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Representations in Undergraduate Physics

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The way physics is taught now is not much different from the way it was taught — to a much smaller and more specialized audience — a century ago, and yet the audience is vastly changed. This shift has made the teaching of introductory physics a considerable challenge.

Eric Mazur, Harvard

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Overview

Overview of problem solving research

Shift in focus

Fluency in critical constellations

Disciplinary affordance

Illustrations

Summary

Conclusions

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Problem solving

Problem solving plays an important role in undergraduate physics.

Received a lot of attention in physics education research (PER) and still does.

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Problem solving: experts vs novices

Original focus was on helping students solve problems.

Compared the ways experts and novices solved problems. Larkin, McDermott, Simon & Simon (1980), Larkin (1983), Larkin & Simon (1987)

Large body of work see resource letter on problem solving Hsu et al (2004)

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Problem solving: experts vs novices

Experts use sketches, diagrams and graphs to understand the problem, whereas novices try to move directly to equations.

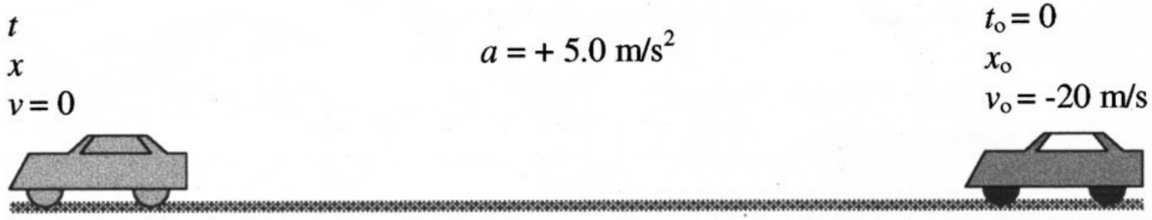
Suggestion that students should be taught to integrate sketches diagrams and graphs into their problem solving (e.g. Hsu et al (2004)

)

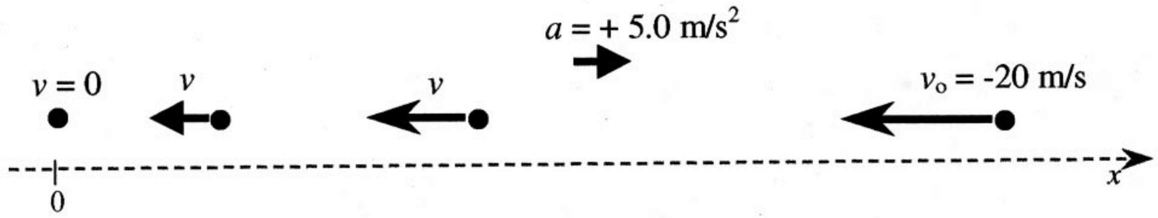
(a) Word Description

A car initially moving west at speed 20 m/s slows to a stop with an acceleration of magnitude 5.0 m/s^2.

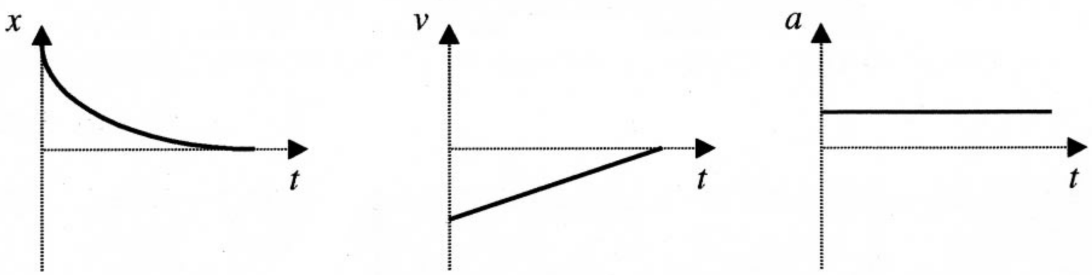
(b) Picture Description



(c) Diagrammatic Description



(d) Graphical Description



(e) Mathematical Description

$$0 - (-20\ \text{m/s}) = (+\,5.0\ \text{m/s}^2)\, t$$

$$x - x_o = (-20\ \text{m/s})\, t + 0.5\,(+\,5.0\ \text{m/s}^2)\, t^2$$

van Heuvelen (1999) Millikan Lecture

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Many students have experienced only formula-centered didactic instruction. For these students, it may be difficult to apply this ***new multiple-representation method*** *in their problem solving. Some students like only equations and think it wastes time or is a redundant task to represent a problem in different ways. For a novice with little conceptual understanding, this is not true.*

Van Heuvelen & Zhou 2001:193

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The force concept inventory

Force concept inventory (FCI)

Hestenes, Wells & Swackhamer (1992)

30 multiple choice questions

Tests conceptual understanding of velocity, acceleration and force.

Common sense distracters.

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The force concept inventory

A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction. As observed by a person standing on the ground and viewing the plane as in the figure below, which path would the bowling ball most closely follow after leaving the airplane?

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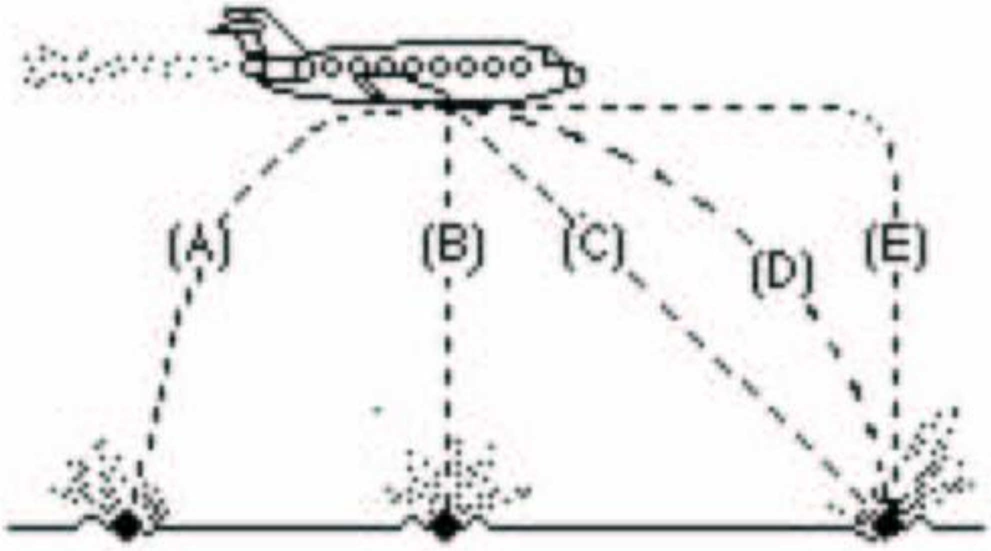
The force concept inventory



