**Coordinating theoretical models
of student reasoning
with evidence:**

An example from special relativity

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Outline of presentation

- **Two models of student reasoning**
- **Student reasoning in special relativity**
  *Observing the fit between models
  and evidence*
- **Summary**

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Two models of student reasoning

Misconceptions model	*Primitives* model
Students reason by referring to coherent, stable frameworks of ideas ("alternative theories").	Students reason by referring to a collection of highly intuitive generalizations from experience.

Characteristic student responses:

• "precompiled"	• *ad hoc*
• stable	• fragile
• self-consistent	• self-contradictory
• independent of context	• dependent on context

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Two models of student reasoning

Misconceptions model	*Primitives* model
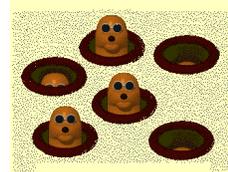
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Research question

Which model
best fits the available data
about student reasoning
in special relativity?

How can we tell?

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Student reasoning in special relativity

Scherr, Shaffer, and Vokos
"Student understanding of time in special relativity: Simultaneity and reference frames," Phys. Educ. Res., Am. J. Phys. Suppl. 69, 2001
"The challenge of changing student beliefs about the physical world: An example from the relativity of simultaneity," accepted for publication in Phys. Educ. Res., Am. J. Phys. Suppl., 2002

Posner, Strike, Hewson, and Gertzog (1980-82)

Panse, Ramadas, and Kumar (1994-96)

Saltiel and Malgrange (1980)

Villani and Pacca (1987-90)

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Misconceptions model of student understanding

(Quotations from Scherr et al)

"Evidence…suggests many students **construct a conceptual framework**"

"Ideas… **harmoniously co-exist**"

three core **"beliefs"**

[determine] "what students **actually thought**"

[attempt to] "obtain a **detailed picture** of student thinking"

Student ideas are described as being a fixed structure of entities, reliably present in students' minds.

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Sample research task: "Spacecraft question"

Mt. Rainier and Mt. Hood erupt at the same time in the reference frame of a seismologist at rest in a laboratory midway between them. A spacecraft flying past Rainier towards Hood at v=0.8c is directly over Mt. Rainier when it erupts.

Let Event 1 be "Mt. Rainier erupts," and Event 2 be "Mt. Hood erupts."

In the spacecraft frame, does Event 1 occur before, after, or at the same time as Event 2?

Spacecraft

$v = 0.8c$

Rainier   *Seismologist*   **Hood**
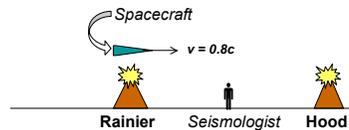
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A correct response

Application of the Lorentz transformations:

$$\Delta t_{RH}{}' = \gamma \left(\Delta t_{RH} - v\Delta x_{RH}/c^2\right)$$

Time between eruptions in ground frame (zero)

Velocity of spacecraft (positive)

Distance from Rainier's eruption to Hood's eruption (positive)

Negative: **Rainier erupts after Hood**

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The misconception(s)

1. Belief that events are simultaneous if an observer receives signals from the events at the same instant

2. Belief that simultaneity is absolute

3. Belief that every observer constitutes a distinct reference frame

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Characterizing the data

Are student responses
- **"precompiled"?**
- **stable?**
- **self-consistent?**
- **independent of context?**

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Characterizing the data

Are student responses
- "precompiled"? *Apparently*
- stable?
- self-consistent?
- independent of context?

Students answer immediately and with confidence.

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Characterizing the data

Are student responses
- "precompiled"? *Apparently*
- stable? *Yes*
- self-consistent?
- independent of context?

Students answer similarly before and after questioning.

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Characterizing the data

Are student responses
- "precompiled"? *Apparently*
- stable? *Yes*
- self-consistent? *Yes – to the students*
- independent of context?

They make explicit, simultaneous use of all three "beliefs."

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Characterizing the data

Are student responses
- "precompiled"? *Apparently*
- stable? *Yes*
- self-consistent? *Yes – to the students*
- independent of context? *Maybe*

Responses are unaffected by changes in wording or physical setting.

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Characterizing the data

Are student responses
- "precompiled"? *Apparently*
- stable? *Yes*
- self-consistent? *Yes – to the students*
- independent of context? *Maybe*

The data support a misconceptions model.

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Primitives model of student understanding

Student ideas are described in terms of intuitive ideas that are obviously correct in some situations.

