Is understanding really the point of physics teaching?

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- Some data collected in projects funded by NSF and FIPSE
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- Interactions with many colleagues in PER
  - Some are here today...many thanks
- Interactions with many, many students
  - to whom I owe the greatest debt.

Why teach physics?

- Students should be in possession of a way to understand each phenomenon studied which they did not have when they started their study of those phenomena.
  - Not just certain students, but all students

Is this goal of new understanding generally accomplished?

Students' and Teachers' Conceptions in Science

- A bibliography kept by Reinders Duit's group at the Institute for Science Education (IPN) at the University of Kiel in Germany
- Just updated (Mar, 2004) containing 6314 entries
- Not a PER bibliography, but a focussed bibliography of work on conceptions in Science
- Can be downloaded from
  - <http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html>
  - a quick stroll through the bibliography...

Students' and Teachers' Conceptions in Science

- Entries to the bibliography now go back to 1903
- Entries in:
    - Physics, Chemistry, Biology & Earth Science
- The "modern" era of this work dates back to the '70's when science educators began to take the work of Piaget and his group into account.
    - People began to do individual demonstration interviews similar to those conducted at Piaget's Institute for Genetic Epistemology in Geneva.

Students' and Teachers' Conceptions in Science

- From this work in the late '70's and early '80's
  - People working in physics found evidence of students' pre-instruction conceptions hardly changing at all as a result of standard instruction.
  - Here is a sample...

Early Modern PER Work

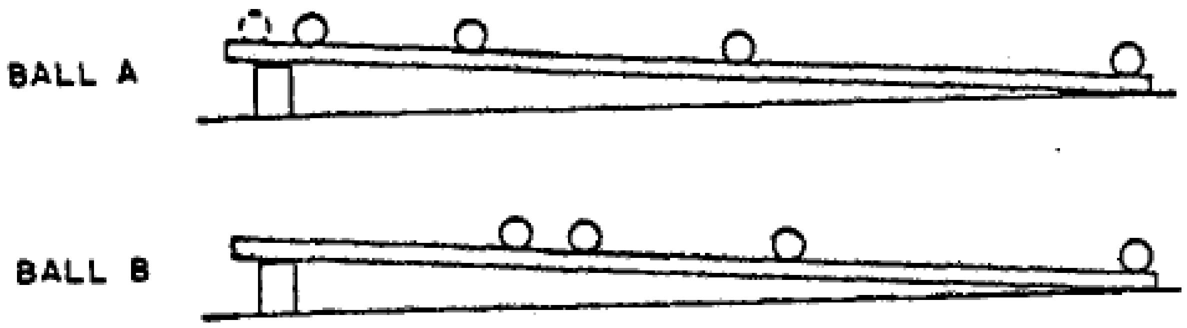


Fig. 5. Acceleration Comparison Task 1. Motion is from left to right. Successive positions are shown as they would appear in a strobe light photograph. Dashed circle indicates initial position of ball *A*. Solid circles indicate corresponding positions of balls at equal time intervals.

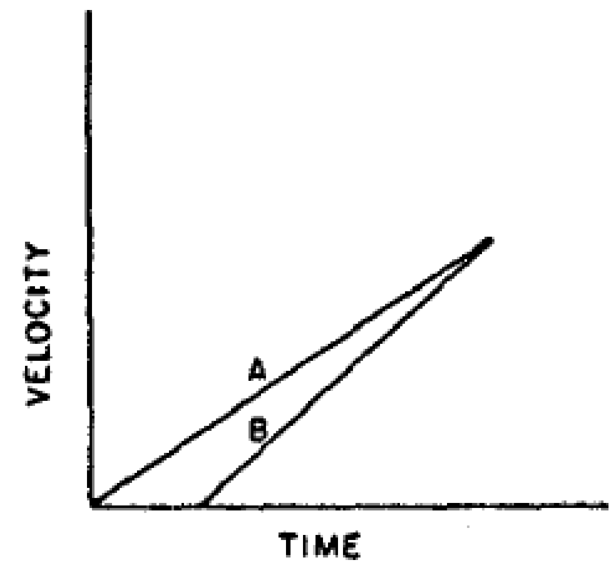


Fig. 7. Velocity-time graph of motion demonstrated in Acceleration Comparison Task 1. Balls reach the same velocity just as they enter a tunnel at the bottom of the incline.