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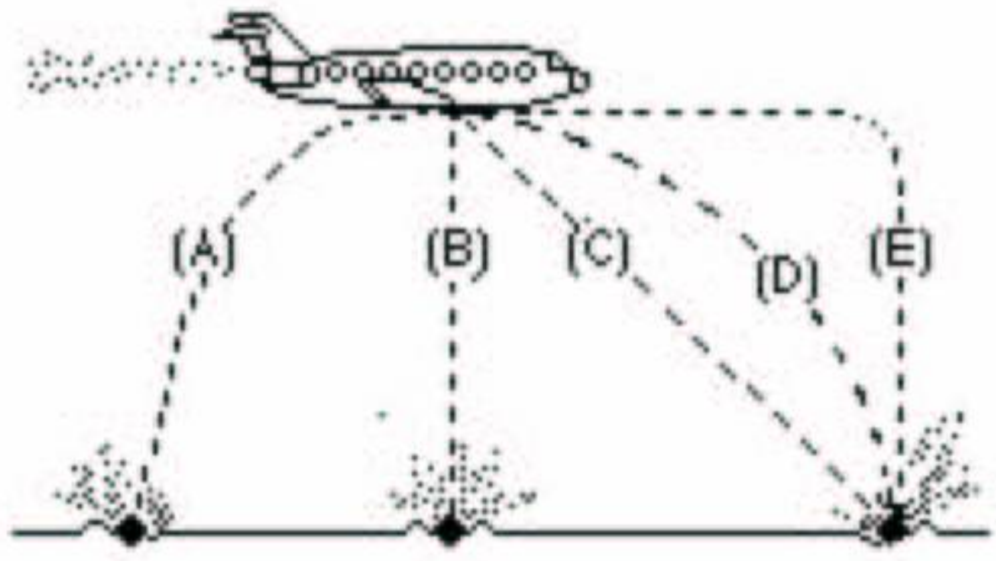
The force concept inventory



Showed that being able to solve problems does not necessarily mean students understand.

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The force concept inventory (FCI)

The results of the test came as a shock: the students fared hardly better on the FCI than on their midterm examination. Yet, the FCI is simple, whereas the material covered by the examination (rotational dynamics, moments of inertia) is, or so I thought, of far greater difficulty.

Eric Mazur, Harvard

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Quotes from two physics professors

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1. Even ’A’ students don’t understand…

One of the most striking findings from the interviewing studies on which this work is based is that MIT undergraduates, when asked to comment about their high school physics, almost universally declared they could solve all the problems (and essentially all had received A's) but still felt they really didn’t understand at all what was going on.

Andy di Sessa, MIT

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2. Dead leaves

Most of our students do not know what you and I mean by "doing" science. Unfortunately, the most common model for learning science in my classes seems to be:

(a) Write down every equation the teacher puts on the board.

(b) Memorize, along with the list of formulas at the end of each chapter.

(c) Do enough end-of-the-chapter problems to recognize which formula applies to which problem.

(d) Pass the exam by selecting the correct formulas.

(e) Erase all information to make room for the next set

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2. Dead leaves

I call this "the dead leaves model" It is as if physics were a collection of equations on fallen leaves. One might hold

$S = 1/2\ gt^2$ another $F = ma$ and a third $F = -kx$.

These are considered as of equivalent weight, importance and structure. The only thing one needs to do when solving a problem is to flip through one's collection of leaves until one finds the appropriate equation.

I would much prefer to have my students see physics as a living tree!

Joe Redish, University of Maryland

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Observations such as these together with the FCI led to the PER communitiy reconsidering the role of problem solving

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Shift in focus

Emphasis changed from teaching students to solve problems to *teaching them to use different representations* in their problem solving to help them make connections.

Problem solving is a *means to an end.*

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Jeopardy physics

Students are given an equation that describes a physical process. They then work backwards to construct diagrammatic, graphical, pictorial, and/or word descriptions of a process that is consistent with the equation.

The problem solution becomes an effort to represent a physical process in a variety of ways—sketches, diagrams, graphs, and equations.

Van Heuvelen & Mahoney (1999)

See also Gullström (2013)

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Representational competence

*In terms of multiple representations, **the goal of solving physics problems** is to represent physical processes in different ways—words, sketches, diagrams, graphs, and equations. The abstract verbal description is linked to the abstract mathematical representation by the more intuitive pictorial and diagrammatic physical representations*

van Heuvelen & zhou (2001:184)

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Representational competence

What started as help for students to solve problems has changed to helping students achieve representational competence.

Representations or something else?

Now want to describe some of the work we have been doing in this area in the physics education research group.

First a quote from Jay Lemke

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Representations or something else?

We can partly talk our way through a scientific event or problem in purely verbal conceptual terms, and then we can partly make sense of what is happening by combining our discourse with the drawing and interpretation of visual diagrams and graphs and other representations, and we can integrate both of these with mathematical formulas and algebraic derivations as well as quantitative calculations, and finally we can integrate all of these with actual experimental procedures and operations. In terms of which, on site and in the doing of the experiment, we can make sense directly through action and observation, later interpreted and represented in words, images, and formulas.

Lemke (1998:7)

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Disciplinary discourse

Airey & Linder (2009)

Define disciplinary discourse as the complex of representations, tools and activities of a discipline

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Disiplinary discourse

- Representations
  - Oral & written text, mathematics, diagrams, graphs, computer simulations, gesture, etc.
- Tools
  - physical objects e.g. apparatus.
- Activities
  - ways of working, practice and praxis.

- These are all semiotic resources

Airey (2009)

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Discursive fluency

Students need to become *fluent* in the disciplinary discourse

i.e. They need to learn to appropriately *interpret and use* disciplinary-specific semiotic resources.

Still don't say *which* semiotic resources.

Need a way to analyse what the semiotic resources do both together and separately.

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Semiotic systems

Building on Lemke and others, Kress *et al*. (2001) discussed different semiotic systems.

