Transfer of Learning & Implications for Physics Education Research & Curriculum Development

Sanjay Rebello

Supported in part by NSF Grants REC-013621, DUE-0206943, REC-0087788

Acknowledgments

Current Collaborators
Edgar Corpuz, Lili Cui,
Aileen Corpuz, Bijaya Aryal, Spartak Kalita, Charles Mamolo,
Brian Adrian, Dean Zollman

Previous Collaborators
Alicia Allbaugh, Kara Gray, Zdeslav Hrepic,
Carina Poltera, Jackie Haynicz
Peter Fletcher, Paula Engelhardt, Salomon Itza-Ortiz

What We Do

Research Question

How do students transfer their knowledge when making sense of a situation?

What is Transfer?

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

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

Views of Transfer

- Identical elements must exist between situations.
- Knowledge must be encoded in a coherent model.
- Researcher can pre-decide what must transfer.
- Static one-shot assessment e.g. tests and exams.
- Focus mainly on students’ internal knowledge.
- Transfer is rare.

Are these views applicable when we examine students’ sense making?

E.g. Gick & Holyoak (1980); Reed & Ernst (1974); Thordike (1908)
Example: Interview on Optic Fibers
(Mateyck, Wagner, et. al., Proc. 2004 PER Conference)

From what I understand, it’s a, it’s almost a series of reflections. … I’m pretty sure it’s reflected light all the way through. … I think just by a series of a-, of angled, um, I don’t want to say mirrors, but it’s got to be mirror-like, a mirror-like substance. … I guess if, if you did just enclose light in. … uh, it can’t be glass ‘cause it’s flexible. …. I don’t know how you would do it … maybe it wouldn’t need to reflect if it, uh, if it, you can’t escape the, the insulator, right? … maybe it can just, shwooo, travel right through. Maybe it doesn’t need to reflect. … I’ve seen, it almost looks like … it’s a plastic substance, I know, cause they use it for now, uh, that, that cable for computers and things, … but I don’t … know what they use, and it’s gotta be reflecting somehow. I don’t know.

In light of this example, do we need to rethink what transfer actually means?

Other Views of Transfer

- (Re)construct knowledge in new context.
- Knowledge can transfer in pieces.
- Researcher must examine ‘anything’ that transfers.
- Dynamic, real-time assessment e.g. interviews
- Focus also on variety of mediating factors.
- Transfer is ubiquitous.

Hammer et al (2005); diSessa & Wagner (2005);

Model of Transfer
(Basic View)

Workbench
Read-Out Information
External Inputs
READ-OUT FILTER
Control
Decision
Prior Knowledge
Epistemic Mode
Information in scenario
Activated Epistemic Mode
Control
Epistemic Mode
The nature of knowledge to be used in sense-making
LONG TERM MEMORY
PRIOR KNOWLEDGE
ASSOCIATION
EXECUTIVE CONTROLLER
Sensory Filter
INPUT INFORMATION STREAM

Model of Transfer
(Complex View)

Transfer is the creation of associations between information read out by the learner & prior knowledge.

The association is controlled by other factors e.g. learners’ epistemology, motivation, etc.

Redish (2004)
Two Kinds of Associations

- Assigning new information to a knowledge element.
  - e.g. The electric field in region is 2 V/m

- Associations between two different knowledge elements.
  - e.g. Integral of electric field is the electric potential.

Two Kinds of Transfer

- 'Horizontal'
  - Activating and mapping a pre-constructed model to a new situation.
  - Associations between read-out information of a situation & elements of model.
  - A "model" is a pre-created set of associated elements.

- 'Vertical'
  - Constructing a new model to make sense of a situation.
  - Association between knowledge elements to create model.
  - New knowledge elements are incorporated in model; others are discarded.

