Transfer of Learning from Mathematics to Physics

N. Sanjay Rebello

K-State PHYSICS DEPARTMENT

Physics Education Research Group
Kansas State University

Supported in part by NSF Grants 0816207, 0206943, 0133621

Acknowledgements


Dr. Elizabeth Gire
Post-doc [1]


Dong-Hai Nguyen
Graduate Student


Lili Cui
Lecturer UMBC [2]


Andy Bennett
Math Prof KSU

[1] Starts tenure-track position at U. Memphis in Fall 2010.
[2] Completed Ph.D. in PER from KSU in 2006.

2

What is Transfer?

Ability to use what you have learned in one situation in a different situation.

E.g. McKeough, Lupart & Marini (1995)

3

Some Early Views of Transfer

- Identical elements must exist between situations.
- Knowledge must be encoded in a coherent model.
- Researchers/educators pre-decide what must transfer.
- Static one-shot assessment e.g. tests and exams.
- Focus mainly on students' internal knowledge.

Transfer is rare.

E.g. Gick & Holyoak (1980), Reed & Ernst (1974), Thorndike (1906)

4

Some Emerging Views of Transfer

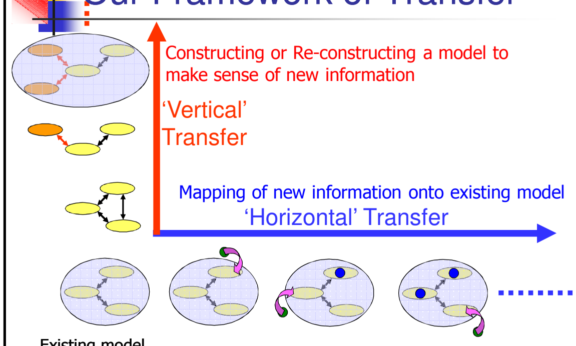
- (Re) construct knowledge in new context.
- Knowledge can transfer in pieces.
- We must examine anything that transfers.
- Dynamic, real-time assessment e.g. interviews.
- Focus also on mediating factors e.g. motivation.

Transfer is ubiquitous.

Hammer *et al* (2005), diSessa & Wagner (2005);
Bransford *et al* (1999), Lobato (2003, 1996), Greeno *et al* (1993)

5

Our Framework of Transfer



6

Some Caveats

'Horizontal' & 'Vertical' Transfer…

- are not mutually exclusive.
  - A given thinking process might involve elements of both 'horizontal' and 'vertical' transfer.
- cannot be universally labeled.
  - What is perceived as 'vertical' transfer by a novice may be perceived as 'horizontal' transfer by an expert.

7

Possible Research Questions

- How do students engage in 'horizontal' and 'vertical' transfer?
- Under what conditions do they engage in each?
- Is there a preferred sequence for these processes?

⋮

and several others….

8

'Calculus to Physics' Study

Research Question

To what extent do students transfer their calculus knowledge while problem solving in introductory calculus-based physics?

Lili Cui

Cui et. al. (2005)

9

'Calculus to Physics' Study

Research Participants

- Students (N = 28)
  - Enrolled in 2nd semester, calculus-based physics
  - After covering relevant topics in electricity and magnetism
- Teachers: Faculty, Instructors and TAs
  - Physics (N = 6)
  - Mathematics (N = 4)

10

'Calculus to Physics' Study

Research Plan

Semi-structured Interviews

- 'Horizontal' Transfer
  - Textbook-like Problems
- 'Vertical' Transfer
  - 'Contrasting Cases'
  - 'Jeopardy' Problems

[1] Schwartz, Bransford & Sears (2005) [2] Van Heuvelen & Maloney (1999)

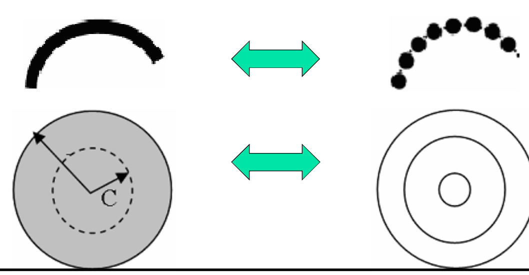
11

'Calculus to Physics' Study

'Contrasting Cases'

Continuous vs. Discrete

When do you use integration in a problem?



