How Students Compare and Contrast the “Discreteness” of Quantum Representations

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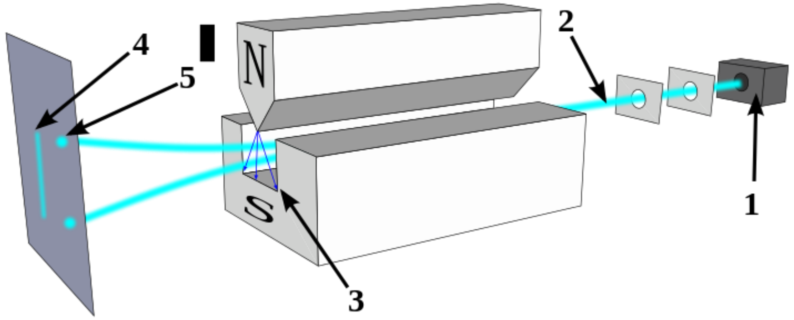
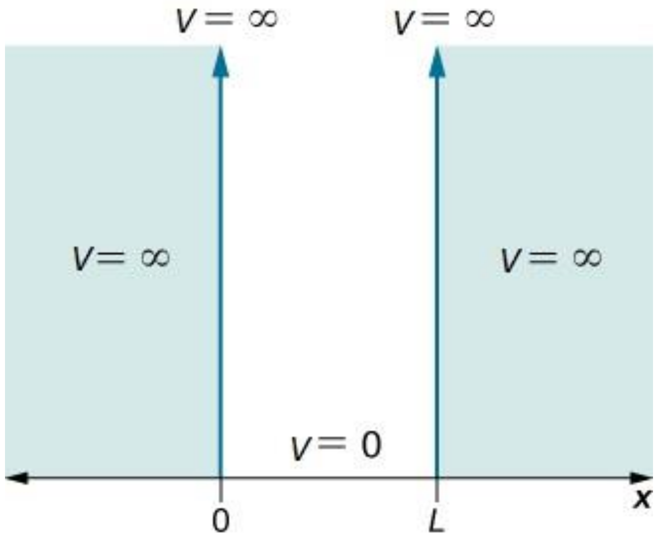
Spin-½ Systems



