v.s Einstein

What happens (2 min)?

Discuss in pairs

- 1. What are the differences between Bohr and Einstein?
- 2. How can these differences be explained?



Philosophy of Science

Comparing interpretations

| Issue | Possible views |
|---|---|
| The nature of quantum object The nature of the wave function | Observer independent existence or observer dependent existence Information wave or matter wave |
| The origin of uncertainty (probability) | Intrinsic indeterminism or lack of information (on the hidden variable) |
| The nature of measurement | Revealing the pre-determined value or realization of potentiality |
| The status of quantum theory | Approximate truth or constructed artifact |
| The role of quantum theory | Reflection of reality or convenient theoretical tool |

Table 1: issues on reality-related interpretation and possible views³

Philosophy of Science

Comparing interpretations



Central question

What quantum interpretation to use when teaching quantum physics?



Question 1

What are the key challenges in teaching quantum mechanics to younger students?



Question 2

How do different interpretations impact student understanding?



Question 3

Which interpretations are more intuitive or accessible for younger audiences?



Intermezzo:

Interpretation in textbooks

- Most align with Copenhagen interpretation^{4,5}
- Only two explicitly mention quantum interpretations⁵
- Most popular textbook takes a pragmatic approach⁵



Question 4

Should teachers/textbooks be explicit about the quantum interpretation they adhere to?



Central question

What quantum interpretation to use when teaching quantum physics?



References

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