Analyzing The Effects Of Spin First Versus Position First Instructional Approaches To The Teaching Of Quantum Mechanics

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Instructional Approaches

We are investigating the effectiveness of two different approaches to teaching upper division undergraduate quantum mechanics:

- **Spin First** (SF)
  - Begins with the analysis of the Stern-Gerlach experiment and discrete two state spin-half bases.
  - Utilizes matrix representations and the analogous Dirac notation to describe quantum states as appose to wave functions[1].
  - Encourages understanding of abstract quantum physics concepts while keeping the mathematics simple.
- **Position First (PF)**
  - Begins with the mathematical description of the wave function of a particle in various potential wells.
  - Mathematically driven and focuses more on computation than sense-making.
  - Critics of this believe that the spontaneous exposure to abstract concepts and heavy mathematics may cause cognitive overload[1].

Research Study

- Data was collected from the following classes:
  - PHY 499 -- taught in SF approach, elective, enrollment (N = 17)
  - PHY 401 -- taught in PF approach, core course, enrollment (N = 46)
- Data for 3 groups of students was analyzed
  - 7 Students from PHY 499 only (SF)
  - 7 Students from both PHY 499 and PHY 401 (SF/PF)
  - 31 Students from PHY 401 only (PF)

Sample Questions

QMCA Q1) Consider a particle which starts in a quantum state given by $|\psi\rangle = \sqrt{\frac{4}{5}}\,|-\rangle + \sqrt{\frac{1}{5}}\,|+\rangle$.
What is **the most probable value** for a measurement of S_z (the z-component of spin) in this system?

$A. +\hbar/2$

$B. -\hbar/2$

$C. 0$

$D. \frac{4}{5}(-\hbar/2) + \frac{1}{5}(\hbar/2)$

$E. \sqrt{\frac{4}{5}}\,(-\hbar/2) + \sqrt{\frac{1}{5}}\,(\hbar/2)$

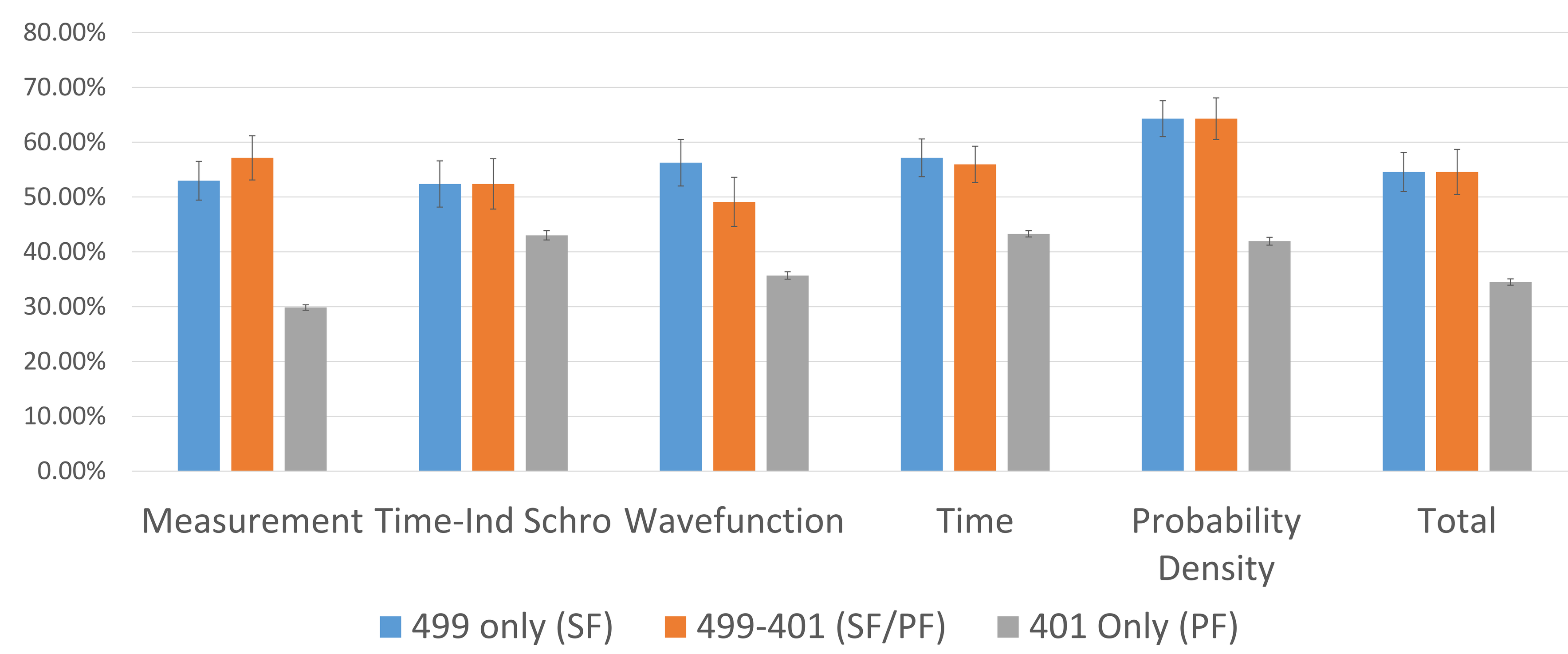
QMCA Q18) If you start at time t = 0 with wave function , does the position probability density vary with time?

