Using gesture analysis to explore embodied cognition in chemistry

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Origins and timeline of the project

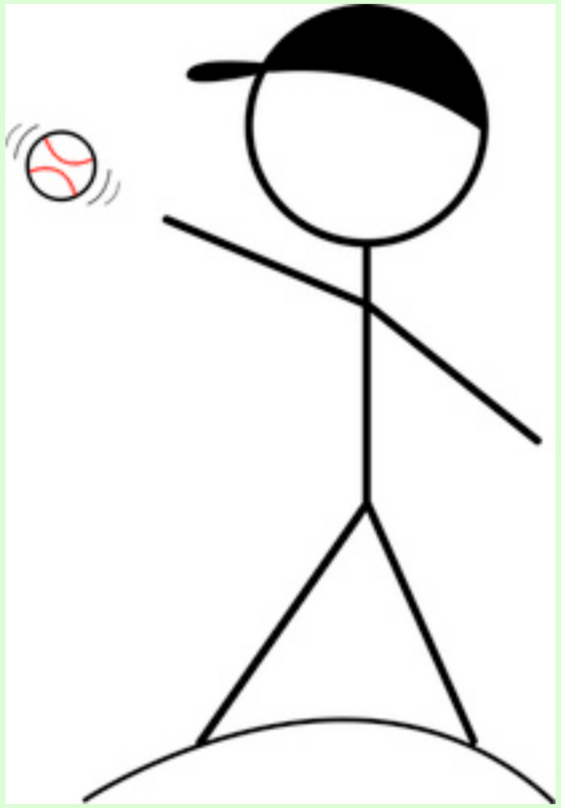
- Lakoff & Johnson, 1999
- TRUSE 2010
- Fall 2010 visit by Ricardo to Maine, team focused on adapting one of our PLTL activities that used a human scale representation of the hydrogen atom energy levels
- Data collection in Spring 2011 and a visit by FGA and VJF to CRMSE in San Diego
- Fall 2011, ongoing data analysis
- Spring 2012, ACS meeting San Diego (FGA, MB)

A framework for thinking about gesture in chemistry teaching & learning

- Embodied cognition: all human concepts are based on our bodily experiences and interactions with the world (Lakoff & Johnson 1999)
- Gestures and bodily actions are genuine constituents of thinking (Radford 2009; Nemirovsky, 2003)
- Enaction posits that organisms create their own experience through their actions. (Hutchins & Palen, 1997; Hutchins, 2010)

What about rational thought?

I'll pose the following problem related to baseball. If I throw a ball to you with a velocity of 7960 (1F18) mm/s and you are 16000 mm (10000) away, how long will it take to reach you?



t=d/v

let's do the experiment!

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Mapping the H atom energy levels to the staircase

$E_n = -E_H/n^2$ $(E_H=2.18\times10^{-19}\ J)$

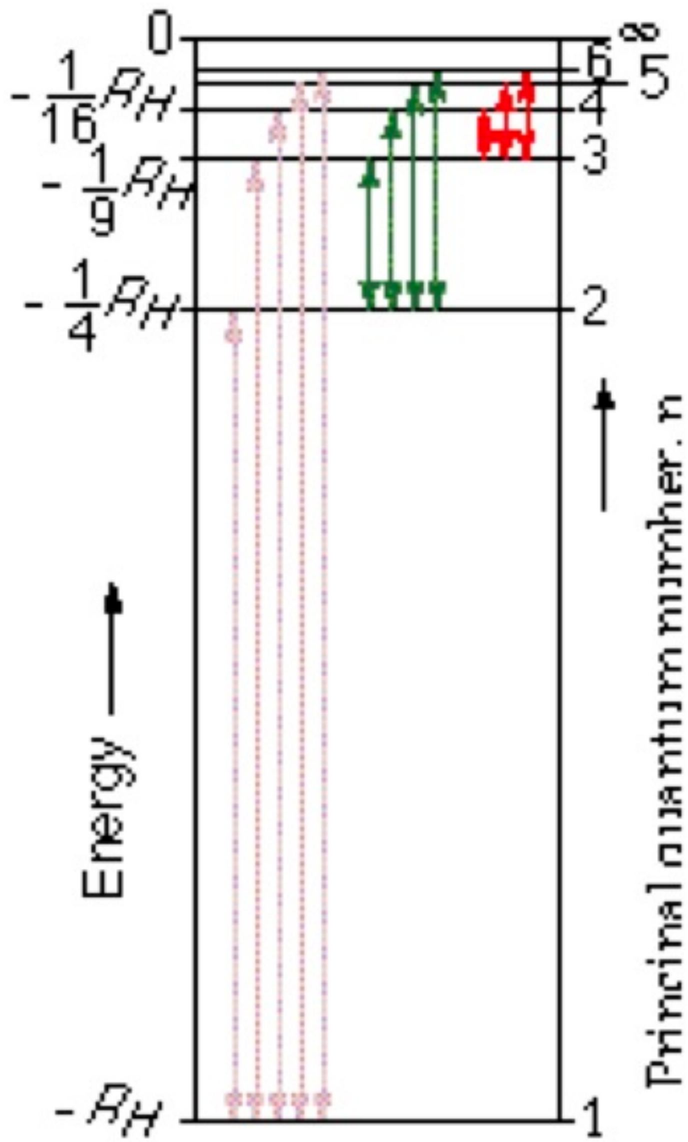
- Students had real difficulties in creating the map between the H atom energy level equation and the staircase (inverse square, negative energies)

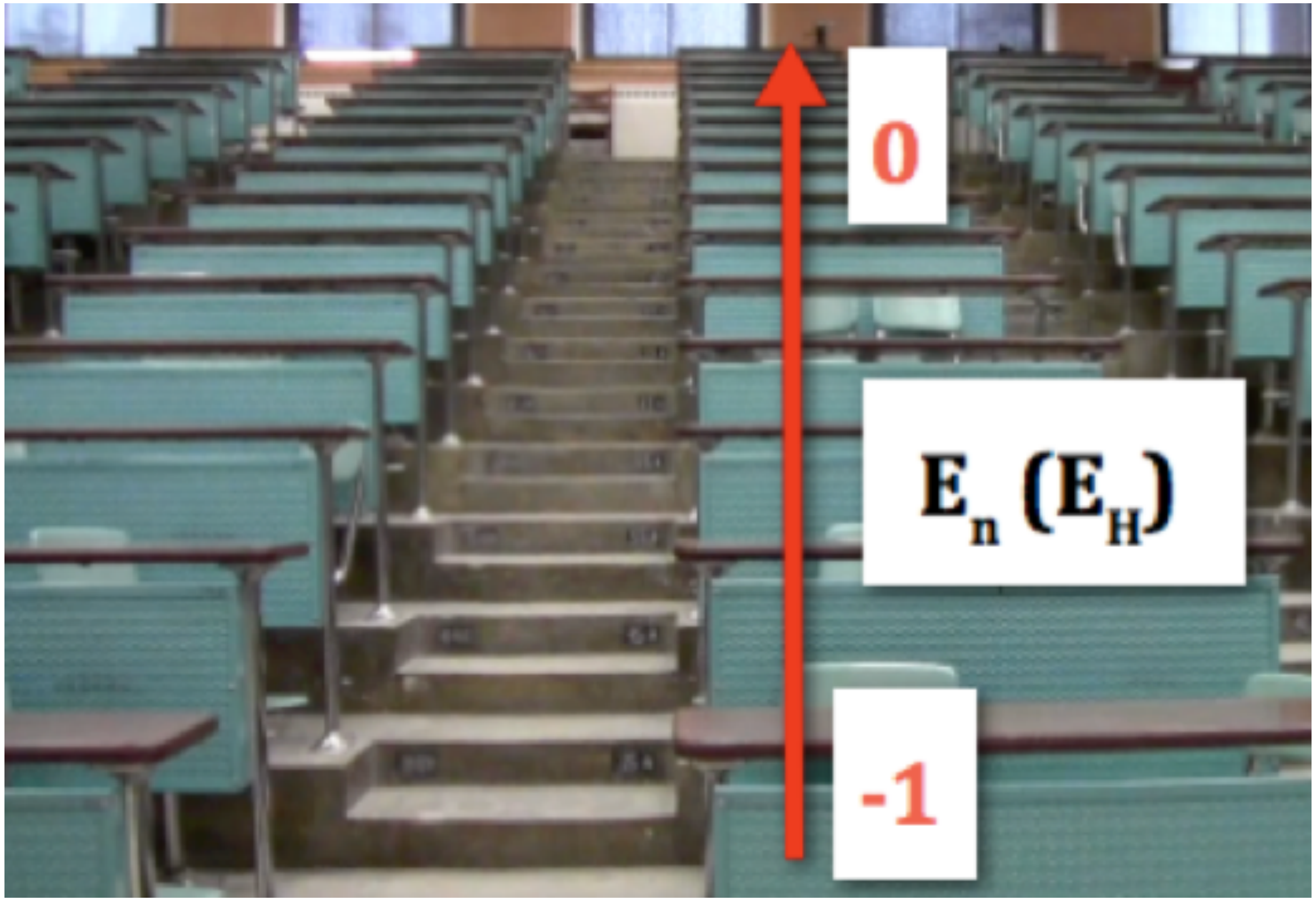
"cognitive dissonance staircase"