1. Belief that events are simultaneous if an observer receives signals from the events at the same instant
2. Belief that simultaneity is absolute
3. Belief that every observer constitutes a distinct reference frame

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"Visual reality:" *What you see is what there is.*

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"Visual reality:" *What you see is what there is.*

"Ultimate reality:" *Things "really happen" in only one way.*

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Primitives model of student understanding

"If I see [the events] at different times, they occurred at different times in my reference frame." (graduate student)

"Visual reality:" *What you see is what there is.*

"If we are in relative motion we will measure different distances and so on but if we are all intelligent observers we will all figure out that the events were simultaneous in our rods-and-clocks reference frame." (graduate student)

"Ultimate reality:" *Things "really happen" in only one way.*

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Characterizing the data

Are student responses
• *ad hoc?*
• fragile?
• self-contradictory?
• dependent on context?

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Characterizing the data

Are student responses
• *ad hoc?*   *Apparently not*
• fragile?
• self-contradictory?
• dependent on context?

Students don't sound like they're "thinking it through."

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Characterizing the data

Are student responses
• *ad hoc?*   *Apparently not*
• fragile?   *No*
• self-contradictory?
• dependent on context?

Students answer similarly before and after questioning.

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Characterizing the data

Are student responses
- *ad hoc?* **Apparently not**
- *fragile?* **No**
- *self-contradictory?* **Yes – to some experts**
- *dependent on context?*

> *Some find the "beliefs" logically incompatible.*

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Characterizing the data

Are student responses
- *ad hoc?* **Apparently not**
- *fragile?* **No**
- *self-contradictory?* **Yes – to some experts**
- *dependent on context?* **Maybe**

> *Tasks in which people see light signals elicit distinctive responses.*

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Characterizing the data

Are student responses
- *ad hoc?* **Apparently not**
- *fragile?* **No**
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- *dependent on context?* **Maybe**

The data do not rule out a primitives model.

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Characterizing the data

Are student responses
- *ad hoc?* **Apparently not**
- *fragile?* **No**
- *self-contradictory?* **Yes – to some experts**
- *dependent on context?* **Maybe**

The data do not rule out a primitives model.

The primitives model is flexible.

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Coordinating models with evidence

✦ **We can model student reasoning either in terms of**
  highly intuitive misconceptions,
  or stably activated primitives.

✦ **The data (or the models) are insufficient for a more definitive characterization.**

> More information might help.

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Two models of conceptual change

Misconceptions model	*Primitives* model

Change is difficult and permanent. **Change is easy and fleeting.**
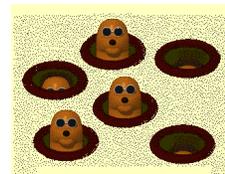
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Misconceptions model of conceptual change:

"Individuals **replace** conceptions when faced with anomalous experiences." [Hewson]

"The instructional strategy can be loosely characterized as *elicit, **confront**, resolve*."
[Scherr et al]

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Classroom observations

Change is difficult

1. Belief that events are simultaneous if an observer receives signals from the events at the same instant
2. Belief that simultaneity is absolute
3. Belief that every observer constitutes a distinct reference frame

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Evidence that change is *difficult*

Denial
> Students make loud verbal objections to a partner's conclusions.

Withdrawal
> Interviewees silent or unresponsive for thirty seconds or more.

Absurdism
> Students ascribe results to magic, or quantum mechanics.

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Evidence that change is *permanent*

Student performance on research tasks is greatly improved.

[See "The challenge of changing student beliefs…" accepted for publication in Phys. Educ. Res., Am. J. Phys. Suppl., 2002]

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Classroom observations

Change is difficult

1. Belief that events are simultaneous if an observer receives signals from the events at the same instant
2. Belief that simultaneity is absolute
3. Belief that every observer constitutes a distinct reference frame

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Classroom observations

Change is not difficult

1. Belief that events are simultaneous if an observer receives signals from the events at the same instant
2. Belief that simultaneity is absolute
3. Belief that every observer constitutes a distinct reference frame

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Evidence that change is
easy **and** *fleeting*

Comfort
>   Students answer questions quickly and agree
>   readily with one another.

Fluidity
>   Students change their minds frequently,
>   progressing and relapsing, revisiting
>   the same ideas many times.

Common sense
>   Students appeal to everyday experience.

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Summary

Both prevailing models
for student reasoning
are useful for describing
student reasoning in
special relativity.

Theoretical models can add to the
meaning of empirical evidence.

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Summary

Neither model fits all the data.

Possible refinements or hybridizations:

- **Perhaps some misconceptions (or primitives) are
  stable, and some are fragile.**
- **Perhaps some "beliefs" are misconceptions and
  others are primitives.**
- **Perhaps misconceptions are made up of primitives.**

Empirical studies can have
theoretical implications.

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