- Discrete, finite bases

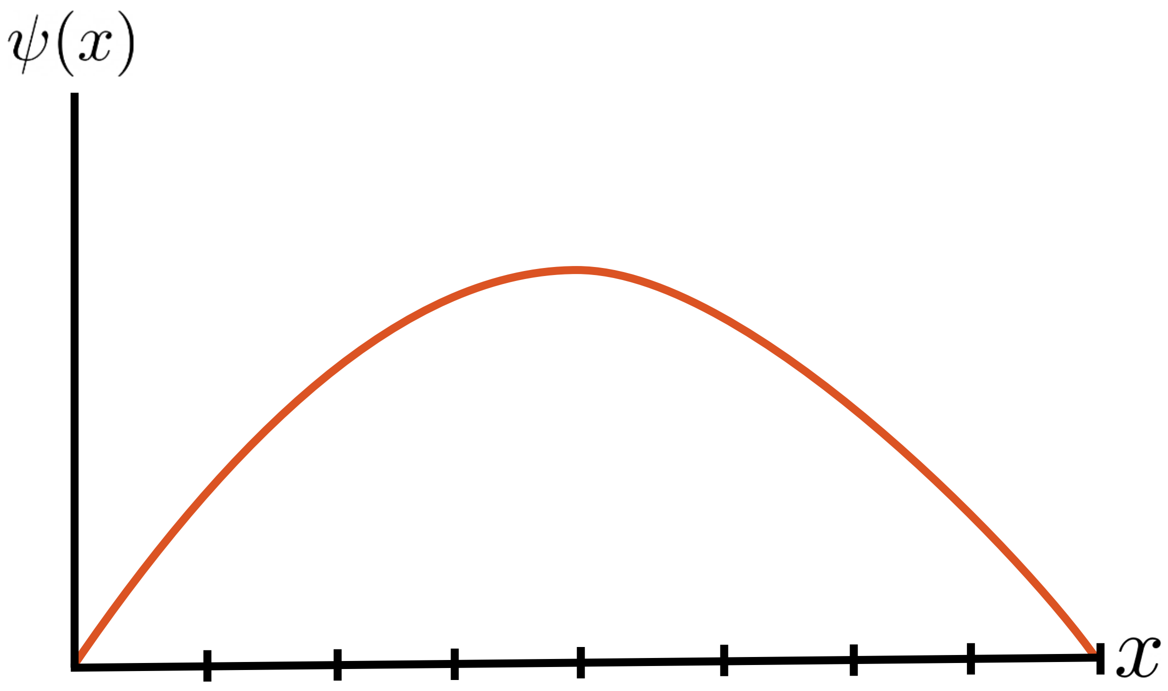
Infinite Square Well



- Continuous bases

Discretization!

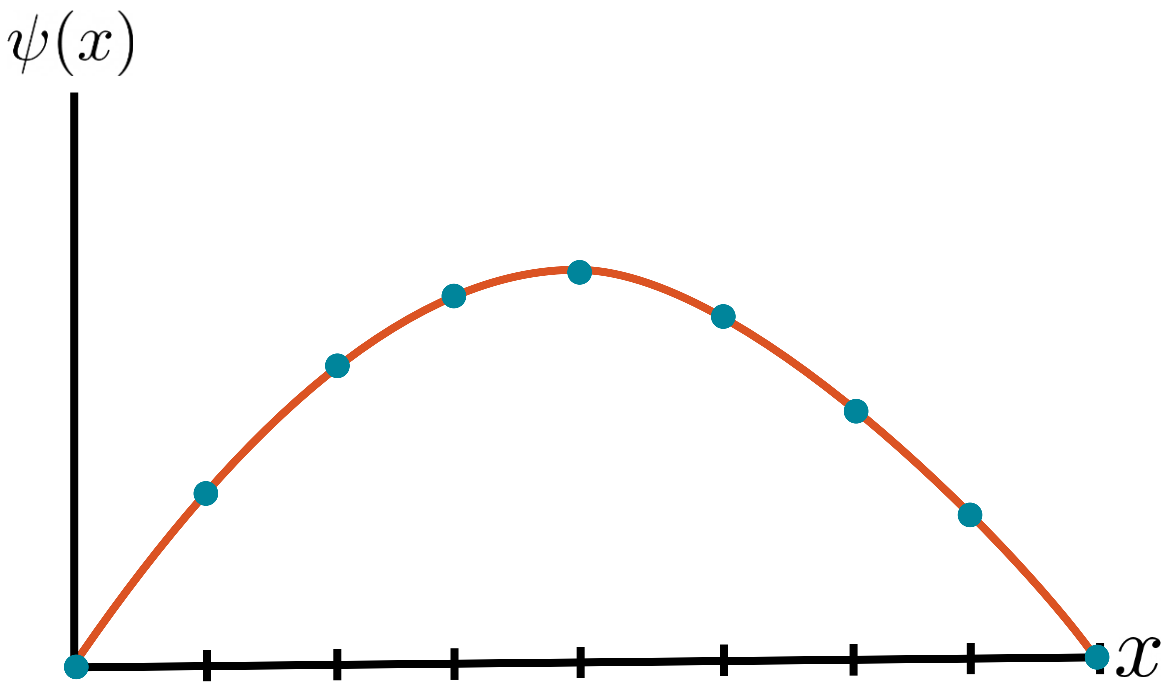
- Wavefunctions are discretized for computational operations



$$\psi(x) = Ax(L - x)$$

Discretization!

- Wavefunctions are discretized for computational operations



$$\psi(x) = Ax(L - x)$$

$$\Downarrow$$

$$\psi(x) \rightarrow \{\psi(0), \psi(\Delta x), \psi(2\Delta x), \ldots \psi(L)\}$$