12

'Calculus to Physics' Study
'Jeopardy' Questions

Construct a physical situation that is described by the following expression

$$2\times\left[\int_0^{\frac{\pi}{6}} (8.99\times10^9\, N\cdot m^2/C^2)\,\frac{(2\times10^{-10}\, C/m)(5\times10^{-2}\, m)\cos\theta d\theta}{\cdots}\right]$$

Our goal is not to find out whether they get these problems right, rather the process they use to attempt the problems

$2\pi R$

13

'Calculus to Physics' Study
Student Interview Results

- Textbook-like Problem
  - no difficulty in recalling
  - difficulty setting up the
- 'Contrasting Cases':
  - used similarity of textb
  - had difficulty determinin
- 'Jeopardy' Problems:
  - used pattern matching to
  - used units to find physical quantity represented by expression.
  - About half used variable of integration to figure out geometry.

"I know how to integrate it, but it is just figuring out what to integrate, that is the

"I look for pieces of terms that I recognize,…, they will tell what kind of problem they are, I just tend the recognize forms, like derivative… I do not know why those formula work, I just use them"

… take into account, I get confused, … the objective of what I am actually looking for… as soon as I set it up, there is no problem"

14

'Calculus to Physics' Study
Teacher Interview Results

- Mathematics teachers..
  - focus on techniques of calculus.
  - realize value of applications, but cannot address them.
  - seldom use 'word' problems.
- Physics teac
  - to attend to
  - math teach
    - Do more 'V
    - Focus on u

"Studen try…som that is th but for some reason, translati… word problem into a mathematical problem i… the big step. They do not do well on the word problems, so as far as on exams I mean I was trying to put some on them, but I do not want to make the exam too hard"

"…I do not hav actually know w

"I would be happier if the mathematicians put more emphasis on the theoretical basis of calculations."

'Calculus to Physics' S
SUMMARY

From students' perspective perhaps this was 'vertical' transfer ??

- 'Horizontal' Transfer : Students have
  - no difficulty recalling model to solve calculus problems.
  - difficulty mapping physics problem variables into model.
- 'Ve
  - d
  - d … e
  - b
- Teachers' Perspective
  - Math: Focus on techniques, not concepts or applications.
  - Physics: Would like math teachers do what they do not!

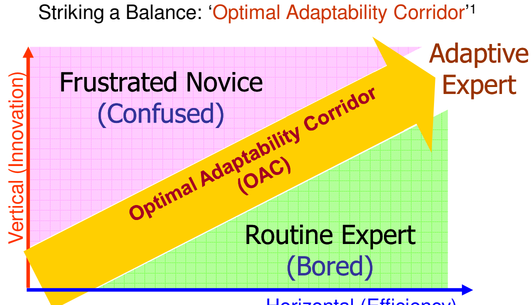
How do we address these issues?
Could some of our what we have learned elsewhere give us some clues?

16

What Transfer do We Want?

Horizontal (Efficiency) **AND** Vertical (Innovation)

Striking a Balance: 'Optimal Adaptability Corridor'[1]



[1] Schwartz, Bransford & Sears (2005) [2] Murray & Arroyo (2002)

17

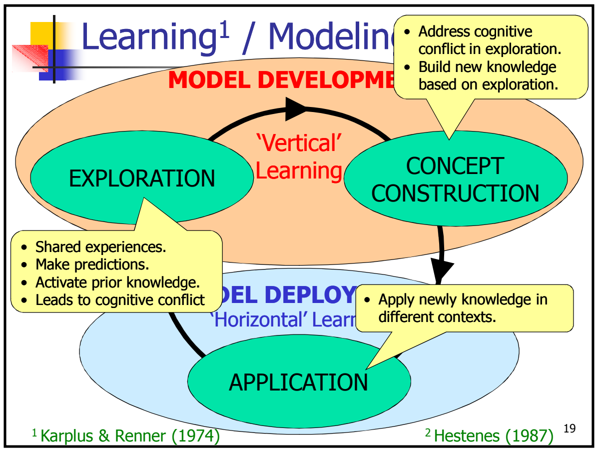
Characteristics of Instructional Strategies

- Balance 'horizontal' and 'vertical' transfer
  - Follow an 'Optimal Adaptability Corridor'[1]
- Adapt proven pedagogical strategies e.g.
  - Small steps of Model Development (Vertical) followed by Model Deployment (Horizontal).[2]
- Emphasize multiple models
  - Sensitivity to activate appropriate model

[1] Schwartz, Bransford & Sears (2005)

[2] Hestenes (1987)