Is speech say, best for this, and image best for that? **Kress *et al*. (2001:1)**

i.e. interested in the different *communication potentials* of semiotic systems

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Overview

Overview of problem solving research

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Summary

Conclusions

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Critical constellations

Airey & Linder (2009)

Build on Kress to propose

A critical constellation of semiotic resources

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Critical constellations

Experiencing physics concepts can be likened to viewing a multi-faceted object from different angles

Each semiotic resource allows us to ‘view the object’ from a ‘different angle’

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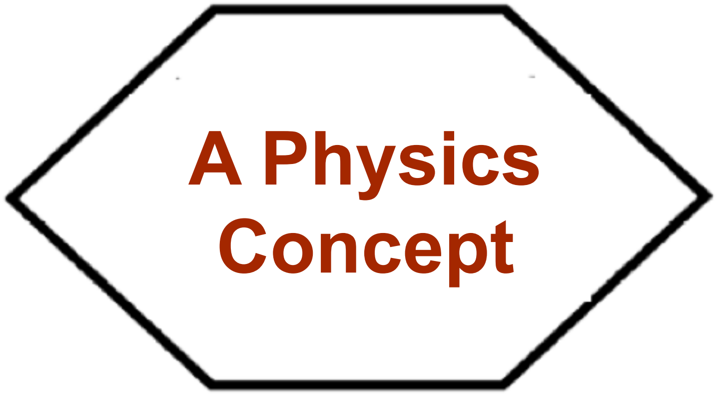
Critical constellations



Airey & Linder (2009)

This hypothetical physics concept has six separate attributes or facets

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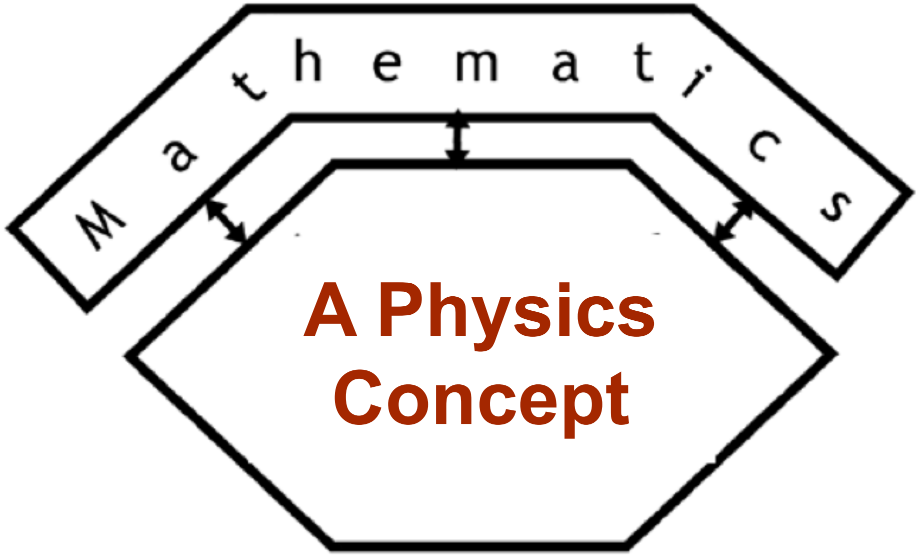
Critical constellations



Airey & Linder (2009)

A mathematical resource affords access to three of the six facets of the physics concept

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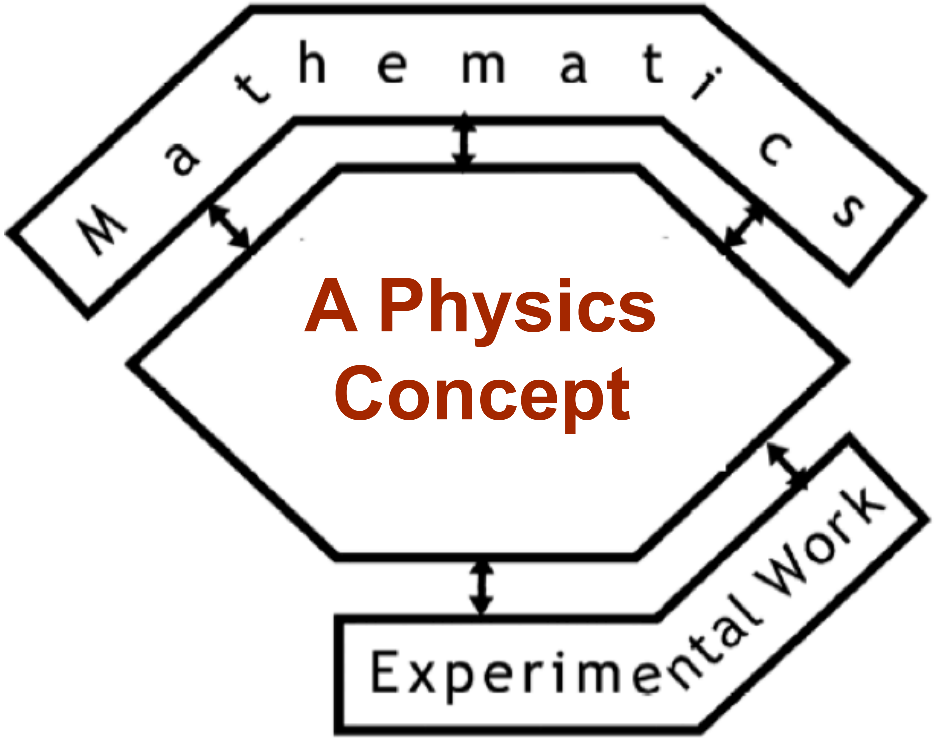
Critical constellations



Airey & Linder (2009)