Research Question

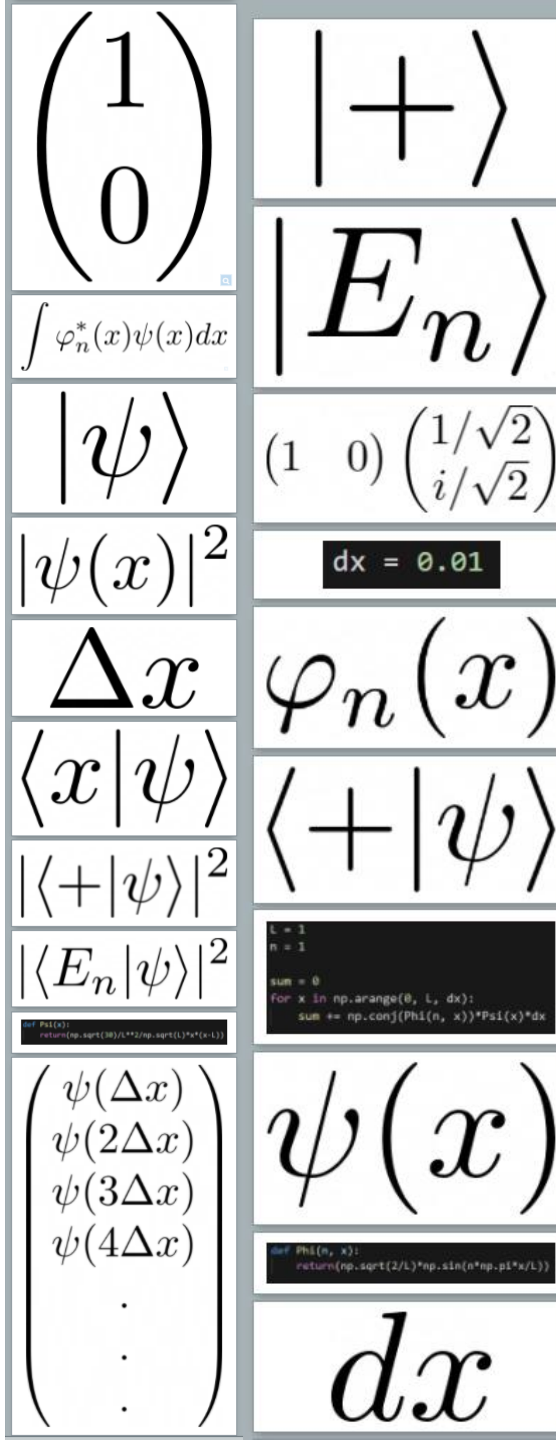
How do students understand discreteness in quantum mechanics?

Computational Lab Course Structure

- Supports physics learning in the context of programming
- Pair-programming in Python
- Taught by an instructor and a team of TAs
- Wavefunctions focused approach

Card Sorting Task Interview Methods

- Conducted semi-structured interviews with 6 participants
- Organized 20 quantum mechanics cards
- Used Optimal Workshop’s OptimalSort
- Participants followed a *think aloud* protocol



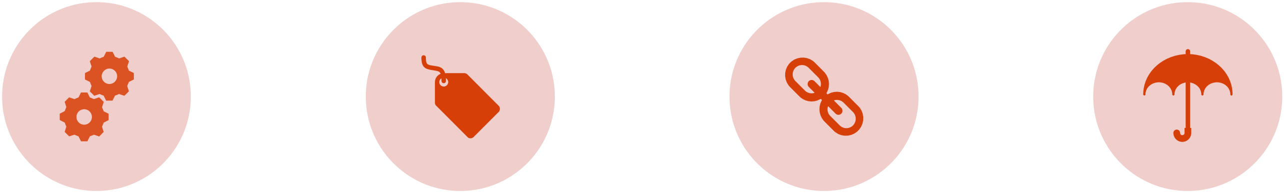
Interview Structure

Participants…

- Described each card in their own words
- Sorted the cards in three ways
  - Initial Sort
  - Second Sort
  - Discrete and Continuous sort

Analysis Overview

- Phenomengraphical Approach
- Concept image as a theoretical framework
- Thematic analysis
  - Emergent coding scheme



PROCESS DATA | CODE DATA | LINK CODES | ESTABLISH THEMES

Themes

Discreteness of Representations	Computational Approximations
Representations are used to determine how discrete something is	Code is recognized as a discretized approximation to the analytical case

Separation between Particular Values	Continuity of Function vs. Continuity of Domain
A discrete thing has particular possible values and/or separated by a particular value	The continuity of something is determined by the continuity of the function (e.g., $\psi(x)$) *or* the continuity of the domain