Table III. Results for Acceleration Comparison Task 1. Percentages and numbers (*n*) of students in each group who received scores of 0, 1, or 2.

		Precourse interviews				Postcourse interviews			
		0	1	2	total	0	1	2	total
In-service teachers	(IT)	87 (13)	0 (0)	13 (2)	100 (15)				
Academically disadvantaged	(AD)	94 (17)	6 (1)	0 (0)	100 (18)	35 (7)	25 (5)	40 (8)	100 (20)
General physics (self-paced)	(GPS)					65 (15)	13 (3)	22 (5)	100 (23)
General physics (lecture)	(GPL)					46 (13)	25 (7)	29 (8)	100 (28)
Calculus physics	(CP)	61 (28)	22 (10)	17 (8)	100 (46)	31 (12)	31 (12)	38 (15)	100 (39)

"At the completion of instruction, fewer than half of the students demonstrated sufficient qualitative understanding of acceleration as a ratio to be able to apply this concept in a real situation."

Students' and Teachers' Conceptions in Science

- Thorough documentation that very little conceptual change occurs in normal instruction even after multiple treatments
  - Findings duplicated in every study of conceptual change
    - ...on every topic studied...
    - ...over the whole of the 20th century.

Students' and Teachers' Conceptions in Science

- The notion that these pre-instruction conceptions are very resistant to change was repeated often in the literature.
  - ...and still is being repeated...

Conceptions Resistant to Change?

The findings that the conceptions do not change could be because...

- (1) the conceptions themselves are resistant to change, in which case maybe we should not set as our goal as changed understanding for all or

- (2) there is so little change in conceptions because only certain people who have worked diligently can actually accomplish these changes, in which case we cannot set our goal as changed understanding for all or

- (3) the conceptions have not changed because the "treatment" (in this case, normal, content-driven instruction) is ineffective, in which case another "treatment" (an entirely different pedagogy) might be much more effective.

    - In other words, neither the conceptions, nor the students are the "problem." The instruction is the "problem" and we can indeed set as our goal changed understanding for all.

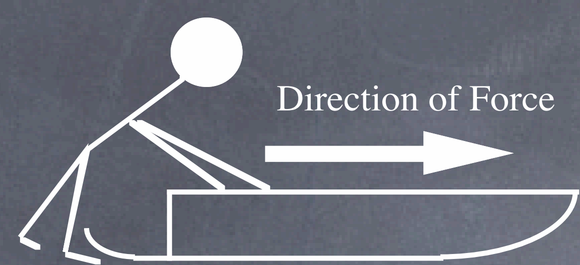
A closer look at a specific set of data…

A conceptual diagnostic

- Force and Motion Conceptual Evaluation (FMCE)
- R. K. Thornton & D. R. Sokoloff, "Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula," Am. J. Phys. 66(4) 338 – 352 (1998).

Choice	Question 1	2	3	4	5	7
A	77	0	2	4	3	7
B	13	84	0	0	68	14
C	3	2	53	1	1	7
D	0	5	16	1	12	14
E	0	0	8	4	2	45
F	1	4	10	6	8	4
G	2	2	5	81	2	3
H	0	0	0	0	0	0
I	0	0	0	0	0	0
J	0	0	2	0	0	3

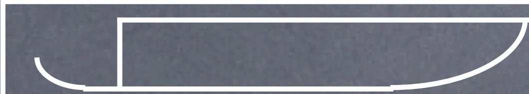
Pre-Diagnostic
Frequency of Choice Table