A. Yes
B. No
C. More information is needed to decide

Results

We compared students' performance using the Quantum Mechanics Concept Assessment (QMCA). The QMCA is a research validated 40-question conceptually-focused survey that tests students' knowledge of five topics in quantum mechanics: quantum measurement, the time-independent Schrodinger equation, wave functions, time evolution, and probability density[1].

Average Score on QMCA



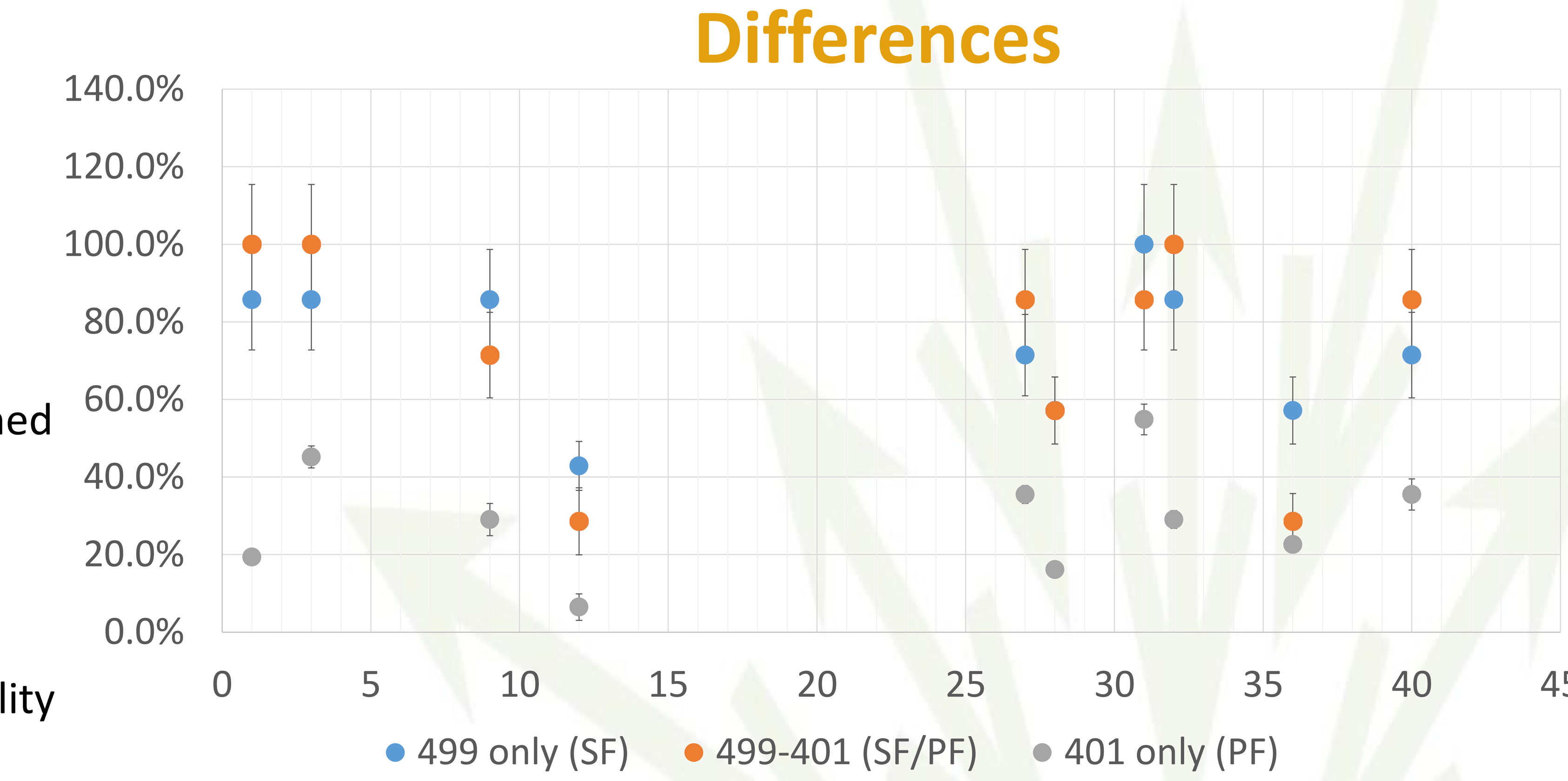
- Overall SF and SFPF students outperformed PF students.
  - SF = 54.58 3.56%
  - SF/PF = 54.58 4.10%
  - PF = 34.49 0.59%
  - Results align with previous research[2].
- SF and SF/PF students had distinctly higher scores in all categories, especially in the measurement and probability density categories.

We compared student performance on individual questions and found that PF students had lowest scores on 26 out of 40 questions, and 10 out of 40 questions had a 30% difference between SF and PF students. Out of these questions with the highest score differences, 9 out of 10 tested students' knowledge of quantum mechanical measurement.

- **QMCA Q1** had highest discrepancy between scores.
  - SF = 85.7% $\pm$ 12.97%
  - SF/PF= 100.0% $\pm$ 15.43%
  - PF= 19.4% $\pm$ 0.58%
- Tests students' knowledge of most probable value for spin half system (measurement).

- **QMCA Q18** -- PF students outperformed SF and SF/PF students.
  - SF = 42.9% $\pm$ 9.9%
  - SF/PF= 42.9 $\pm$ 8.0%
  - PF= 58.1% $\pm$ 4.92%.
- Tests students' knowledge of probability density and time evolution.

Questions with Highest Score Differences



*Error Bars represent standard error

Conclusion and Future Work

- Indication that SF courses are beneficial to students' knowledge of quantum mechanics, especially in the measurement and probability density categories.
- Compare Fall 2016 data to data sets from prior years.
- Analyze context of questions and how it affected students' scores.

References

1. "Spin First Vs. Position First Instructional Approaches To Teaching Introductory Quantum Mechanics" H. Sadaghiani, *American Institute of Physics (AIP) Proceeding, Phys. Edu. Conference*, (2016)
2. "Spin First instructional approach to teaching quantum mechanics in sophomore level modern physics courses," H. Sadaghiani and J. Munteanu, *AIP Proceeding, Phys. Edu. Conference*, pp. 287-290 (2015)

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