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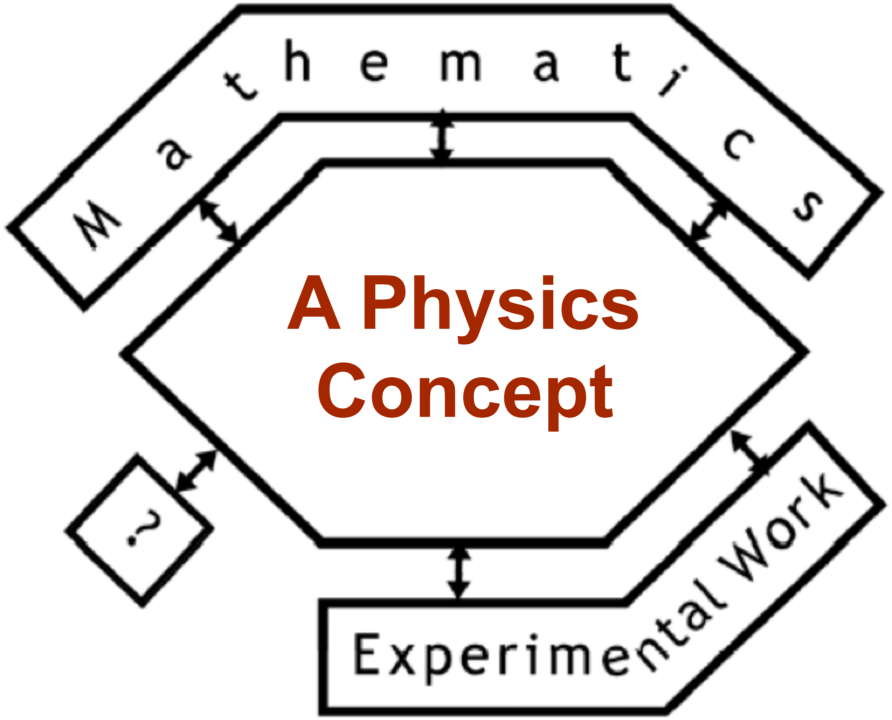
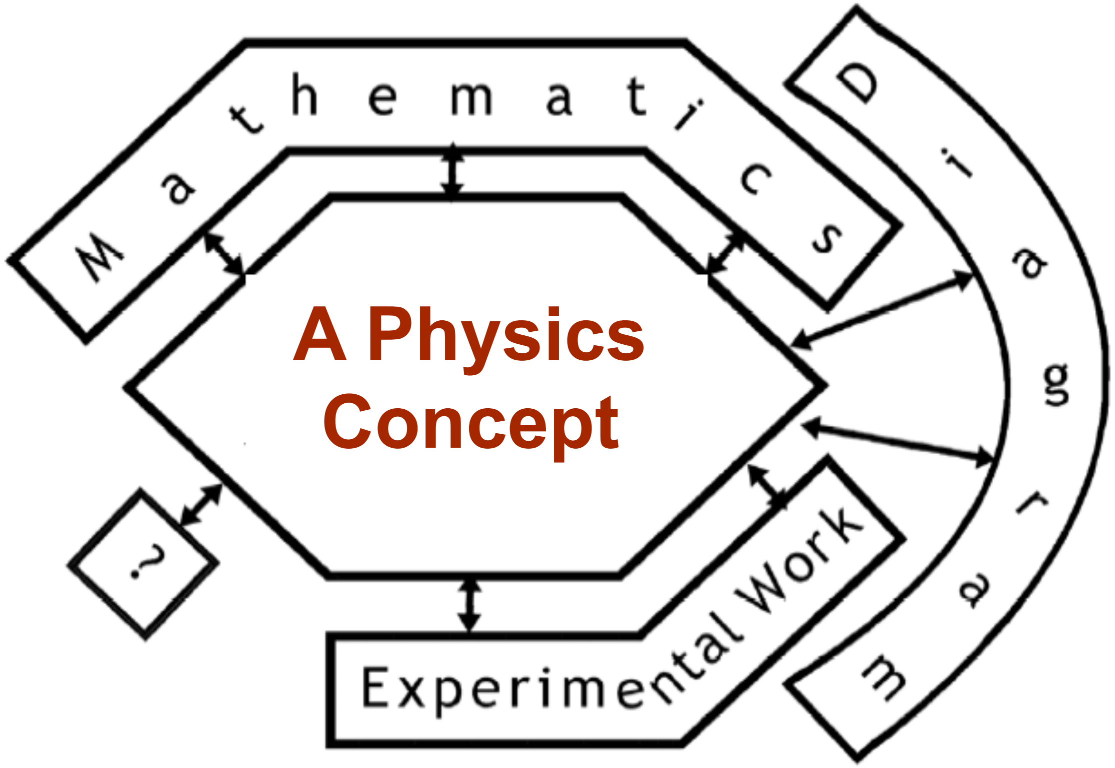
Critical constellations



Airey & Linder (2009)

Critical constellations



Airey & Linder (2009)

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Critical constellations

- Learning a particular physics concept is dependent on becoming ***fluent in a critical constellation of semiotic resources.***

- i.e. learning to use and coordinate the various semiotic resources in an appropriate, disciplinary manner.

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Discourse imitation

What do students do when they are not fluent?

They *imitate* the discourse.

We claim all students have to *imitate before they understand*.

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Disciplinary affordance

Research thus far has focused on training students in a range of semiotic resources.

The more the better…

No still no analysis of *which resources* provide access to *which knowledge.*

Overview

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Illustrations

Summary

Conclusions

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Disciplinary affordance

Fredlund *et al.* (2012) suggest the term disciplinary affordance for semiotic resources

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Disciplinary affordance

Definition:

The potential of a given semiotic resource to provide access to disciplinary knowledge

Fredlund *et al.* (2012:658)

Deals with individual semiotic resources

Focuses on the *discipline's* interpretation of the resource rather than the learner's experience

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Disciplinary affordance

Physics learning can be thought of as *coming to appreciate the disciplinary affordances of semiotic resources*

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Disciplinary affordance

Appropriate disciplinary learning is only possible when there is *a match* between:

- **what a given semiotic resource *affords to the discipline***

(i.e. *its disciplinary affordance*)

And

- **what it affords to the student**

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The affordance of semiotic resources

Amongst other things, the disciplinary affordance of a semiotic resource is shaped by its:

Materiality

Rationalization

Historical convention

Cf. glossary of multimodal terms (Mavers)

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Overview

- Overview of problem solving research
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- **Illustrations**
- Summary
- Conclusions

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The affordance of semiotic resources

Illustrate these three concepts for one semiotic system—diagrams.

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Materiality

Fredlund et al (2012) asked a students to describe why light bends in refraction.

The students had difficulties until they changed the diagram they had produced.

Intrigued.

Gave another lecturer the problem

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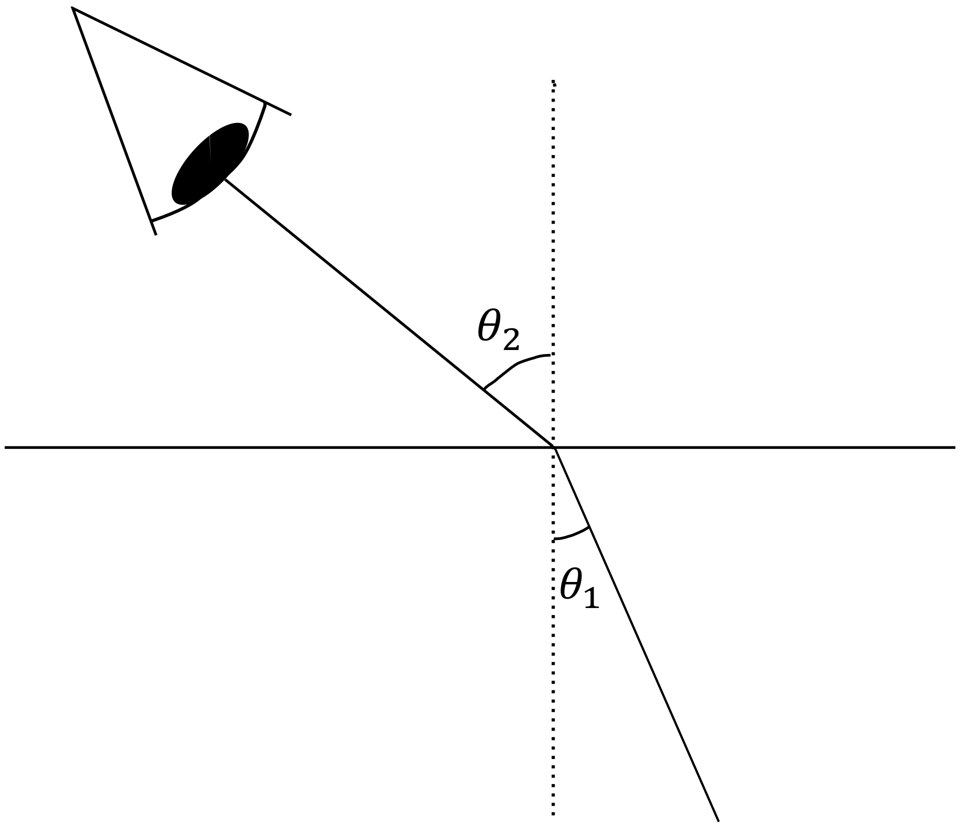
Materiality



$$\theta_1 < \theta_2$$

Why does the light bend?