- Students were more successful in enacting quantum transitions on the staircase if we prepared the scenario explicitly.

"cognitive dissonance sociocultural grainsize staircase"

Students investigate the energy levels of the hydrogen atom using an embodied learning activity*





*ELAs: Scherr, 2010; Morrow, 2004

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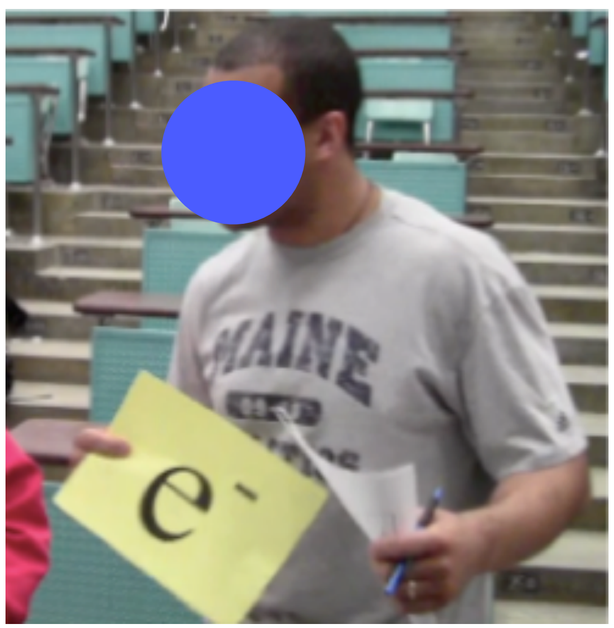
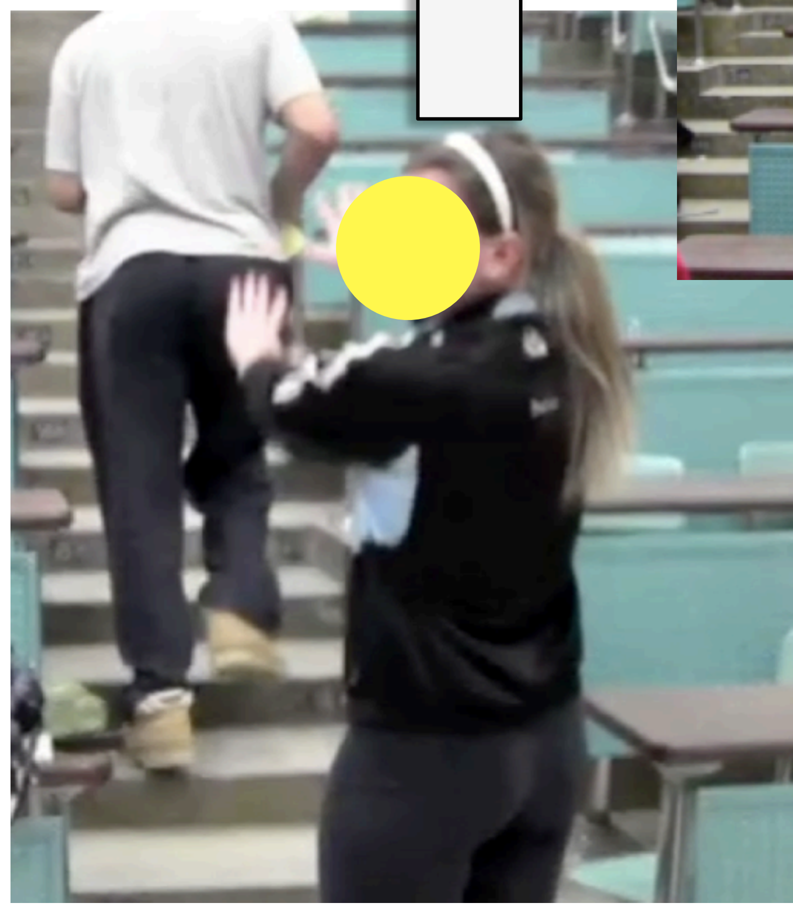
Students acted out quantum transitions

One student was the photon. . .



. . . and another was the electron



Different groups of students chose different ways of telling the story of the absorption and emission of light

There was pushing, dancing, arm-linking . . .

After four weeks we asked students about the hydrogen atom...

"The photon was the person that was pushing and he needed some type of energy to be able to do the work and the electron was the one being pushed from one quantum to a higher quantum number."

We noticed that words don't always tell the whole story

In the informal interviews, we asked students to describe how they imagine the electronic structure of a hydrogen atom:

Sophie

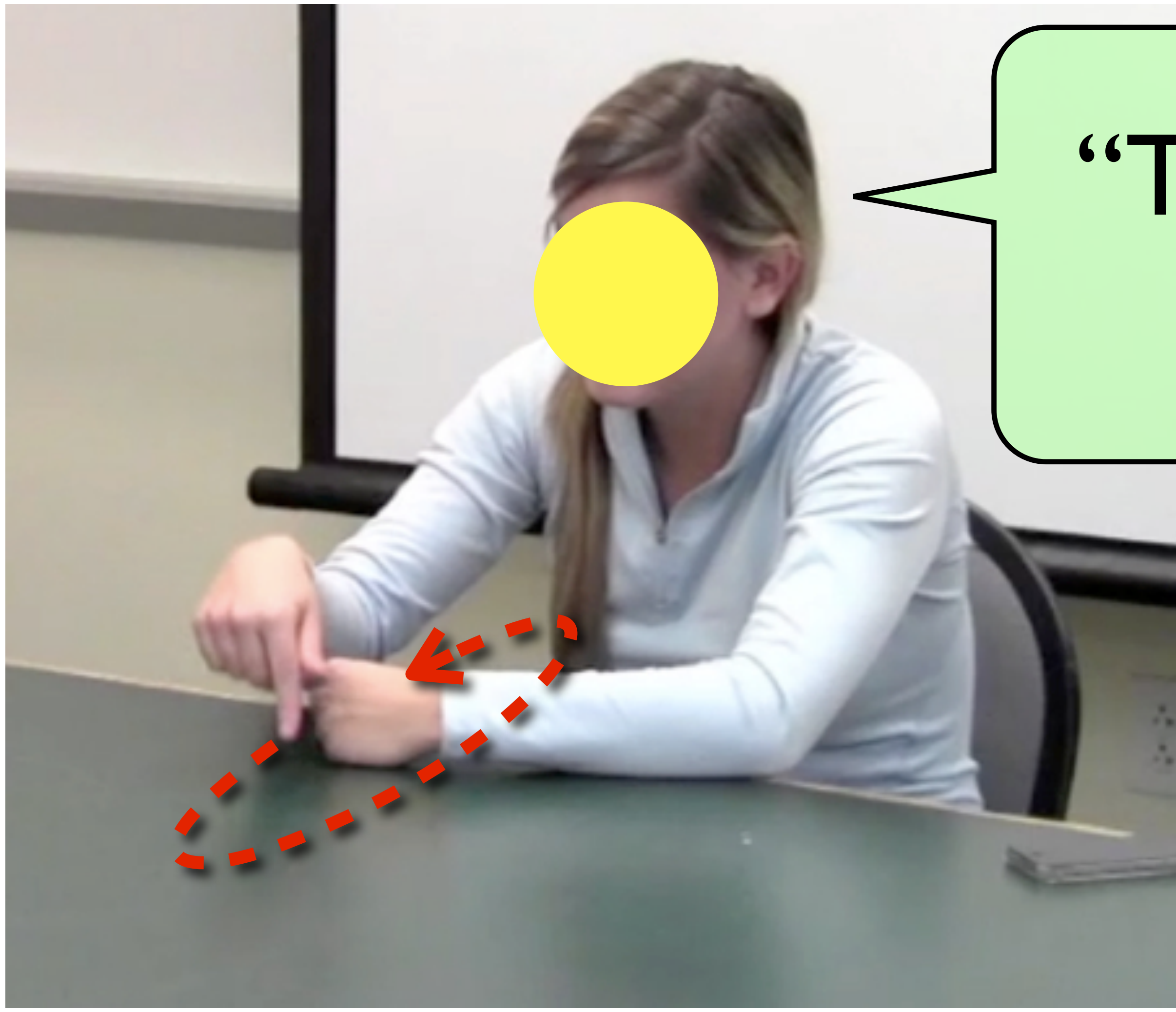
"That first electron is gonna be on the first orbital"

"I can see the moving electrons in an orbital"

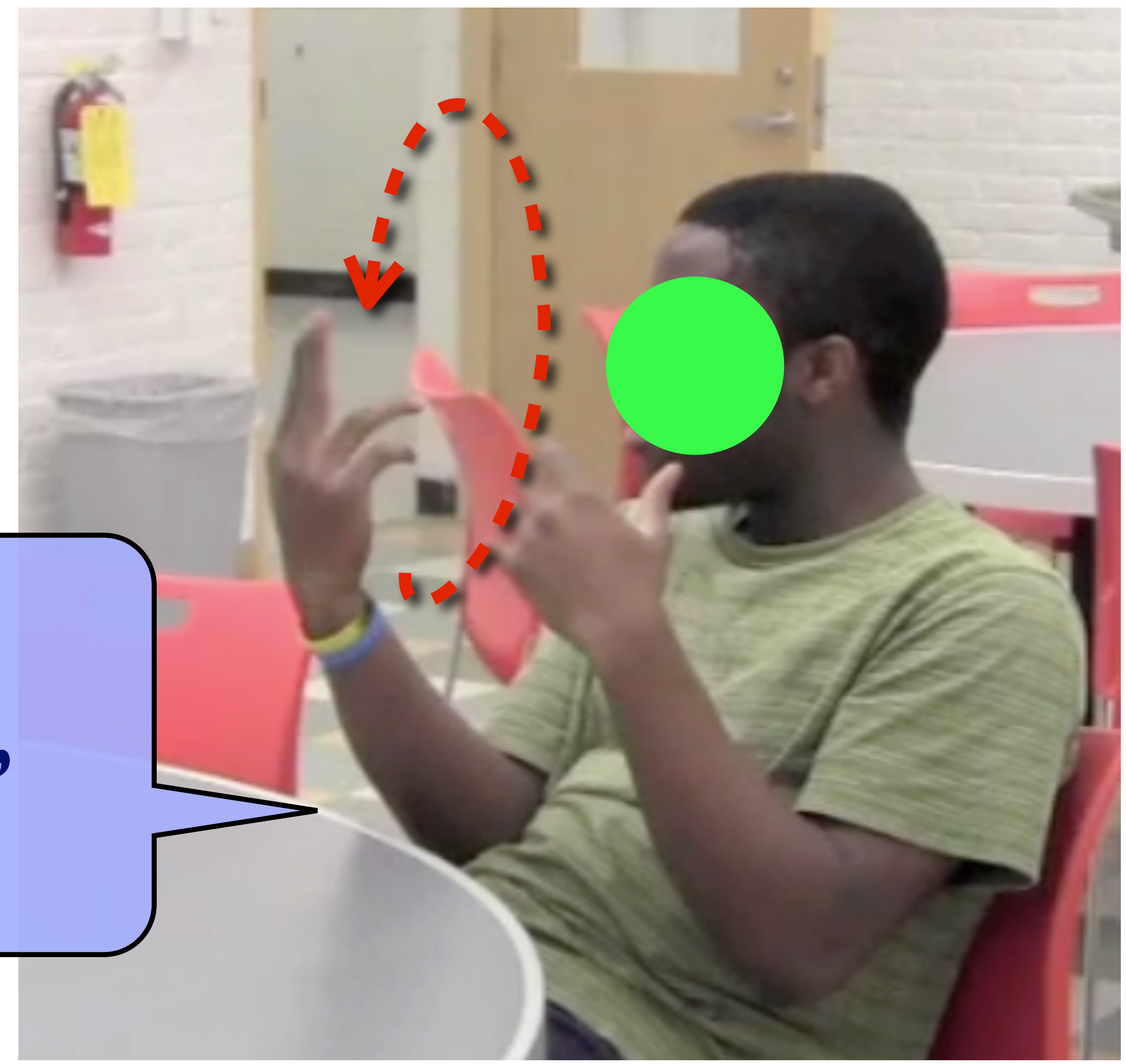
Peter

Both students use the term orbital, but. . .

Their gestures tell a different story:



"That first electron is gonna be on the first orbital "



"I can see the moving electrons in an orbital"

Orbital or orbit?

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Our interviews were filled with moments where students struggled to produce a technical term:

What's the molecular geometry of PF_5?