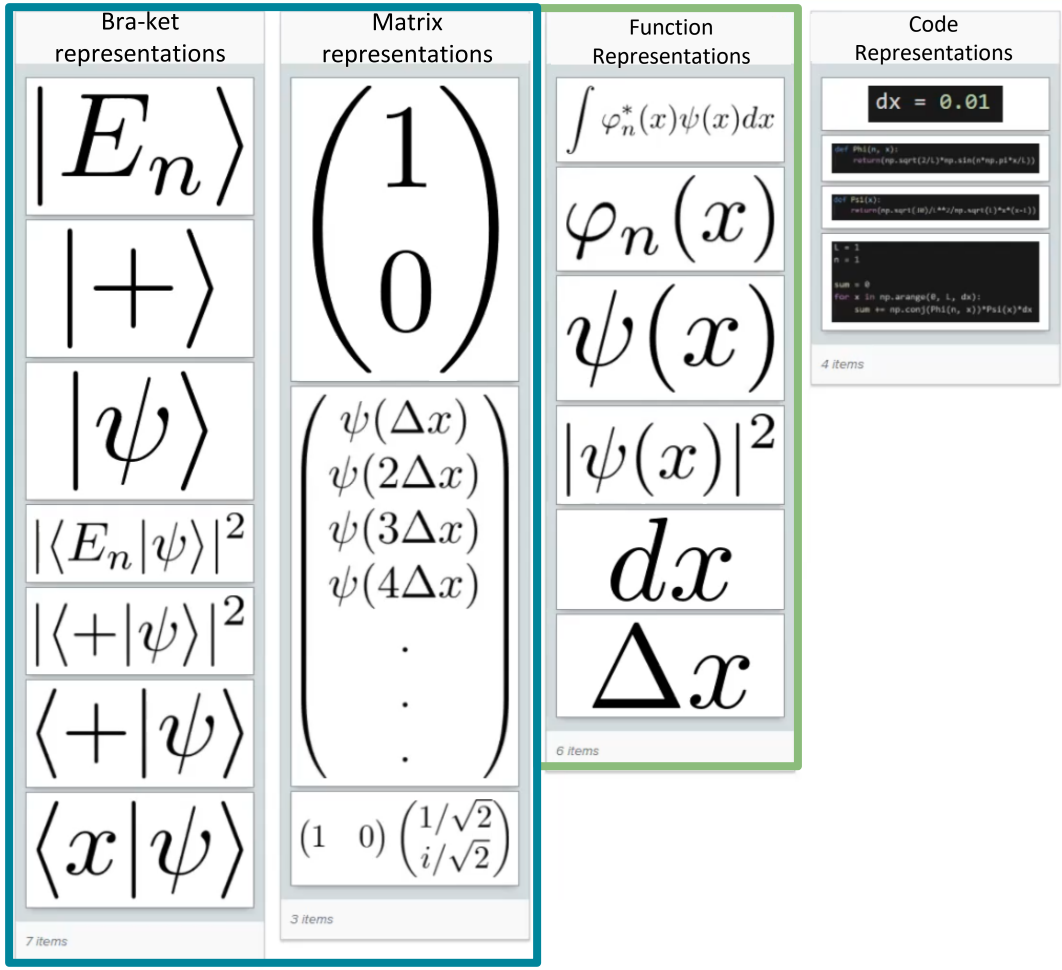
Discreteness of Representations Examples

- Dirac and Matrix Notation
- Functions of x
- Code

Mary

2nd Sort

"You definitely use this [group] for an infinite square well, versus these [groups] are best used probably for like spin systems."