Theoretical Framework

- 'Vertical' Transfer
  - Creating a new model to make sense of new information
  - Activation & Mapping of new information onto existing model

- 'Horizontal' Transfer
  - Existing model

Alignment with Others’ Views

<table>
<thead>
<tr>
<th>'Horizontal'</th>
<th>'Vertical'</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Low Road,” 3 “Class C” 4 Transfer</td>
<td>“High Road,” 3 “Class A” 4 Transfer</td>
</tr>
<tr>
<td>“Assimilation” of new experiences 3</td>
<td>“Accommodation” of new experiences 3</td>
</tr>
<tr>
<td>Involves deductive reasoning:</td>
<td>Involves inductive reasoning:</td>
</tr>
<tr>
<td>‘Model Deployment’ 4</td>
<td>‘Model Development’ 4</td>
</tr>
<tr>
<td>Uses “Applicative” knowledge 3</td>
<td>Uses “Interpretive” knowledge 3</td>
</tr>
<tr>
<td>Focus on “Efficiency” 4</td>
<td>Focus on “Innovation” 4</td>
</tr>
<tr>
<td>‘Sequestered Problem Solving’ 7</td>
<td>‘Preparation for Future Learning’ 7</td>
</tr>
<tr>
<td>Structured, traditional problems 8</td>
<td>Ill-structured, non-traditional problems 8</td>
</tr>
<tr>
<td>Single/few internal representations activated repeatedly 8</td>
<td>Choosing, using and constructing multiple internal representations 8</td>
</tr>
</tbody>
</table>

Alignment with Others’ Views

- 1 Salomon & Perkins (1989)
- 2 diSessa & Wagner (2005)
- 3 Piaget (1952)
- 4 Hestenes (1987)
- 5 Broudy (1977)
- 6 Schwartz, Bransford & Sears (2005)
- 7 Bransford & Schwartz (1989)
- 8 Jonassen (2003)

Some Other Points

- ‘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.

‘Horizontal’ or ‘Vertical’?

- What type of transfer do these problems entail?

Cart A, moving at 3 m/s, has an inelastic collision with Cart B, initially at rest. After the collision, the carts move together up an inclined plane. Neglecting friction, determine the vertical height of the carts before they reverse direction.

Some Other Points

- ‘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.

‘Horizontal’ or ‘Vertical’?

- What type of transfer do these problems entail?

You help your friend prepare for her next skateboard exhibition. She takes a running start and jumps onto her skateboard that will glide along a level track, then a sloped wall. To win she must reach at least 10 feet above where she starts. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned.

‘Horizontal’ or ‘Vertical’?

- What type of transfer do these problems entail?

You help your friend prepare for her next skateboard exhibition. She takes a running start and jumps onto her skateboard that will glide along a level track, then a sloped wall. To win she must reach at least 10 feet above where she starts. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned.

‘Horizontal’ or ‘Vertical’?

- What type of transfer do these problems entail?

You help your friend prepare for her next skateboard exhibition. She takes a running start and jumps onto her skateboard that will glide along a level track, then a sloped wall. To win she must reach at least 10 feet above where she starts. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned.

‘Horizontal’ or ‘Vertical’?

- What type of transfer do these problems entail?

You help your friend prepare for her next skateboard exhibition. She takes a running start and jumps onto her skateboard that will glide along a level track, then a sloped wall. To win she must reach at least 10 feet above where she starts. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned.

‘Horizontal’ or ‘Vertical’?

- What type of transfer do these problems entail?

You help your friend prepare for her next skateboard exhibition. She takes a running start and jumps onto her skateboard that will glide along a level track, then a sloped wall. To win she must reach at least 10 feet above where she starts. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned.

‘Horizontal’ or ‘Vertical’?

- What type of transfer do these problems entail?

You help your friend prepare for her next skateboard exhibition. She takes a running start and jumps onto her skateboard that will glide along a level track, then a sloped wall. To win she must reach at least 10 feet above where she starts. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned.

‘Horizontal’ or ‘Vertical’?