Peter:
"So that's gonna be uh [. . .] Pyra— How do I want to say this? Pyramidal? I think? It's pyramidal. It's something else before the pyramidal. Pyra—"

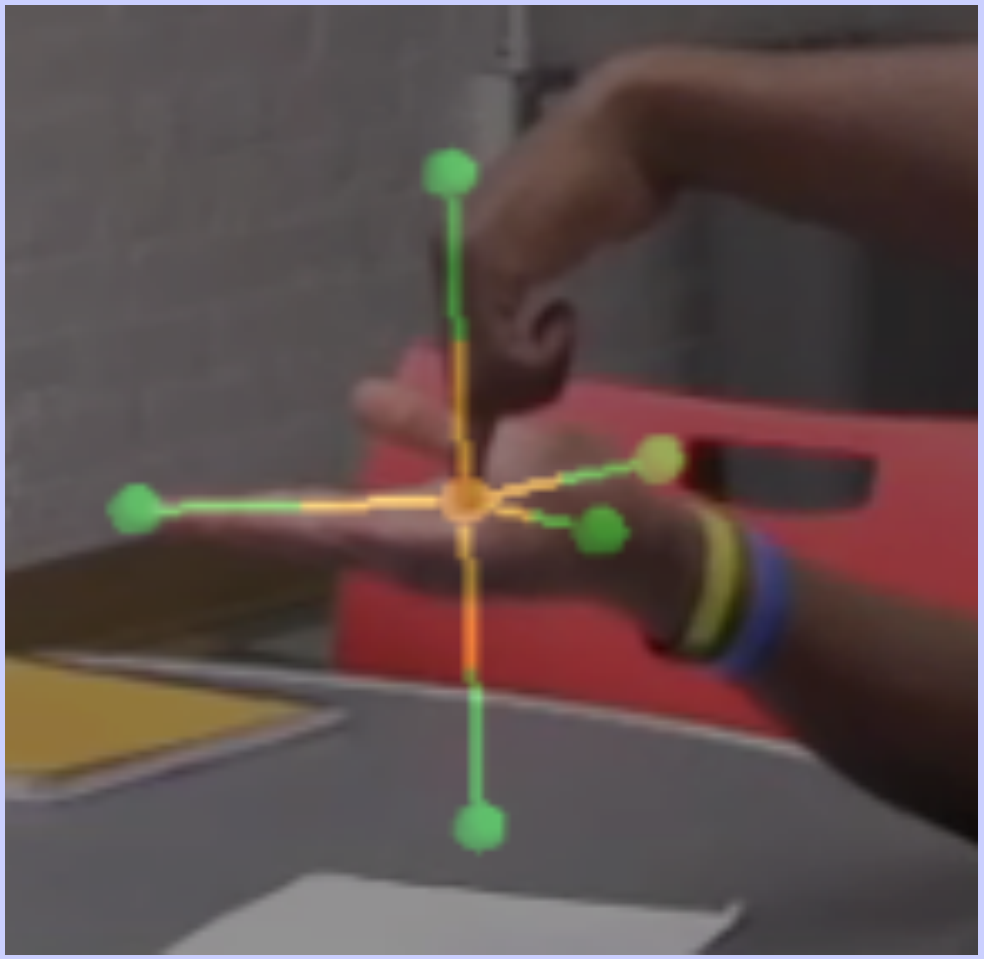
What's the molecular geometry of methane?

Drew:
"This is [. . .] it's not trigonal planar, but, I'm trying to think of the actual term, but I don't know."

However, despite this, students were able to answer the question

Students spontaneously use their bodies to answer questions about molecular geometry

Peter's PF_5:



Drew's methane:

In these cases, knowledge of the shape of a molecule exists only in the shape and motion of the hands and body

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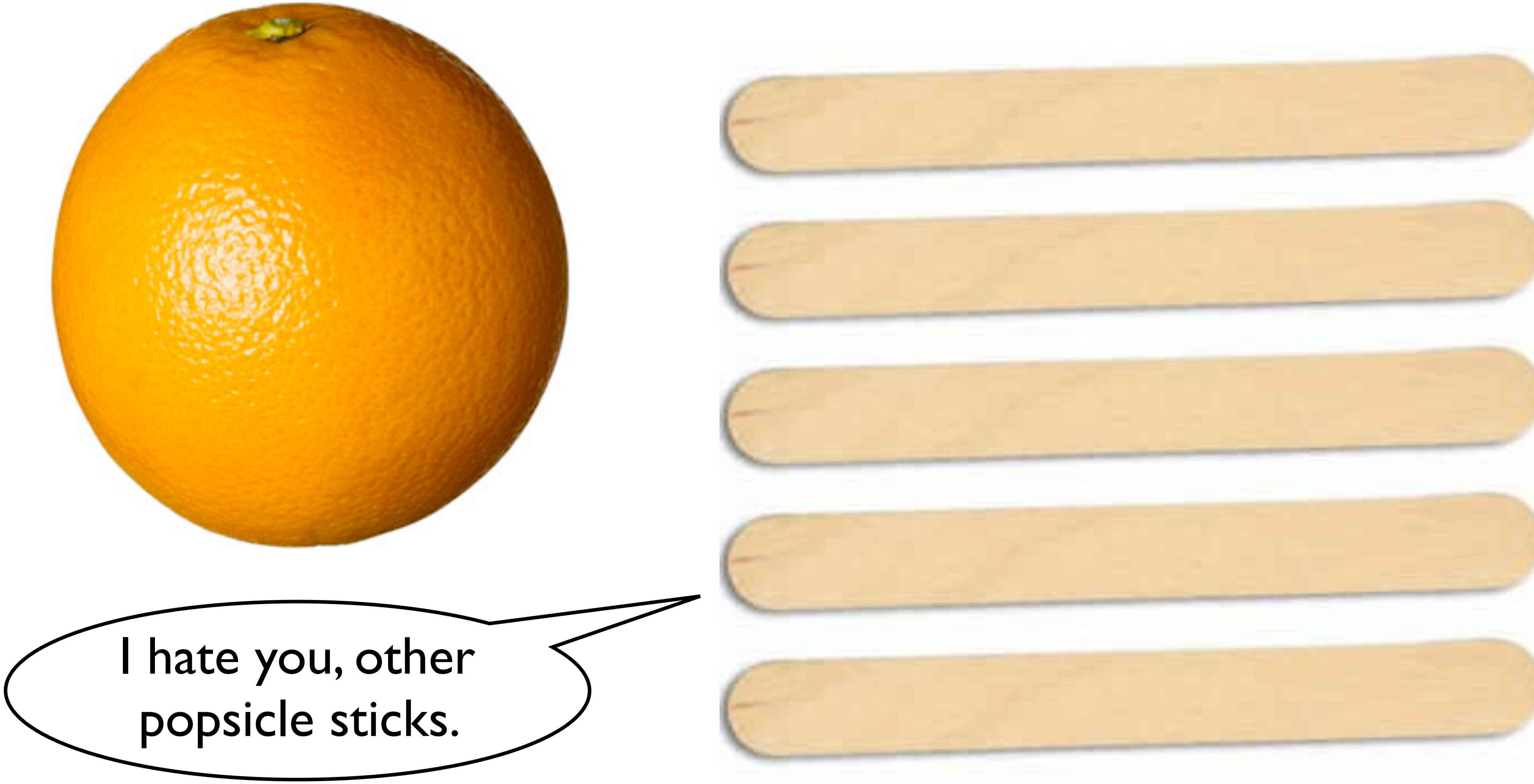


How can you stick five popsicle sticks into an orange so that they are all equidistant from each other?

Drew, when asked about the shape of PF_5 flat out tells us he doesn't have an answer. . .

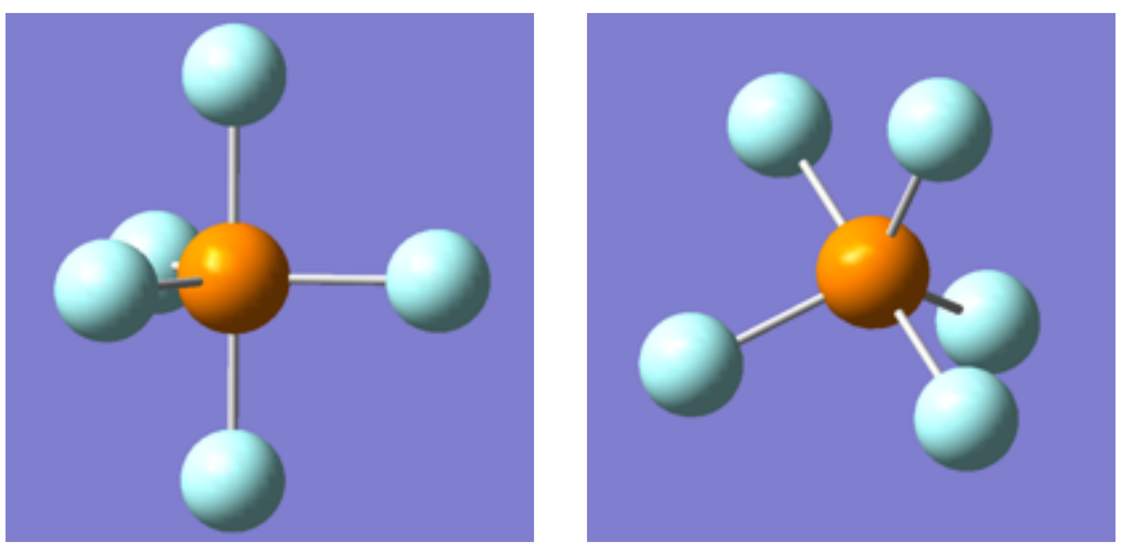
"I haven't memorized the chart yet"

When asked to try and work out a solution, he obliges:

How did Drew get from

it's whatever it says in that chart

to this?