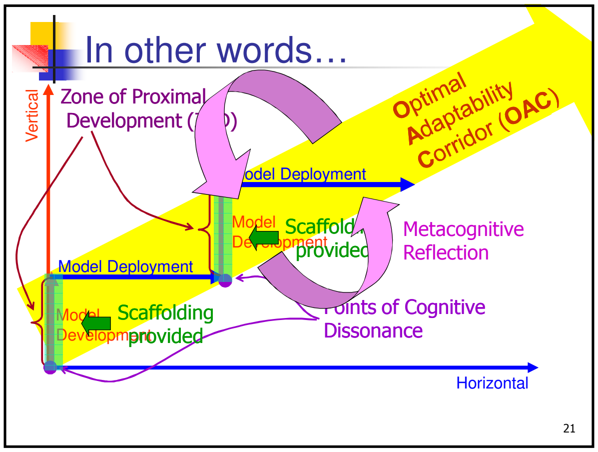
18



Implications for Instruction

- Balance horizontal and vertical transfer
  - Follow an 'Optimal Adaptability Corridor'
- Adapt the Modeling Cycle
  - First Model Development
  - Then Model Deployment
- Employ strategies that …
  - Use cognitive conflict to promote model development
  - Scaffold learning within Zone of Proximal Development
  - Use metacognitive reflection to create adaptive learners

20



We can also apply this to…

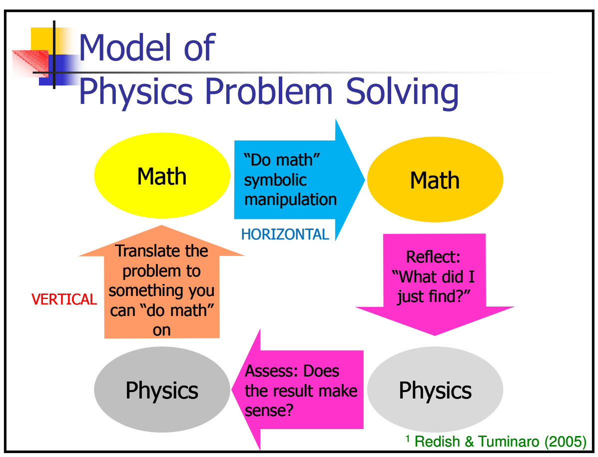
- Learning how to Learn:
  - Students deploy strategies to succeed in science/math, based on their model of what it takes to succeed in this course.
  - If they fail, they reach a point of dissonance – model does not work.
  - We can then facilitate a process by which they reflect and develop a revised model of how to learn science/math.

22

We can also apply this to…

- Learning how to Teach:
  - As teachers we deploy our model of how students learn and how we should teach.
  - If students fail our assessments, we reach a point of dissonance – our model of learning and teaching does not work.
  - We then develop a revised model of how they learn, and think about how we can teach more effectively.

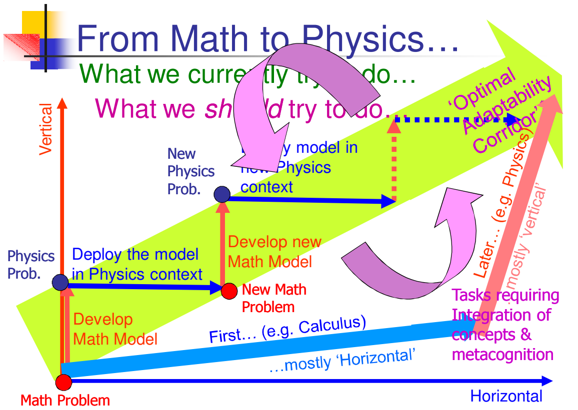
23



From Math to Physics…

What we currently try to do…

What we should try to do…



$ Schwartz, Bransford & Sears (2005)

25

Is there any evidence that this will work in helping students transfer math knowledge to physics?

26

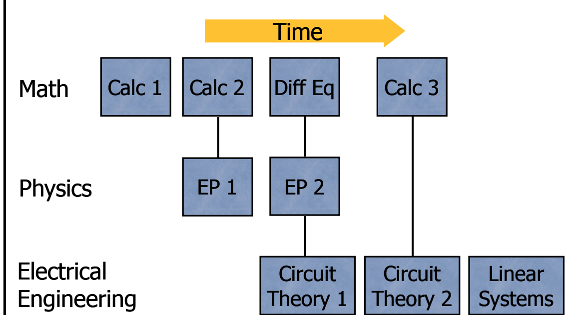
'Representational Fluency' Study

- How do students develop representational fluency?
- What kinds of difficulties do students encounter when solving problems in multiple representations?
- What kinds of scaffolding are useful in helping students overcome those difficulties?