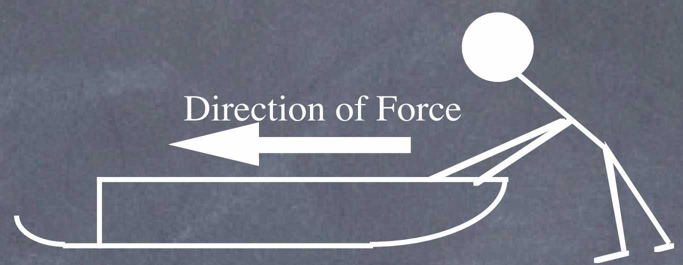
A. The force is toward the **right** and is **increasing** in strength (magnitude).

B. The force is toward the **right** and is of **constant** strength (magnitude).

C. The force is toward the **right** and is **decreasing** in strength (magnitude).



D. No applied force is needed



E. The force is toward the **left** and is **decreasing** in strength (magnitude).

F. The force is toward the **left** and is of **constant** strength (magnitude).

G. The force is toward the **left** and is **increasing** in strength (magnitude).

- (sled on ice, friction can be ignored)

1. Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)?
2. Which force would keep the sled moving toward the right at a steady (constant) velocity?
3. The sled is moving toward the right. Which force would slow it down at a steady rate (constant acceleration)?
4. Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)?
5. The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity?

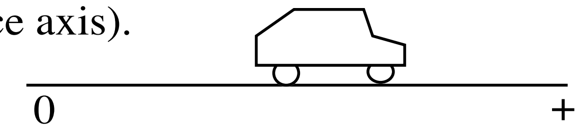
7. The sled is moving toward the left. Which force would slow it down at a steady rate (constant acceleration)?

		Question							
		14	15	16	17	18	19	20	21
C	A	76	3	10	5	1	1	1	11
h	B	3	3	2	59	2	8	0	3
o	C	10	1	64	8	13	8	1	4
I	D	1	1	8	9	8	51	0	0
c	E	5	85	0	2	4	1	1	7
e	F	0	0	0	1	9	1	73	25
	G	0	1	5	4	11	9	4	16
	H	1	0	5	7	42	6	8	19
	I	0	0	0	0	0	0	0	0
	J	0	3	3	1	6	10	8	12

Pre-Diagnostic
Frequency Table

- The pattern of choices repeating in a different context tends to corroborate the notion that conceptions drive the choices.

Questions 14-21 refer to a toy car which can move to the right or left along a horizontal line (the positive part of the distance axis).