Materiality

How would you do this with wavefronts?

Oh, then it’s easy.

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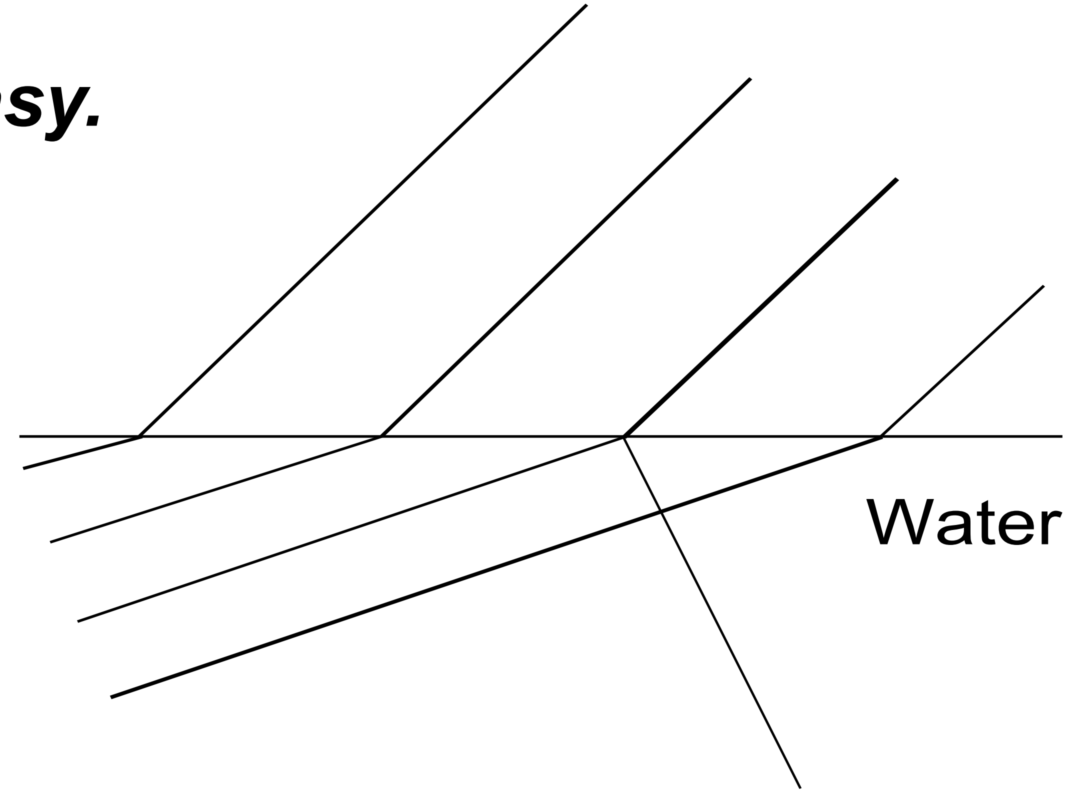
Materiality

How would you do this with wavefronts?

Oh, then it's easy.



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Materiality

Physics treats the two diagrams as equivalent

But, the materiality of the diagrams is different.

Easier to ”see” the speed of light changing in the wavefront diagram.

This difference was *tacit knowledge* for the physicist.

Fredlund et al (2012)

Rationalization

Rationalization has occurred over many years

What has been ”left out” might be what students need to make sense of the diagram.

Lecturers do not see that things have been left out.

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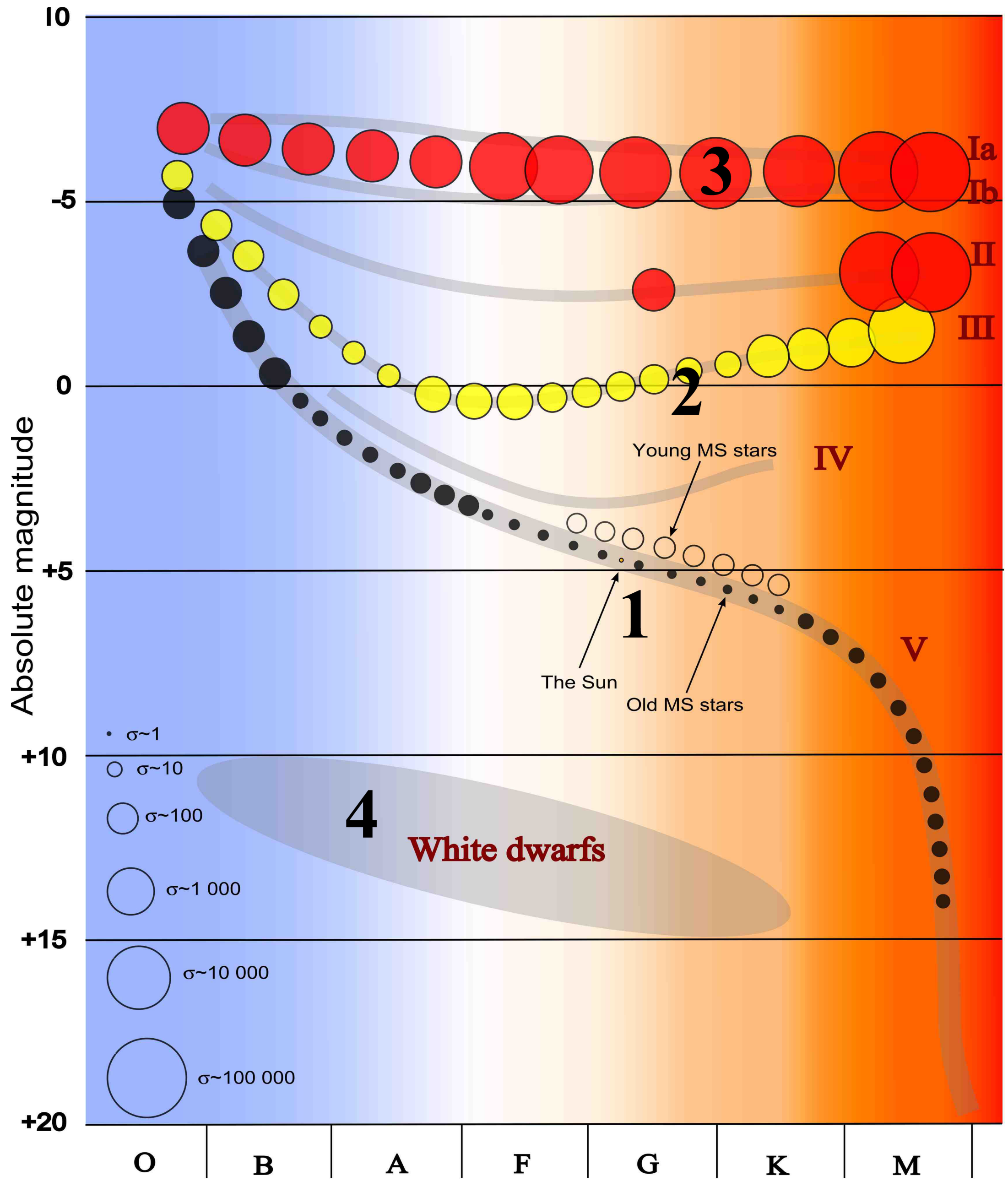
Historical convention: The HR diagram