Dong-Hai Nguyen

27

'Representational Fluency' Study
Research Plan



'Representational Fluency' Study
Data Collection (Spring & Fall 2009)

Spring 2009 — Individual Interviews

n=20 EP1 students
EE/CSE majors

1 2 3 4

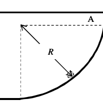
Fall 2009 — Individual Interviews

n=15 EP2 students
EE/CSE majors

1 2 3 4

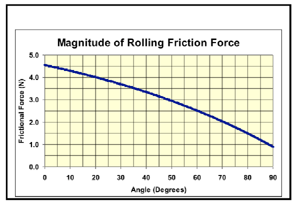
'Representational Fluency' Study
Example Interview Problems

Original Problem
Verbal



Find the speed at point A.

Graphical



Equational

$$F_{roll}(\theta) = -0.7\theta^2 - 1.2\theta + 4.5$$

'Representational Fluency' Study
Individual Interviews General Results
(Spring & Fall 2009)

- All students able to solve problems with hints.
- Initially had trouble invoking integral = area under the curve.
- Had difficulty coordinating geometric and algebraic modes of thinking.
- Little evidence that students can interpret integration as accumulation.
- Fewer difficulties when graph problem before equation problem, than vice-versa.

31

'Representational Fluency' Study
Data Collection (Spring 2010)

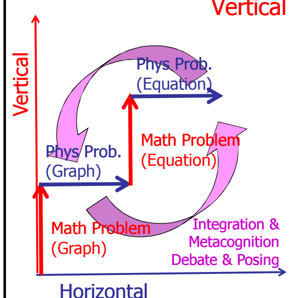
'Representational Fluency' Study
Focus Group Interviews (Spring 2010)

Control Group	Treatment Group
Pre-Test : Prob. 2 & 3 from Fall 2009 Interview	
1. Physics Problem (Graph)	1. Math Problem (Graph)
2. Physics Problem (Graph)	2. Physics Problem (Graph)
3. Physics Problem (Equation)	3. Math Problem (Equation)
4. Physics Problem (Equation)	4. Physics Problem (Equation)
5. Physics Problem (Similar to Fall 2009 Prob. 1, Verbal)	5. Debate Problem (Similar to Fall 2009 Prob. 1, Verbal)
	6. Problem Posing (Combine previous problem w/Graph, Equation)
Post-Test : Similar to Pre-Test, different numbers	

33

'Representational Fluency' Study
Focus Group Interviews (Spring 2010)

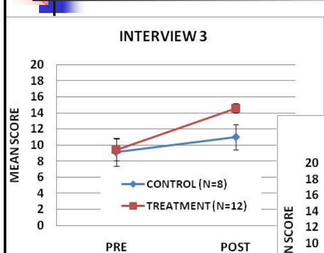
Looking at Treatment Group through Horizontal & Vertical Transfer Lens



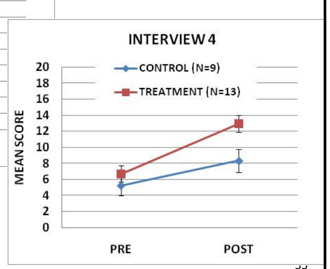
1. Math Problem (Graph)
2. Physics Problem (Graph)
3. Math Problem (Equation)
4. Physics Problem (Equation)
5. Debate Problem (Similar to Interview Prob. 1, Verbal)
6. Problem Posing (Combine Prob.5 with Graph, Eqn.)

34

'Representational Fluency' Study
Conclusions



Interview 3
Mann Whitney
U = 74.0, p-value = 0.0448



Interview 4
Mann Whitney
U = 94.0, p-value = 0.0178

'Representational Fluency' Study
SUMMARY

- Students have difficulty…
  - solving problems that present information in graphical and equational representations.
  - recognizing how to appropriately apply the concept of integration in physics problems
- Promising interventions…
  - involve the use of vertical and horizontal transfer.
  - use a sequence of math and physics problems.
  - use debate problems and problem posing tasks to facilitate metacognition.

36

OVERALL SUMMARY

- Transfer of learning is a complex process and must be considered from different perspectives.
- Students instinctively engage in 'horizontal' transfer and attempt 'vertical' transfer only if 'horizontal' transfer has not worked for them.
- Most of instruction focuses on 'horizontal' transfer and does not prepare students for 'vertical' transfer.
- To create adaptive learners, we must balance both; we have some evidence that this can perhaps be done through carefully designed sequences of small steps of both 'vertical' and 'horizontal' transfer.

37

Thank You

For further information

srebello@phys.ksu.edu

38