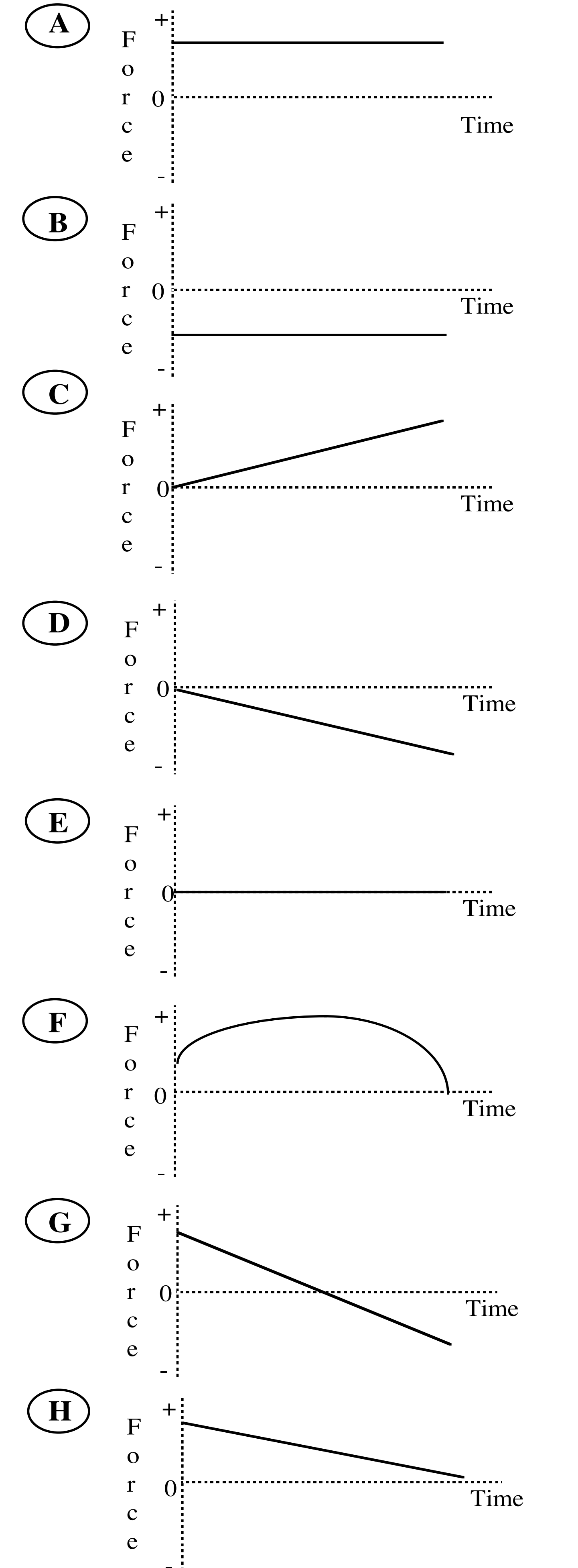
Assume that friction is so small that it can be ignored.

A force is applied to the car. Choose the one force graph (**A** through **H**) for each statement below which could allow the described motion of the car to continue.

A force to the right is depicted on the graphs as positive. A force to the left is depicted on the graphs as negative.

You may use a choice more than once or not at all. If you think that none is correct, answer choice **J**.

14. The car moves toward the right (away from the origin) with a steady (constant) velocity.
15. The car is at rest.
16. The car moves toward the right and is speeding up at a steady rate (constant acceleration).
17. The car moves toward the left (toward the origin) with a steady (constant) velocity.
18. The car moves toward the right and is slowing down at a steady rate (constant acceleration).
19. The car moves toward the left and is speeding up at a steady rate (constant acceleration).
20. The car moves toward the right, speeds up and then slows down.
21. The car was pushed toward the right and then released. Which graph describes the force after the car is released.



J None of these graphs is correct.

"Old" view of force

- A view of force that is consistent with the phrase: 'the velocity goes as the force.' (The force graph looks like the velocity graph)
- Includes the notion that the force responsible for the motion is in the direction of motion
- Majority view at the beginning of the semester, every semester of...
  - every course: HS and both intro college level courses
  - even on the second and third exposure to typical instruction.
- The adjective "old" comes from PIPS students who realize a distinction between this view and the new one they develop.
  - Could be called: everyday or person-on-the-street view of force

A “New” view of force

- The view of force that is consistent with the phrase: ‘acceleration goes as the net force.’
- The net force graph looks like the acceleration graph.
- Includes the notion that the acceleration is always in the direction of the net force
- Again, the adjective “new” comes from PIPS students who realize a distinction between this view and the one they started with.
  - Most physicists would recognize this as the conceptual foundation of what can be called a Newtonian view of force.