A plot of how bright stars are against their surface temperature.

Mentioned that it was counterintutitive to an astronomer.

***What! But it's perfect! You can't say that! I use it every day*.**



10
-5
0
+5
+10
+15
+20
Absolute magnitude
Ia
Ib
II
III
IV
V
3
2
1
4
Young MS stars
The Sun
Old MS stars
White dwarfs
σ~1
σ~10
σ~100
σ~1 000
σ~10 000
σ~100 000
O
B
A
F
G
K
M

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What are the disciplinary affordances?

Why does the diagram look like it does?

Need a little history lesson…

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Annie Jump Cannon

Astronomer from Harvard
Catalogued nearly 400 000 stars
Discovered 300 variable stars
First woman to gain a honorary doctorate from Oxford

Worked for at Harvard for 40 years but only received tenure two years before retirement.

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Annie Jump Cannon

Oh Be A Fine Girl Kiss Me

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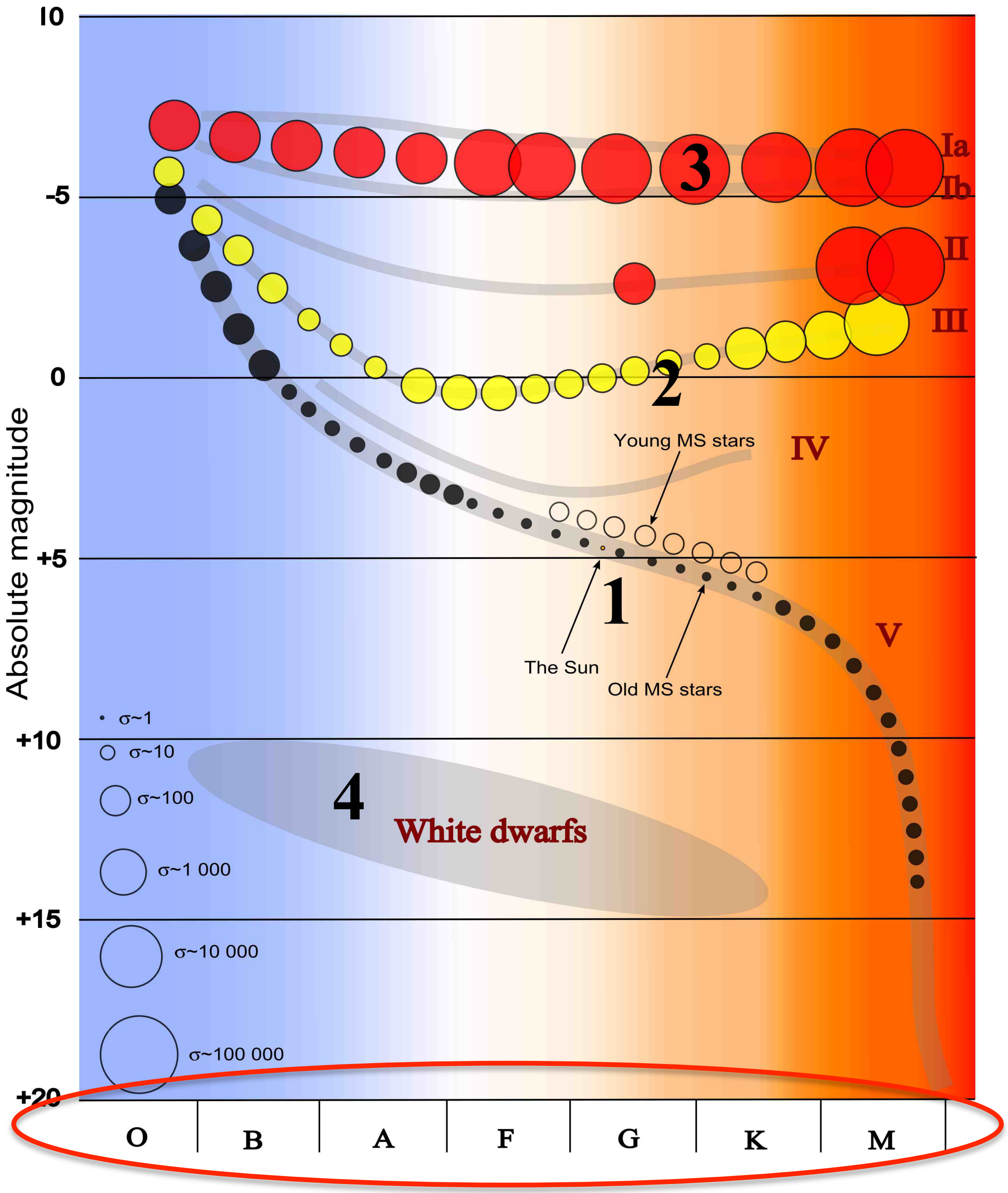
Annie Jump Cannon

Oh Be A Fine Girl Kiss Me

O B A F G K M



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σ~1 000
σ~10 000
σ~100 000
O
B
A
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Reordering the horizontal axis

The colours of stars (their spectra) were originally classified alphabetically A-Q

Cannon realised that these essentially arbitary categories could be rationalized and re-ordered to make more sense from an astrophysical point of view

The original 17 alphabetical categories became seven ordered O B A F G K M

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New meaning for the horizontal axis

Discoveries in physics later showed that this ordering on the horizontal axis of the HR diagram was related to the surface temperature of stars.