Different orientations of trigonal bipyramidal PF_5

Drew's final solution

He solves the problem by engaging in a complex mixture of gesture, speech, and interaction with the white board

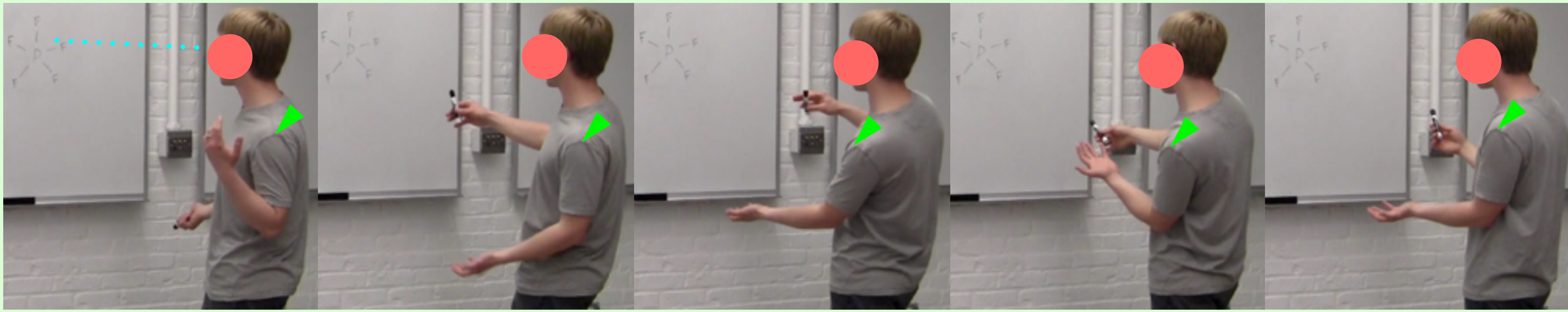
Here's an example of what annotations looks like for the first gesture he produces. It's 9.5 seconds. . .

The body seems to play a role in spatial cognition:

People gesture more frequently when talking about spatial topics (Feyereisen & Harvard, 1999) and preventing people from gesturing when they talk about space trips them up (Krauss, 1996)

People will gesture without speaking to solve mechanical reasoning problems and spatial rotation problems (Schwartz & Black, 1996; Chu & Kita 2010)

First, Drew sets a condition to work from. . .



“Um. I know that they're going to be equal in all directions {. . .} so { . . .}”

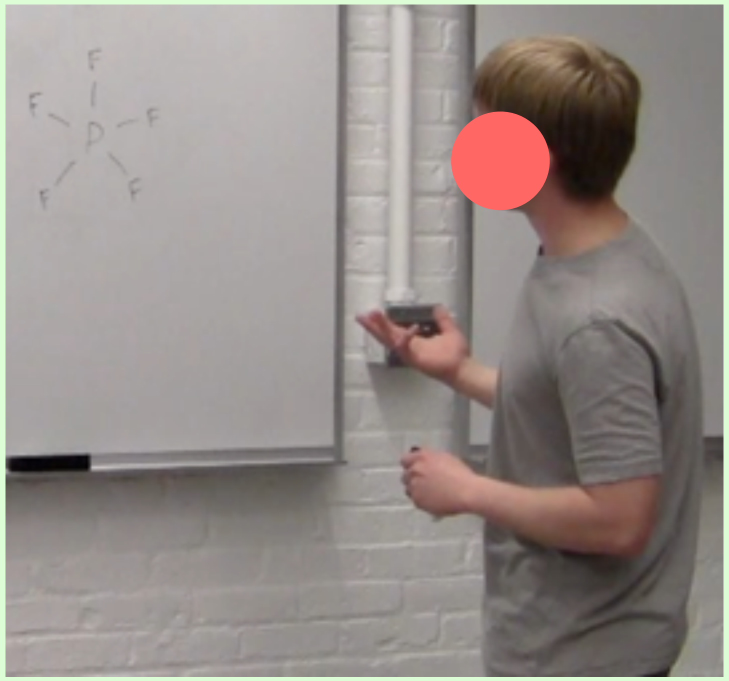
Drew’s hands move to several locations in space as if testing out different possible positions for atoms that would result in equality

From watching his shoulder, you can appreciate
that his whole body is involved in this process (he leans in and out)

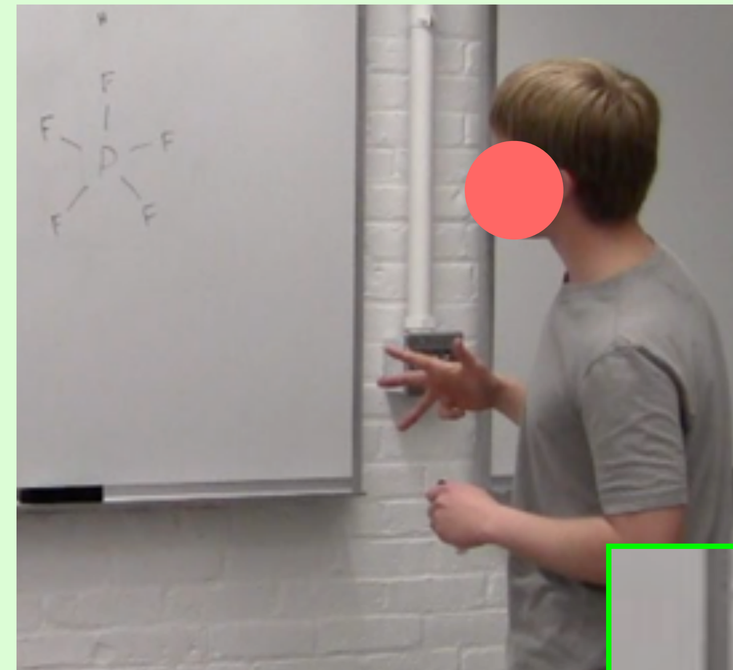
He continues to move his hands in silence after he says “so”

We think he’s using his hands here to explore space and experience possibilities: this motion and the positions of his hands, are all something he is feeling

Drew's gestures go beyond his speech. . .



Okay {. . .} I'd say {. . .} it's gonna be {. . .} I'm trying to think with five {. . .}



Um {. . .}

In silence, he starts to extend three fingers on his right hand

Drew's hands are working new things out, even when he is not talking about them.