Old view, New view scores

- Two scoring keys: based on Old view & New view of force
- Relating to Newton's first and second laws of motion
- 11 of the first 21 questions
  - 1, 2, 3, 4, 5, 7, 14, 16, 17, 18, 19
- Plus two sets of three involving gravity
  - 8, 9, 10
  - 11, 12, 13
  - If in a set, all three responses are consistent with a particular view of force then a score of 2 was added.
- Involves 17 questions with a max score of 15.
- Matched pairs of data used exclusively

- Both the particular set of 17 and the use of the six questions in groups of 3 are suggestions made by Thornton based on his work in...
  - R. K. Thornton, "Conceptual Dynamics: Following changing Student Views of Force and Motion," In The Changing Role of Physics Departments in Modern Universities: Proceedings of ICUPE, E. F. Redish & J. S. Rigden (eds) (American Institute of Physics: College Park, MD, 1997) Abstract online at <http://ase.tufts.edu/csmt/html/abstracts/icupe_cd.html>
- Thornton is able to detect the presence of more positions or views about force for which there is evidence of a developmental sequence.
- The two view (old vs. new) characterization used here is simplified or more coarse characterization than is possible.

Standard Physics Instruction

Algebra-Trig Level Intro Physics

Whole class			FMCE averages							
			Pre (0 - 15)				Post(0 -15)			
Year	Term	N	Old	□	New	□	Old	□	New	□
West Coast Public Univ. A										
1990		99	10.1	3.0	1.5	2.2	8.5	3.7	3.3	3.8
"Prairie State" Public Univ.										
2002	SP	112	10.3	3.0	0.9	1.4	9.0	3.8	2.7	3.5
Calculus Level Intro Physics										
North East State Public Univ.										
1998		72	9.6	3.2	1.7	2.6	8.5	4.6	3.5	4.5
West Coast Public Univ. B										
1999	W	87	9.3	4.2	2.6	3.9	6.5	4.7	5.4	5.1
1999	SP	73	9.1	4.1	2.3	3.8	7.6	4.4	4.0	4.9
2000	SP	115	9.2	3.8	2.4	3.3	7.2	4.2	4.8	4.8
West Coast Private Univ.										
2000	SP	38	9.8	2.7	0.6	0.8	9.6	3.9	1.9	3.3

- Ph. D.'s in Physics and Physics grad student TA's teaching at major institutions
- Looks like student conceptions of force are resistant to change, but are they?

Algebra-Trig Level Intro Physics

Whole class			FMCE averages							
			Pre (0 - 15)				Post(0 -15)			
Year	Term	N	Old	▯	New	▯	Old	▯	New	▯
West Coast Public Univ. A										
1990		99	10.1	3.0	1.5	2.2	8.5	3.7	3.3	3.8
"Prairie State" Public Univ.										
2002	SP	112	10.3	3.0	0.9	1.4	9.0	3.8	2.7	3.5
Calculus Level Intro Physics										
North East State Public Univ.										
1998		72	9.6	3.2	1.7	2.6	8.5	4.6	3.5	4.5
West Coast Public Univ. B										
1999	W	87	9.3	4.2	2.6	3.9	6.5	4.7	5.4	5.1
1999	SP	73	9.1	4.1	2.3	3.8	7.6	4.4	4.0	4.9
2000	SP	115	9.2	3.8	2.4	3.3	7.2	4.2	4.8	4.8
West Coast Private Univ.										
2000	SP	38	9.8	2.7	0.6	0.8	9.6	3.9	1.9	3.3

The bibliography supports the claim that this data collected over a dozen years is characteristic of the results over the whole 20th century.

Why?

- There have been many very dedicated, very smart people teaching physics in high school and college for many decades, yet we have these results.

- Maybe some can just “get” physics (if they have worked hard enough) and some just cannot “get” physics (or have not worked hard enough) OR maybe something OTHER than every student “getting” physics has been the driving factor.