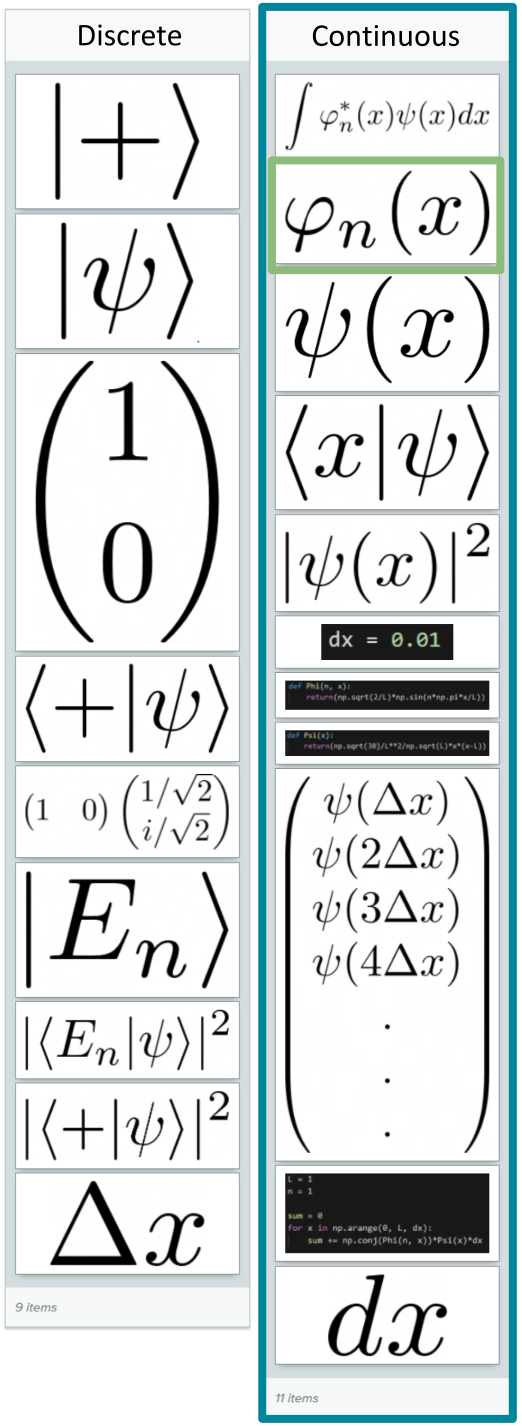
Discreteness of Representations Examples

- Dirac and Matrix Notation
- **Functions of x**
- Code

Jack

Disc. Cont. Sort

"I suppose this [$\varphi_n(x)$ card] is maybe less, less --- because it's a function, you could talk about it in a more continuous way. So yeah, maybe that would be better there because it is a function of x rather than like a braket notation or a matrix"



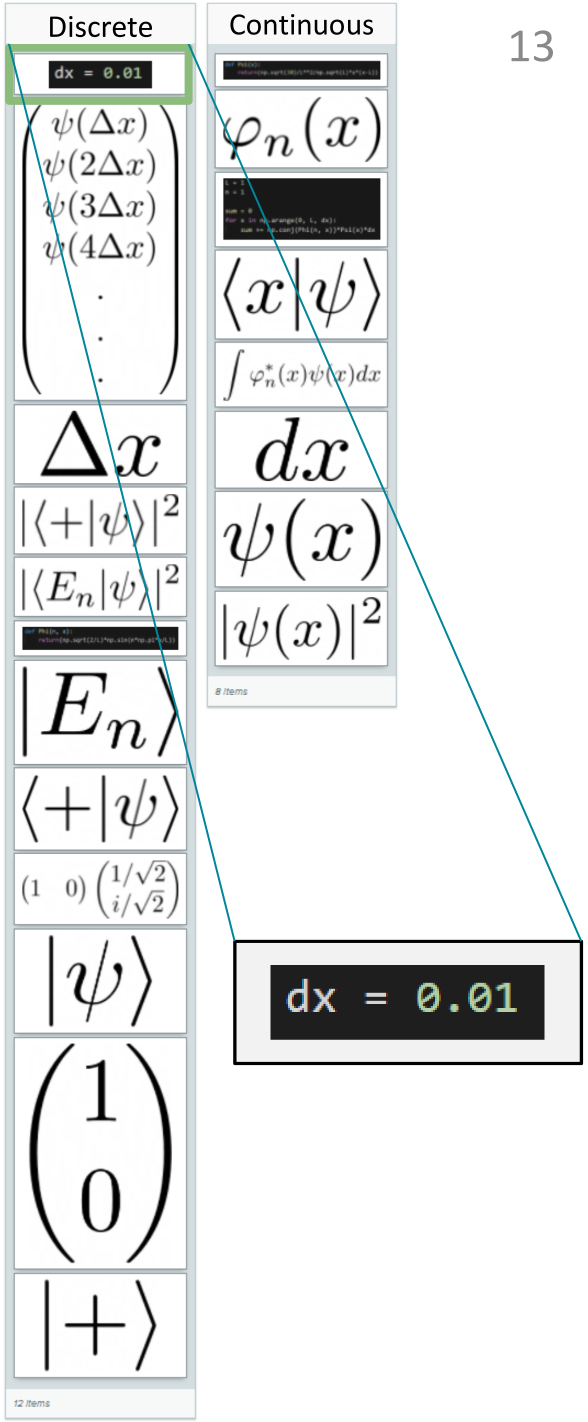
Discreteness of Representations Examples

