Using Think-aloud Concept Map Activity to Probe Students' Understanding of Particle Physics in an Undergraduate Online Course

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INTRODUCTION

- PHY163 (Introduction to Particle Physics) is an online course taught at Fresno State via CSU online.
- It aims to **provides undergraduate access to particle physics** courses and offering paid research internships at CERN.
- Particle physics **poses unique learning challenges due to its diverse and complex nature**, requiring students to integrate various physical regimes and frameworks.[1-3]
- **Concept maps** are highlighted as powerful visual tools that can help organize complex information in particle physics.[4-5]

METHOD

1-on-1 think-aloud interviews

2 Master students, 5 Undergraduate students

Students given a list of words

Described what they thought

4 central dimensions:
- *Particle types & categories*
- *Particle properties*
- *Type of interactions & mediators*
- *Theoretical frameworks*

Interviewer:
- *Record the interviews*
- *Explain what is a concept map*
- *Show an example of a concept map*
- *Followed an interview protocol*

Interview protocols:
1. *Add or delete words*
2. *Sort them into groups*
3. *Create connections using arrows*

** Internet searches were permitted; students must state when they were doing so.*

In a remote setting, the interview protocol became difficult to enforce. By the 3rd interview, the interviewer only offer the steps as guidance and encourage students to proceed intuitively.

WORD LIST

particle, antiparticle, decay, annihilate, scatter, force (interaction), matter, lepton, meson, boson, quark, muon, proton, gluon, Higgs, photon, spin, color, positive, up, charm, strange, strong, electromagnetic, general relativity, quantum electrodynamics, electroweak theory.

REFERENCES

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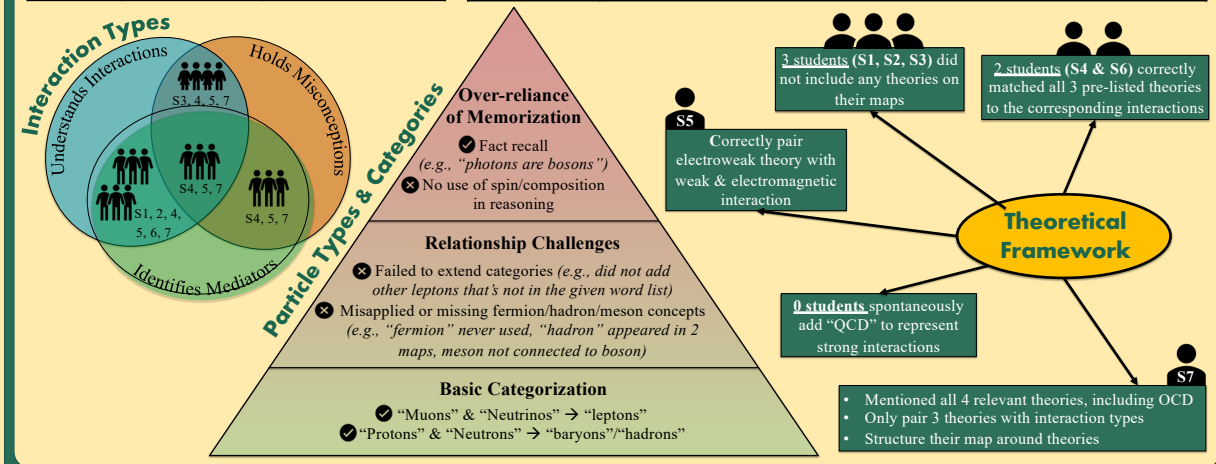
RESULT

General Organizing Approach

Students	Cluster vs. Emergent	Action first vs. Matter first
S1	Cluster	Action first
S2	Emergent	Matter first
S3	Cluster	Matter first
S4	Cluster	Matter first
S5	Cluster	Matter first
S6	Emergent	Matter first
S7	Emergent	Neither (theory first)

Particle Properties

Property	Correct Use	Misconception / Omission
Spin	2 students explicitly group spin under quantum number	**S1** confused up/down quark flavor with spin. **S2** omitted spin value of boson.
Charge	4 students use "charge" or "positive"	2 students omitted any mention of charge; 4 omitted "negative"
	Inconsistency in understanding; mentioned "positive" but omitted "negative"	
Color	6 students correctly associate color with quark	none
Baryon Number	Only **S3** noted conservation of baryon and lepton numbers	6 students omitted baryon number entirely
Mass	3 students included "mass" despite it not being in the word list	



DISCUSSION

- **Cognitive Styles:** Balance between "Cluster" and "Emergent" styles suggests diverse approaches to open-ended tasks.
- **Matter Classification Preference:** Students favored classifying matter first, possibly due to the perceived stability of matter classification over complex interactions in particle physics.
- **Categorization vs. Relationships:** Strong basic categorization but weak understanding of broader particle relationships points to rote memorization over deep comprehension.
- **Ontological Framework:** Students lack an organized framework for reasoning about particle properties.
- **Theoretical Framework:** Good grasp of 4 fundamental forces and mediators, but inconsistent and imprecise in specifying particle participation. Connecting interactions to theories is a higher-level cognitive demand requiring more explicit support.

CONCLUSION

Student Understanding Gaps:
- Good factual recall (categories, mediators) but weak structural understanding.
- Specific issues: overlapping classifications, fragmented quantum reasoning, imprecise terminology.

Instructional Opportunities:
- Instructors can provide more explicit scaffolds.
- Clarify links between particle properties and interactions.
- Support the integration of abstract theoretical concepts.

Concept Mapping as a Tool:
- Effective for revealing student reasoning.
- Useful for guiding instruction, especially online.

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