- What type of transfer do these problems entail?
**Applying the Framework**

Research Question
How do students transfer their knowledge when making sense of a situation?

**Reframed 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....

---

**‘Calculus to Physics’ Study**

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

**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)

**Research Plan**
- Semi-structured Interviews
  - ‘Horizontal’ Transfer
    - Textbook-like Problems
  - ‘Vertical’ Transfer
    - ‘Contrasting Cases’
    - ‘Jeopardy’ Problems

---

2. Van Heuvelen & Makone (1999)
‘Calculus to Physics’ Study
‘Jeopardy’ Questions
Construct a physical situation that is described by the following expression
\[ 2 \times \int_0^\infty (8.99 \times 10^8 \text{ N} \cdot \text{m}^2/C^2) \frac{(2 \times 10^{-10} C/m)(5 \times 10^{-2} m) \cos \theta d \theta}{(5 \times 10^{-2} m)^2} \]
\[ \mu_0 \int_0^R J(r) \cdot (2 \pi dr) \]
\[ 2 \pi R \]

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

‘Calculus to Physics’ Study
‘Jeopardy’ Questions

Student Interview Results
- Textbook-like Problems: Most students had...
  - no difficulty in recalling the required calculus knowledge.
  - difficulty setting up the problem.
- ‘Contrasting Cases’: Most students...
  - used similarity of textbook problems to decide when to use integration.
  - had difficulty determining variables and limits of integration.
- ‘Jeopardy’ Problems: Most students...
  - used pattern matching to set up the problem.
  - used units to find physical quantity represented by expression.
  - About half used variable of integration to figure out geometry.

Teacher Interview Results
- Mathematics teachers...
  - focus on techniques of calculus.
  - realize value of applications, but cannot address them.
  - seldom use ‘word’ problems.
- Physics teachers would like...
  - to attend to different problem types, but lack time.
  - math teachers to...
    - do more ‘Word’ problems.
    - focus on underlying concepts.

SUMMARY
- Horizontal Transfer: Students have...
  - no difficulty recalling model to solve calculus problems.
  - difficulty mapping physics problem variables into model.
- Vertical Transfer: Students have ...
  - difficulty deciding when to activate appropriate model.
  - difficulty in deconstructing model or constructing a new one based on the problem scenario.
- Teachers’ Perspective
  - Math: Focus on techniques, not concepts or applications.
  - Physics: Would like math teachers to do what they do not!

From students’ perspective perhaps this was ‘vertical’ transfer??

How do we address these issues? Could some of what we have learned elsewhere give us some clues?
(Looks like we researchers have a hard time transferring too!! 😎)
What We Do

Research

Curriculum Development

Pilot & Field Testing

Typical Methodology

Determine students' prior knowledge

Design interventions to change knowledge

Clinical Interviews

Curriculum Design & Development

Pilot- & Field-Testing

Curriculum Design

Alternative Methodology

Carefully examine the process by which students construct knowledge and how they respond to various strategies.

Teaching Interviews

Curriculum Design & Development

Pilot- & Field-Testing

What is a Teaching Interview?

*Mock* instruction:
- Attempts to change student knowledge.
- Rich setting for students to express themselves.
- Variety of instructional strategies.
- Involve groups of up to three students.

Researcher's Role:
- Observer.
- Instructor.

Benefits of Teaching Interviews

Provide insights about...
- Dynamics of horizontal and vertical transfer.
- Effectiveness of materials & strategies.
- Student interactions with...
  - instructional materials,
  - peers and
  - instructor.

Teaching Interviews are a useful paradigm for research & development of instructional strategies.

Characteristics of Instructional Strategies

- Balance 'horizontal' and 'vertical' transfer
- Follow an 'Optimal Adaptability Corridor'\(^1\)
- Adapt proven pedagogical strategies e.g.
  - Model Development followed by Model Deployment\(^2\)
  - Scaffolded learning in Zone of Proximal Development\(^3\)
- Emphasize multiple models
  - Sensitivity to activate appropriate model.