- Dirac and Matrix Notation
- Functions of x
- Code

Emily

Disc. Cont. Sort

"The way this is being coded, you're not really making a continuous function in actuality, … but I think it is trying to mimic a continuous thing, it's just not that."



Takeaways

Students use representations as a heuristic to determine discreteness

Dirac notation and matrix notation are strongly associated with being discrete

The presence of “x” signals continuous, regardless of representation

Code is discrete or continuous, depending on if students key into the structural limitations of code or what the code represents

Thank you!

Many thanks to the OSUPER team, our participants, and our funding supporters!

Find the slides:

Additional Questions: solorich@oregonstate.edu

Find resources & research:

- paradigms.oregonstate.edu
- osuper.science.oregonstate.edu

See PERC poster:

I-67

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OSU is hiring!

Search has begun for tenure-track positions in PER

Contact Search Committee Chair Dr. Ethan Minot for details

Ethan.Minot@oregonstate.edu

osuper.science.oregonstate.edu

Oregon State University

Code Snippet Sorting Examples

```
L = 1
n = 1

sum = 0
for x in np.arange(0, L, dx):
    sum += np.conj(Phi(n, x))*Psi(x)*dx
```

```
def Phi(n, x):
    return(np.sqrt(2/L)*np.sin(n*np.pi*x/L))
```

```
def Psi(x):
    return(np.sqrt(30)/L**2/np.sqrt(L)*x*(x-L))
```

```
dx = 0.01
```

Definition

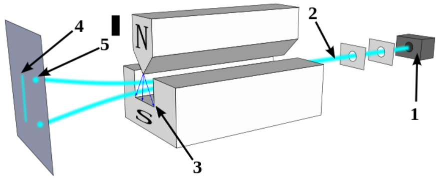
Concept Image

- Describes the “total cognitive structure that is associated with [a] concept” [4]
- Builds up over time through experiences (and can change)
- Different stimuli can activate different parts of one’s concept image
  - Does not need to be coherent

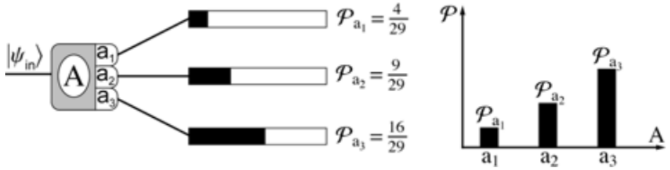
[4] Tall and Vinner, Educ. Studies in Math **12,** 151-169 (1981)

PH 425 Course Structure

Introduce QM with spin-1/2 systems

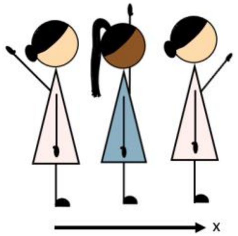


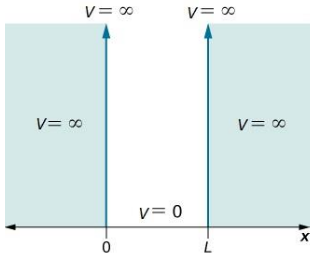
$$\begin{pmatrix}1\\0\end{pmatrix} \quad |+\rangle$$



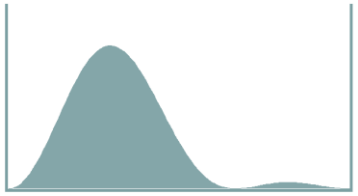
Discrete systems

End with the particle in a box





$$\psi(x) = \sum_{n=1}^{\infty} c_n \sqrt{\frac{2}{L}} \sin\left(\frac{2\pi x}{L}\right)$$



Continuous system