Then, Drew imposes some constraints to the space

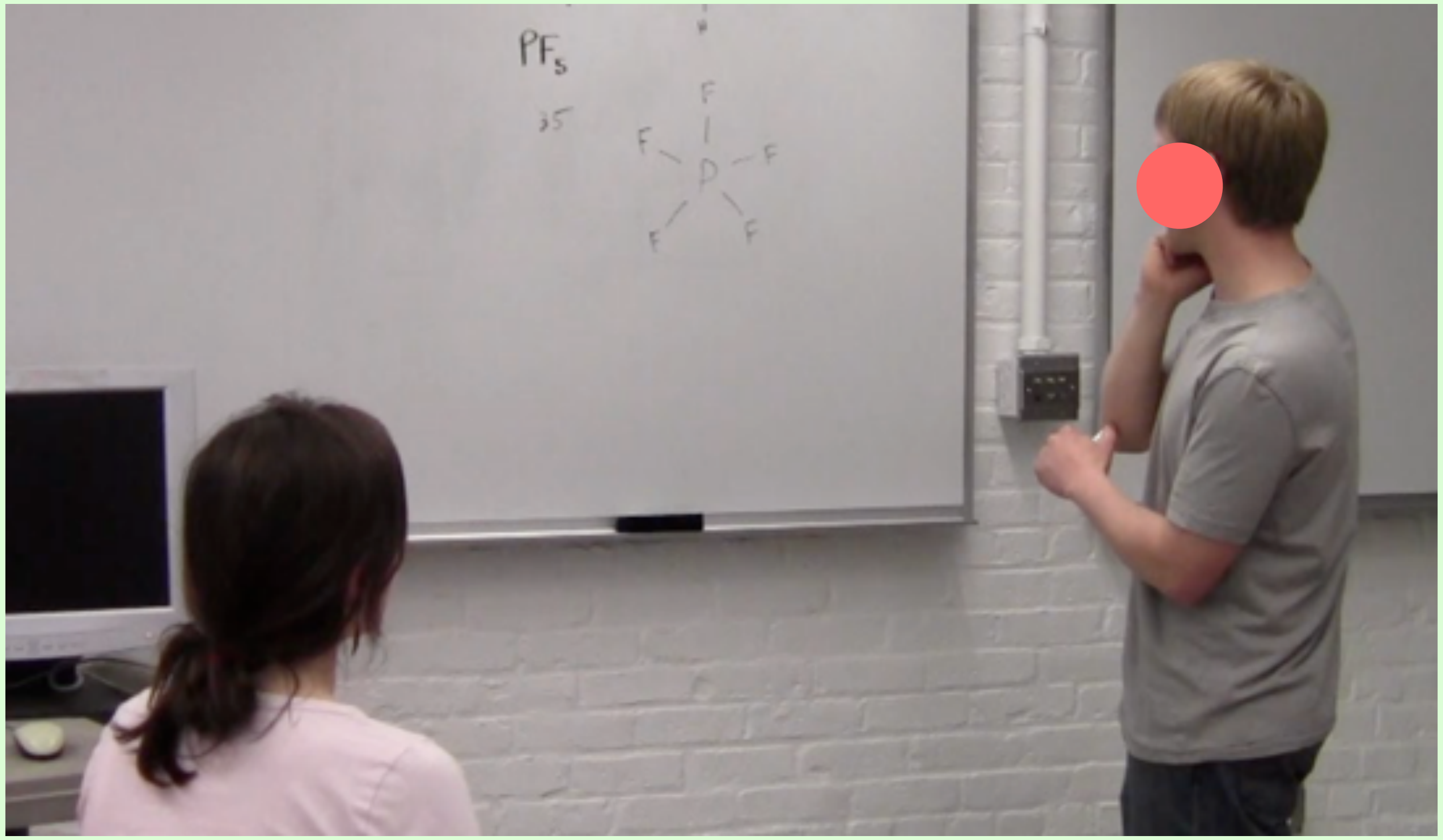
{. . .} how would they most equally be {. . .} separated {. . .} from each other

Drew brings his left hand up to the three extended fingers and then sort of carves out this space around them

He holds his hands apart in the air for several seconds without speaking.

It's as if he's feeling out the boundaries of the space that could contain this molecule

Drew wants to just "picture it" - but can't

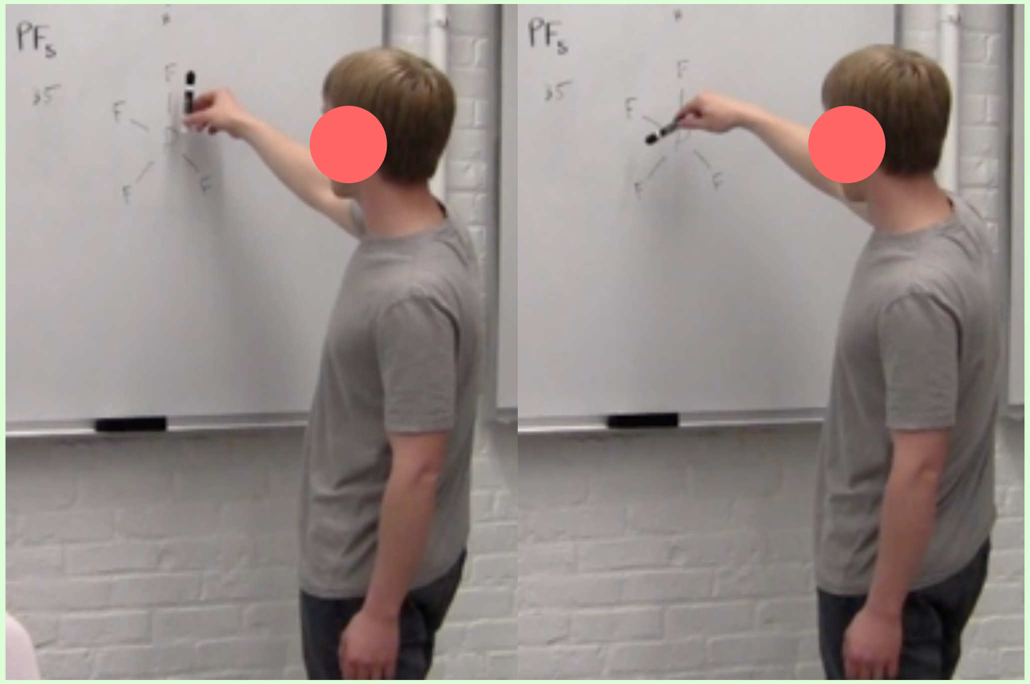


"I'm looking at it trying to picture it three-dimensionally. It's gonna be like {. . .} I honestly can't say, exactly."

He tells us, himself, he can't imagine it in his head

(and he doesn't make any progress when his hands are still)

He enacts and then discards one answer...



"**I can say there's gonna be one straight up, and then {. . .} these could all be in a plane but I don't think so.**"

Drew uses a marker to indicate a ligand that is straight up. Then he circles the remaining fluorine atoms.

But as soon as he experiences this, he rejects it immediately. It's as if this doesn't feel right.

... and then finds a better answer

"I think it's more likely that there's maybe three down and two up"

Next, Drew begins to explore a different possible shape at the board.