Conceptual Physics College Level--Standard PIPS Instruction

Whole class			FMCE Averages							
			Pre (0 - 15)				Post(0 -15)			
Year	Term	N	Old	□	New	□	Old	□	New	□
Boise State University										
1999	SP	97	9.4	3.5	0.9	1.4	3.0	3.2	7.8	4.6
1999	FL	93	9.9	2.8	0.8	1.1	3.6	4.1	7.6	5.3
Conceptual Physics College Level--modified PIPS Instruction										
Boise State University										
2000	FL	90	9.3	3.1	0.8	1.3	2.5	3.1	9.2	4.5
2001	SP	87	9.8	3.0	0.8	1.2	2.2	3.4	9.6	5.0
2002	FL	66	9.4	3.3	0.8	1.3	2.2	3.3	8.8	4.2
High School Level--Standard PIPS Instruction										
2001	FLa	23	11.3	2.4	0.6	0.8	0.6	1.5	13.3	2.7
2001	FLb	24	10.6	3.5	0.9	1.2	0.8	1.4	13.1	2.5

The same results?

- These are non-science majors.
- The college and the HS instruction each taught by a single instructor with no assistants.
- Can it really be that only a certain few, who work hard enough can "get" physics?

Algebra-Trig Level Intro Physics

Whole class			FMCE averages							
			Pre (0 - 15)				Post(0 -15)			
Year	Term	N	Old	□	New	□	Old	□	New	□
West Coast Public Univ. A										
1990		99	10.1	3.0	1.5	2.2	8.5	3.7	3.3	3.8
"Prairie State" Public Univ.										
2002	SP	112	10.3	3.0	0.9	1.4	9.0	3.8	2.7	3.5
Calculus Level Intro Physics										
North East State Public Univ.										
1998		72	9.6	3.2	1.7	2.6	8.5	4.6	3.5	4.5
West Coast Public Univ. B										
1999	W	87	9.3	4.2	2.6	3.9	6.5	4.7	5.4	5.1
1999	SP	73	9.1	4.1	2.3	3.8	7.6	4.4	4.0	4.9
2000	SP	115	9.2	3.8	2.4	3.3	7.2	4.2	4.8	4.8
West Coast Private Univ.										
2000	SP	38	9.8	2.7	0.6	0.8	9.6	3.9	1.9	3.3

Conceptual Physics College Level--Standard PIPS Instruction

Whole class			FMCE Averages							
			Pre (0 - 15)				Post(0 -15)			
Year	Term	N	Old	□	New	□	Old	□	New	□
Boise State University										
1999	SP	97	9.4	3.5	0.9	1.4	3.0	3.2	7.8	4.6
1999	FL	93	9.9	2.8	0.8	1.1	3.6	4.1	7.6	5.3
Conceptual Physics College Level--modified PIPS Instruction										
Boise State University										
2000	FL	90	9.3	3.1	0.8	1.3	2.5	3.1	9.2	4.5
2001	SP	87	9.8	3.0	0.8	1.2	2.2	3.4	9.6	5.0
2002	FL	66	9.4	3.3	0.8	1.3	2.2	3.3	8.8	4.2
High School Level--Standard PIPS Instruction										
2001	FLa	23	11.3	2.4	0.6	0.8	0.6	1.5	13.3	2.7
2001	FLb	24	10.6	3.5	0.9	1.2	0.8	1.4	13.1	2.5

- For comparison, here they are side-by-side.

What about effect size (Cohen's d) & normalized gain (Hake's <g>)?

Effect Size

Algebra-Trig Level Intro Physics

Year	Term	N	Effect Size (□) New	Effect Size (□) Old
West Coast Public Univ. A				
1990		99	0.59	-0.47
"Prairie State" Public Univ.				
2002	SP	112	0.66	-0.40

Calculus Level Intro Physics

North East State Public Univ.				
1998		72	0.47	-0.30
West Coast Public Univ. B				
1999	W	87	0.60	-0.62
1999	SP	73	0.38	-0.36
2000	SP	115	0.59	-0.50
West Coast Private Univ.				
2000	SP	38	0.54	-0.08

Conceptual Physics College Level
Standard PIPS Instruction

Year	Term	N	Effect Size (□) New	Effect Size (□) Old
Boise State University				
1999	SP	97	2.00	-1.90
1999	FL	93	1.78	-1.80