Surface temperature of stars *decreases* as we move through Cannon's classification from O to M

Right on the HR diagram means colder

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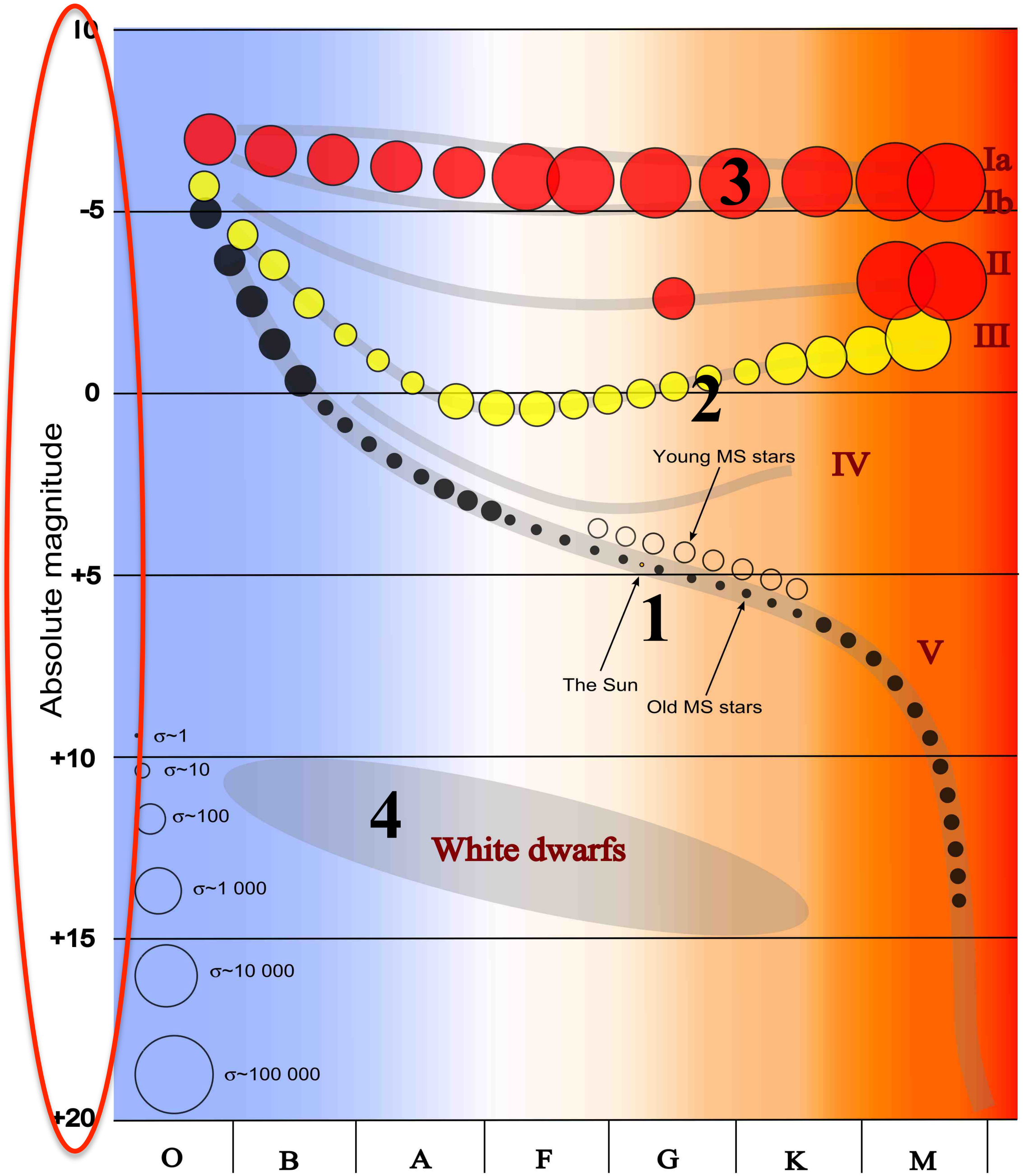
Counter-intuitive

Semiotically we expect graphs to move from lower quantities on the left to higher quantities on the right.

So history leaves us with essentially ‘random’ labelling OBAFGKM of a counter-intuitive temperature scale

What about the vertical axis?



-10
-5
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Absolute magnitude
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Young MS stars
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σ~1 000
σ~10 000
σ~100 000
O
B
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M

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Brightness

The vertical axis on the HR diagram is linked to how bright a star is—its *Apparent magnitude*

Apparent magnitude

Hipparchos (≈150 B.C.)

Six levels:

Brightest: magnitude 1

Faintest: magnitude 6

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Brightness

Stars are at different distances from us.

Astronomers wanted a standard brightness value.

Absolute magnitude: how bright a star would be at a standard distance. (10 parsec)

Kept the original scale

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Important for teaching

The astronomer agreed that these historical issues would need to be unpacked for students before they could properly understand the HR diagram.

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Important for teaching

Finish this lecture by showing some examples of *discourse imitation* in students

Show how when you look closely students who appear to be fluent often are not.

Videoed a course in electromagnetism at a Swedish university.

Intervewed the students showing them video clips to *stimulate recall*.

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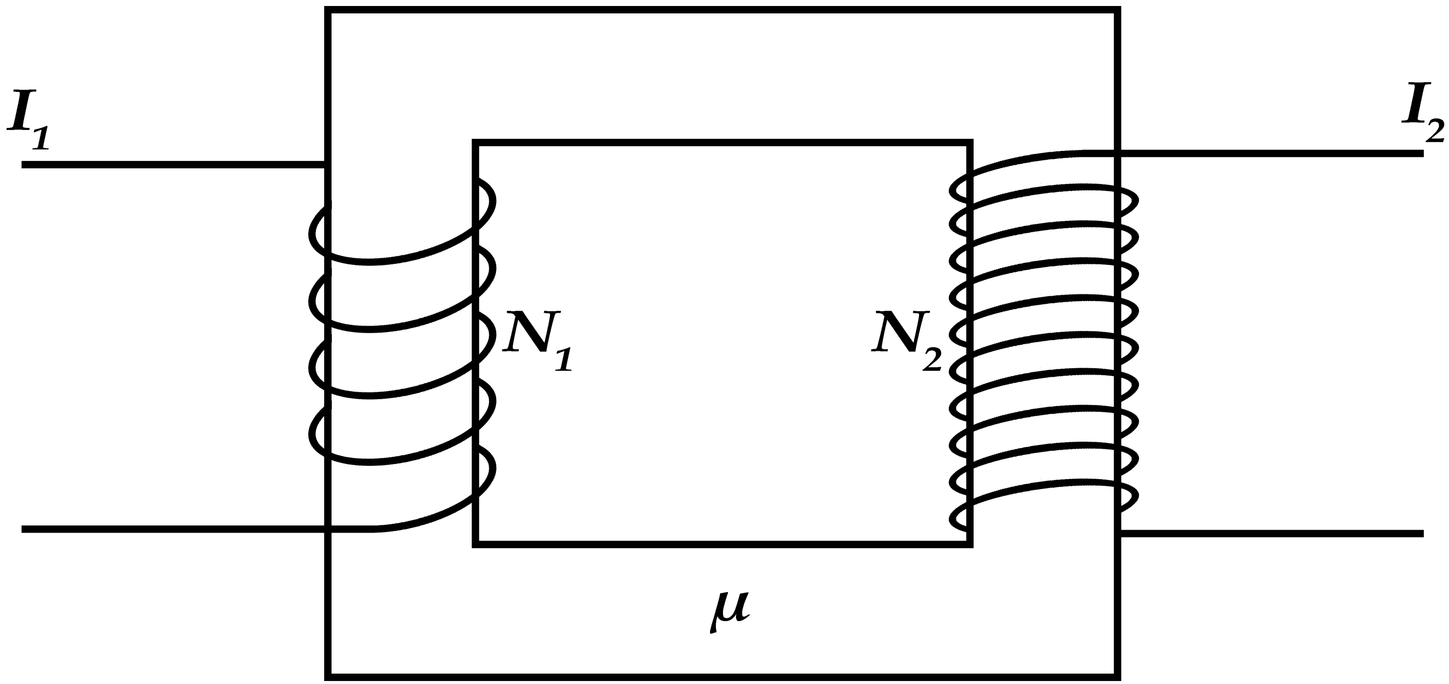
Illustrating disciplinary affordance (I)