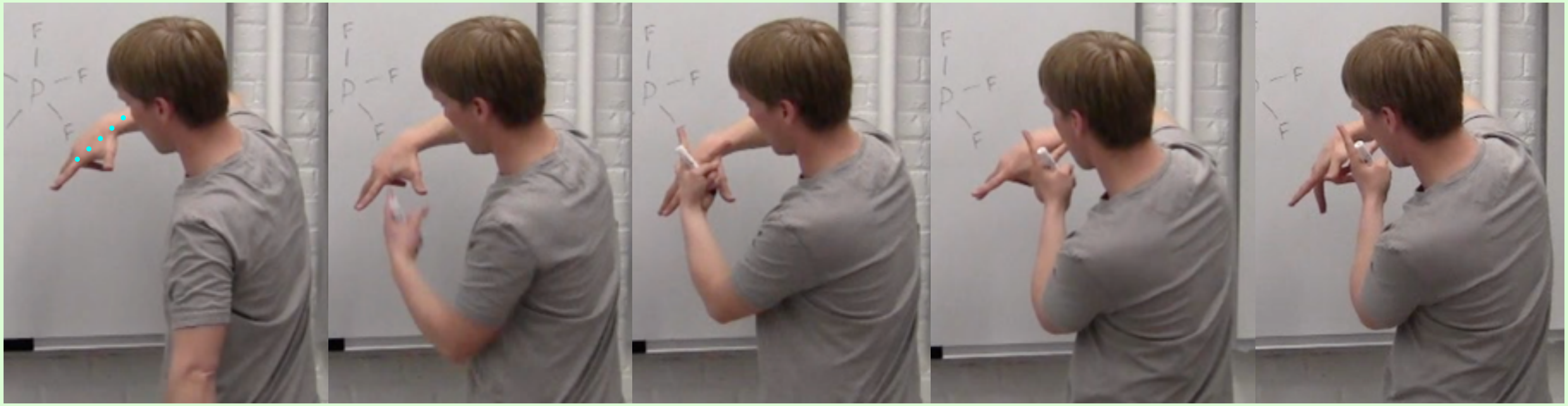
He raises both hands and then drops them.

Then he uses his two fingers to point up.

He repeats the first motion without speaking.

...and then he comes up with a solution

With the general shape established in the previous gesture, Drew now uses his fingers to represent ligands



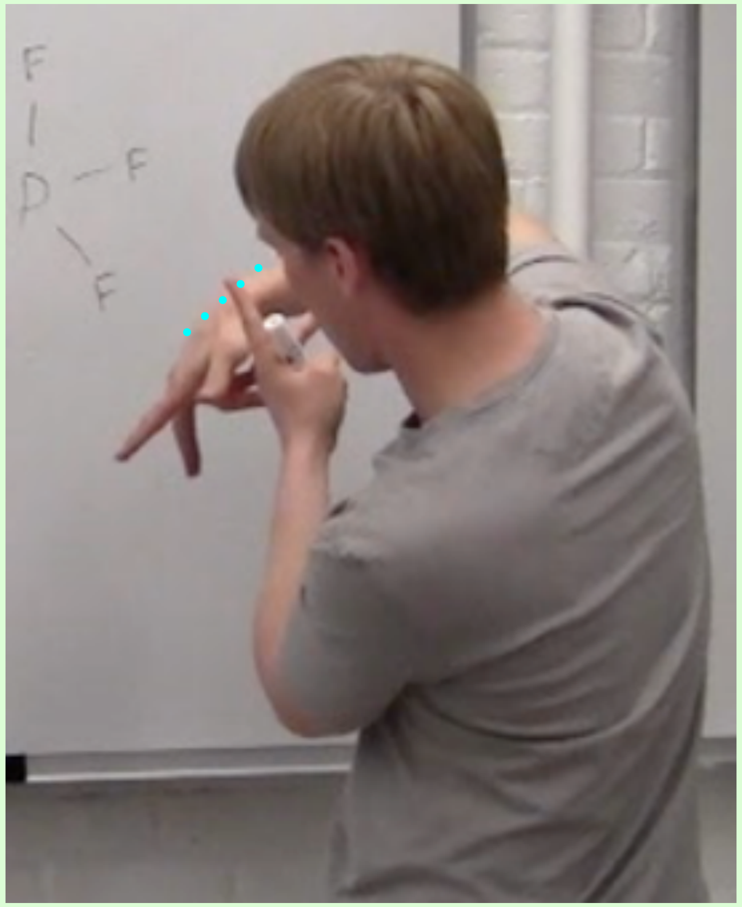
“Like, you know what I’m saying, like three down and-”

He puts three fingers in a pyramid shape and then adds two fingers to this with his left hand

He brings his hands closer to his face to examine them visually.

While looking at his hands, he rotates the bottom pyramid hand, as if visually evaluating the angles and spacing contained in his hand

He never actually ever finishes the idea in words.
His solution exists in the shape of his hands in this moment.

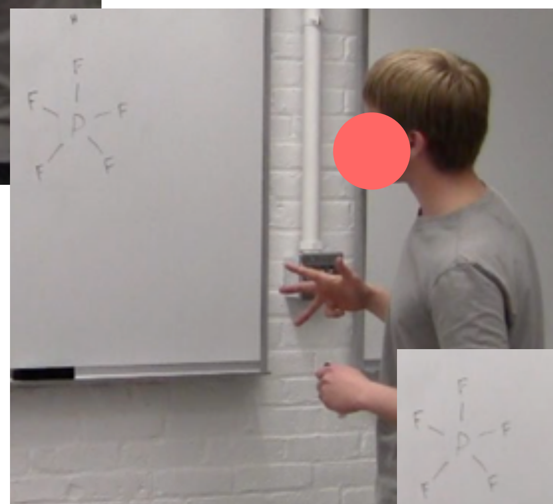


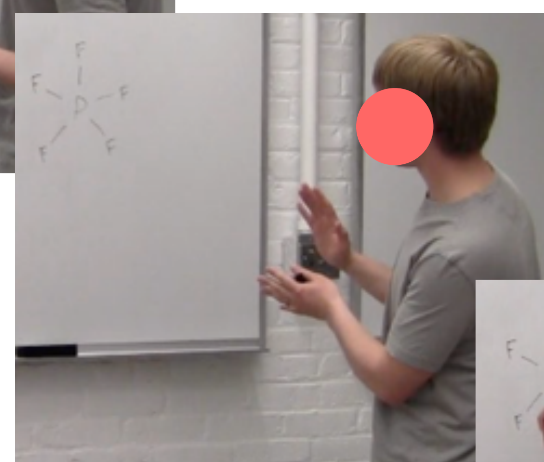
Why would Drew study his own gesture?

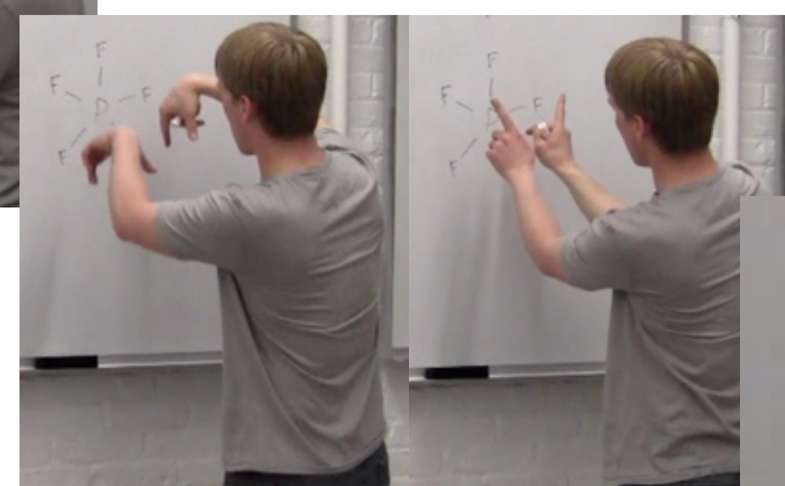
He can look at his hands and find something not in his head: the information about angles and spaces and positions exists in the locations of his fingers…

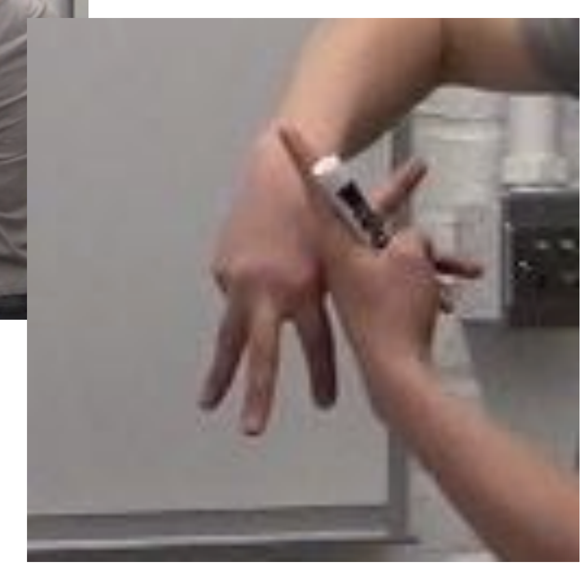
He has to look to see what his body figured out.