Modified PIPS Instruction

Boise State University				
2000	FL	90	2.50	-2.20
2001	SP	87	2.40	-2.40
2002	FL	66	2.62	-2.19

High School Level
Standard PIPS Instruction

2001	FLa	23	6.30	-5.40
2001	FLb	24	6.10	-3.70

Normalized Gain and Loss

Algebra-Trig Level Intro Physics

Year	Term	N	Normalized Gain <g>	Normalized Loss <L>
West Coast Public Univ. A				
1990		99	0.14	-0.09
"Prairie State" Public Univ.				
2002	SP	112	0.13	-0.06

Calculus Level Intro Physics

North East State Public Univ.				
1998		72	0.15	-0.06
West Coast Public Univ. B				
1999	W	87	0.22	-0.30
1999	SP	73	0.12	-0.01
2000	SP	115	0.15	-0.10
West Coast Private Univ.				
2000	SP	38	0.09	0.05

Conceptual Physics College Level
Standard PIPS Instruction

Year	Term	N	Normalized Gain <g>	Normalized Loss <L>
Boise State University				
1999	SP	97	0.49	-0.68
1999	FL	93	0.48	-0.63

Modified PIPS Instruction

Boise State University				
2000	FL	90	0.59	-0.66
2001	SP	87	0.62	-0.74
2002	FL	66	0.57	-0.72

High School Level
Standard PIPS Instruction

2001	FLa	23	0.89	-0.95
2001	FLb	24	0.86	-0.93

- These two sets of data suggest that it is neither the case:
  - (1) that conceptions are so resistant to change nor
  - (2) that only certain students can really “get” the new understandings.
- The pedagogy is apparently a far greater factor here.
  - The alternative pedagogy used in this study is student-understanding driven.
- There are other examples of PER-based instruction with similar results.

- The claim that standard, content-driven physics instruction has the goal of the students actually understanding “physics” is not supported by the actual outcome of traditional physics instruction as revealed in the data collected over the whole of the 20th century.

- If it is okay that the change in understanding is almost zero in physics instruction, then
  - (1) the point of physics instruction cannot actually be the development of understanding in all students and
  - (2) we should probably stop calling it "physics education" and instead refer to physics instruction as physics vocational selection and training.

- If it is not acceptable that there is so little change in understanding, then
    - we must change our own pedagogy
    - we must start changing how we prepare teachers
- Can we ethically do otherwise?
- We know how to prepare Jr Hi teachers who can achieve similar results with 9th graders to those in the HS physics classes in this study...and HS teachers who can take them further.
    - Incidentally the HS teacher in this study had never taught this way before. He had access only to written material and e-mail communication for advice in his efforts. Several years later his students' understandings are still far superior to the science and engineering majors in introductory physics in college.

Do we have the courage?

- To change our own pedagogy?
- To change how we prepare teachers?
- PER "gives us good guidance" in making effective change.
    - ...as is evidenced in the data presented here, in other talks at this meeting, and the PER literature.

Thank you.

- Those of us in PER are ready to work with anyone who wishes to work on these two tasks.
- Feel free to get in touch:
  - Dewey Dykstra--ddykstra@boisestate.edu
  - ...and others at this meeting...

An existing conceptual scheme

- Our understandings are our own mental constructs as such only we can make or modify our own understandings for ourselves.
- We make changes in our personal mental constructs when we decide our existing ones do not fit experience.
- Because our understandings are mental entities and not physical, they reside only in our minds not in any physical object or process.

What the research "says"

- "If I didn't already believe it, I never would have seen it ." - John Layman
- If we can fit the data within our existing conceptual scheme, the data corroborates our conceptual scheme. (Piaget-cognitive assimilation)
- When we cannot fit the data within our existing conceptual scheme (Piaget-disequilibration), we have two choices:
  - avoid, disparage, ignore the data or
  - adjust our conceptual scheme (Piaget-cognitive accommodation) to fit the data. (conceptual change)