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Illustrating disciplinary affordance (I)

Interviewer:	*This is him starting this thing about transformers—what did you think about this particular part?*
Student:	*Ummmh. Yeah, I don't know what this is. I didn't know what he was writing…*
Interviewer:	*Okay, he's drawing some kind of diagram, but you don't really know what that is that he's drawing?*
Student:	*No.*
Interviewer:	*Okay, so…*
Student:	*And I think it's quite often like that in the lectures he's drawing something on the whiteboard and he assumes that we know this from before.*
Interviewer:	*You've got no idea what this transformer thing is?*
Student:	*[laughing] No.*

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Illustrating disciplinary affordance (II)

Clearly this student has not experienced the disciplinary affordance of this semiotic resource

But the student was in second-year electromagnetism and had passed all the exams so far.

Must have been imitating discourse to some extent.

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Illustrating disciplinary affordance (II)

$$\nabla x E = 0$$

Equation written by the lecturer on the whiteboard

Interviewer: *You've seen these equations before..?*
Student: *Yeah I've seen them before er… but I really don't know exactly what they mean [laughs].*
Interviewer: *Can you tell me what this means to you? [pointing to the equation* ∇xE=0]
Student: *Um, I think the E is er the intensity of er an electric field. And then the curl of E… [quietly to herself] mmh equals zero…*
Erm, I think this is erm a conservative vector field— and I know how to calculate it but I don't know what it means.

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Illustrating disciplinary affordance (II)

This student has not experienced the disciplinary affordance of this semiotic resource

Amazingly, the student can ”read” the resource and say what it means. The student can even use it to calculate, but the meaning is still hidden.

The student is *imitating the discourse* (Airey, 2009)

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Summary

Experts and novices solve problems differently

Larkin *et al.* (1980)

Students often *move directly to equations* without understanding.

Research shows many students can calculate correctly but do not really understand.

Problem solving is not an end in itself.

Should be a route to fluency in a range of semiotic resources.

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Summary

There are ***critical constellations*** of semiotic resources needed for appropriate knowledge construction in physics.

Students need to ***become fluent*** in each of these resources and then integrate across them.

Students initially ***imitate discourse*** because they can't become fluent in everything all at once

(Airey & Linder 2009)

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Summary

Each individual semiotic resource has a particular *disciplinary affordance* **Fredlund *et al.* (2012)**

The disciplinary affordance of a semiotic resource depends for example on *materiality, rationalization* and *historical convention*.

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Conclusions

Lecturers should *expect discourse imitation* and ask students questions even when they appear to understand.

Lecturers need to help their students achieve fluency in a range of semiotic resources

Lecturers need to unpack the *disciplinary affordances* of the semiotic resources they use in teaching.

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Conclusions

Difficult…

The disciplinary affordances of individual semiotic resources are often *tacit*.

Even less is known about the *critical constellations of semiotic resources* that are needed for appropriate knowledge construction.

This is a work in progress so watch this space!

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Questions

References

Airey, J. (2009). Science, Language and Literacy. Case Studies of Learning in Swedish University Physics. Acta Universitatis Upsaliensis. Uppsala Dissertations from the Faculty of Science and Technology 81. Uppsala Retrieved 2009-04-27, from http://publications.uu.se/theses/abstract.xsql?dbid=9547

Airey, J., and Linder, C. (2009). "A disciplinary discourse perspective on university science learning: Achieving fluency in a critical constellation of modes." *Journal of Research in Science Teaching*, 46(1), 27-49.

di Sessa, A. A. (1993). Toward an Epistemology of Physics. *Cognition and Instruction, 10*(2 & 3), 105-225.

Fredlund, T., Airey, J., & Linder, C. (2012). Exploring the role of physics representations: an illustrative example from students sharing knowledge about refraction. *European Journal of Physics, 33*, 657-666.

Gullström, C. (2013) Pictionary Physics: En kvalitativ undersökning av ett didaktiskt verktyg i enlighet med The Scholarship of Teaching and Learning http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-212721

Hestenes, Wells & Swackhamer (1992) Force Concept Inventory, *The physics teacher* (30),141-158.

Hsu, L., Brewe, E., Foster, T. M., and Harper, K. A. (2004). "Resource Letter RPS-1: Research in problem solving." *American Journal of Physics*, 72(9), 1147-1156.

Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: The rhetorics of the science classroom*. London: Continuum.

Linder, C. (2013). Disciplinary discourse, representation, and appresentation in the teaching and learning of science. *European Journal of Science and Mathematics Education, 1*(2), 43-49.

Mavers, D. Glossary of multimodal terms Retrieved 6 May, 2014, from http://multimodalityglossary.wordpress.com/affordance/

Larkin (1981) *The role of problem representation in physics. .Paper* presnted at the mental models conference. University of California San Diego.

Larkin, J., McDermott, J. Simon, D & Simon, H. (1980) Expert and novice performance in solving physics problems. Science, 208, 1335-1342

Larkin & Simon (1987) Why a diagram is sometimes worth ten thousand words. Cognitive science 11, 65-99

van Heuvelen, A., & Maloney, D. (1999). "Playing physics jeopardy." *American Journal of Physics*, 67, 252-256.

van Heuvelen, A., &Zou, X. (1999). "Multiple Representations of Work and Energy Processes." *American Journal of Physics*, 69(2), 184-194.