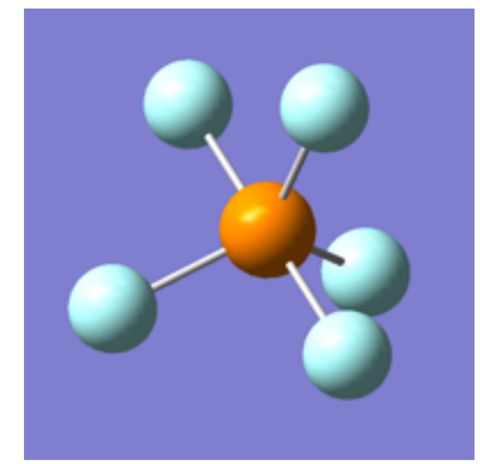
Drew uses his body to progressively construct a solution to this problem







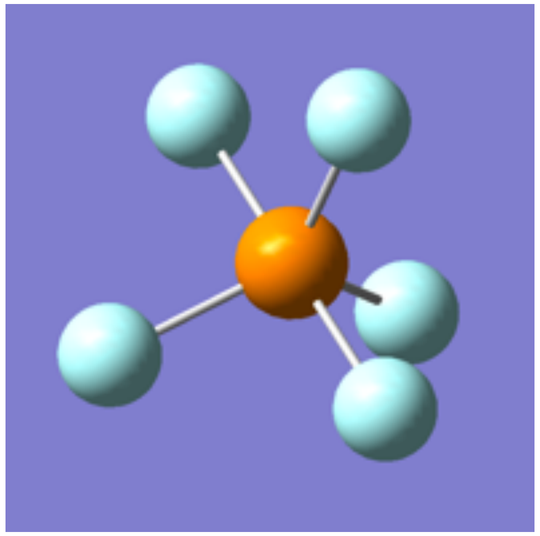




His gestures start out amorphous and gradually grow more structured

Drew often continues to gesture after he has stopped speaking.
Sometimes, he gestures without speaking at all.
And, his final solution is never entirely articulated in speech.
His hands are doing most of the work.

Drew's intermediate insights and his final solution are enacted: they exist in the action of his hands and body.



Drew's bodily activity is the actual process of discovering a solution through the sensorimotor experience of exploring and experimenting with space.

Questions

- Is it helpful to (can we?) alter learning environments in order to emphasize multi-modal thinking?
- How can instructors pay attention to gesture as part of formative assessment in large classes?
- Are there ontological limitations of embodied representations? (FGA question)
- Do we really need the construct of internal representation, e.g. mental imagery, to understand how students think?

The road ahead

Several publications are in process.

We are analyzing video of students in the chemistry laboratory in order to explore the role of the body in sense-making when students engage in analogy activities.

Haptic models for more abstract concepts such as chemical equilibrium and reaction rate.

We are planning grant submissions to extend this work.

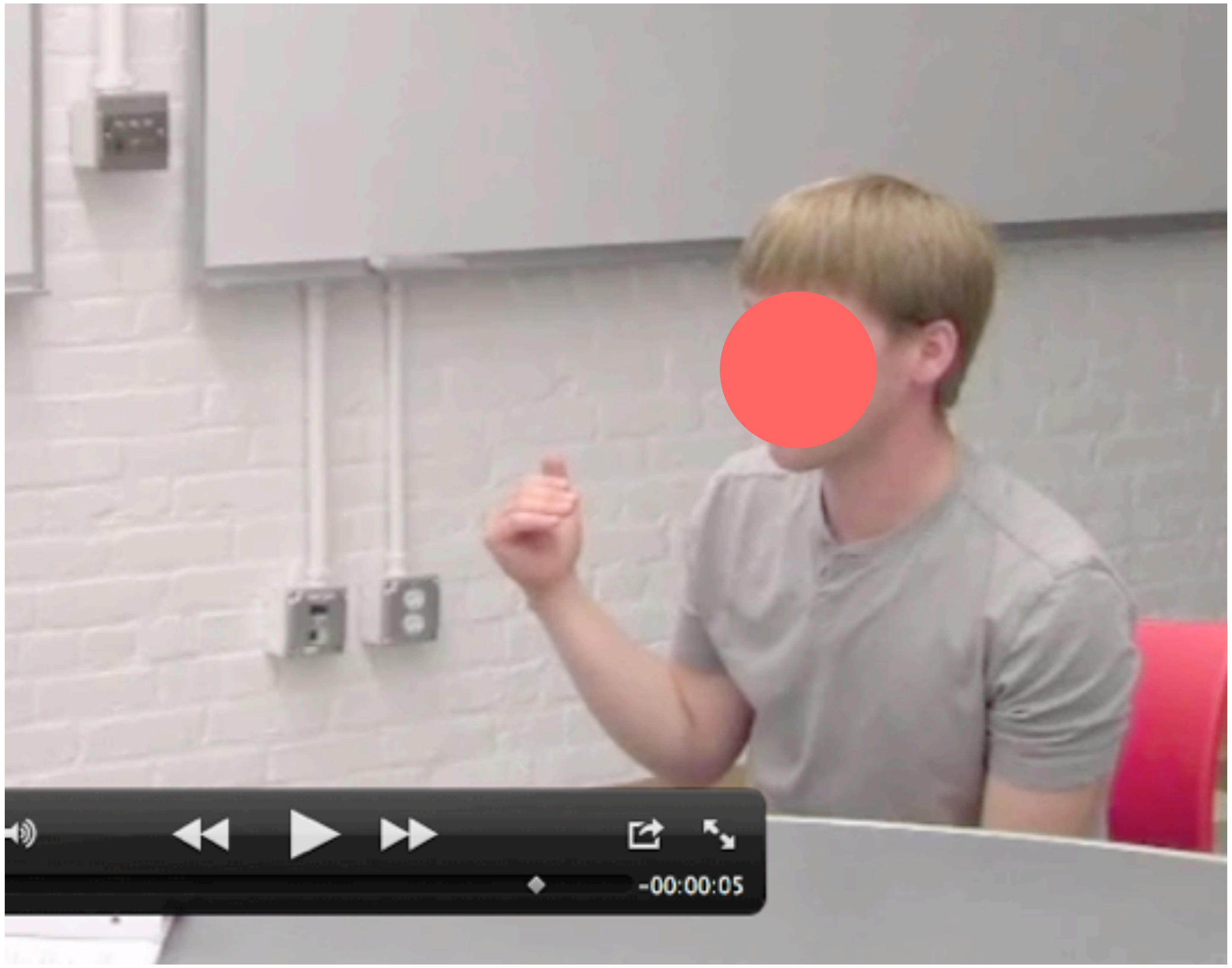
“Did the activity change your ... model of the Bohr model of the hydrogen atom?

“I do think of it as the stairs but I also think of it as this graphical representation here”

...

I think of those stairs in the lecture hall, not another set of stairs, those stairs”

(Drew gestures towards lecture hall)



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Transit of Venus, June 8, 2004

Transit of Venus, June 5, 2012

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