\(^1\) Schwartz, Bransford & Sears (2005)
\(^2\) Hestenes (1987)
\(^3\) Vygotsky (1978)
WHERE IS THE EVIDENCE THAT THIS MIGHT WORK?

'Microscopic Friction' Study
Research Question
How do students construct a model of microscopic friction when provided with appropriate instructional experiences?

What model??
- Friction is due to electrical interactions.
- Friction varies with roughness as shown:

Model Development
Feeling & Sketching of surfaces

Model Development
Feeling & Sketching of surfaces
Model Development

- Feeling & Sketching of surfaces
- Wooden Surface-Sandpaper
- Graphing of Friction vs. Surface Roughness

Model Deployment

- Feeling & Sketching of surfaces
- Wooden Surface-Sandpaper
- Graphing of Friction vs. Surface Roughness

Model Development

- ??COGNITIVE DISSONANCE??
  Can't explain observations with metal blocks using present model.
- Wooden Surface-Sandpaper
- Graphing of Friction vs. Surface Roughness

Model Development

- Sketching of Pair of Surfaces

Model Development

- Papers & Transparency
- Metal Blocks Activity
- Graphing of Friction vs. Surface Roughness
- Wooden Surface-Sandpaper
- Feeling & Sketching of surfaces

Model Development

- Revisit Graph
### Findings

- The metal block and transparency activities seem to facilitate students’ association of friction with increasing smoothness.

### Findings

- The scaffolding activities appeared to facilitate students’ development of a new model of microscopic friction.

### BUT…

**WHY DO WE NEED TO GO THROUGH ALL OF THIS?**

**CAN’T WE JUST TELL STUDENTS THE CORRECT MODEL?**

### What We Do

- **RESEARCH**
- **PILOT & FIELD TESTING**
- **CURRICULUM DEVELOPMENT**

### PILOT TESTING

#### Qualitative Evaluation (N=14)

<table>
<thead>
<tr>
<th>Physics Course</th>
<th>No. of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Semester Algebra-Based Physics</td>
<td>8</td>
</tr>
<tr>
<td>2nd Semester Algebra-Based Physics</td>
<td>4</td>
</tr>
<tr>
<td>Conceptual-Based Physics*</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Quantitative Evaluation (N=56)

<table>
<thead>
<tr>
<th>Physics Course</th>
<th>No. of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual-Based Physics*</td>
<td>56</td>
</tr>
</tbody>
</table>

* Elementary Educ. Majors: Very few have HS Physics
Qualitative Evaluation
- Small Group Activity
  - Recorded students’ model progression
    - open-ended questions
    - student discussion
  - Post-Activity Interviews with students
    - Feedback about activity

Qualitative Results
Individual Ideas Before Activities
Friction is a factor of weight and texture as I understand it. The smoother the object the less friction it will have. Water, oil, or other liquids can reduce friction by filling in small spaces to make a surface smoother. Friction is a force.

Qualitative Results
Individual Ideas After Activities
I’m surprised that smooth objects are so hard to move. But thinking about it on the atomic level, it makes sense that the more surface and close proximity of the atoms creates some friction too.

Qualitative Results
Group Consensus After Activities
Factors Affecting Friction:
- Texture, surface area, contact-bonding.

How each factor affect friction:
Textures that are rough physically grab, textures that are smooth may bond and will have greater surface area to interact.

Cause of friction at the atomic level:
Electrical Charges/ bond of close atoms

Quantitative Evaluation
- Pretest-posttest Control Group design
  - Control Group (N = 24)
    - Videotaped lecture (1 hour)
    - Same content as experimental group
    - Instructor doing activities
  - Experimental Group (N = 32)
    - Developed instructional material (1 hour)
- Multiple-choice Test

Quantitative Results
PRE-TEST & POST-TEST
CONTROL (N=24)
- 31%  ± 10%
- 69%  ± 10%
EXPERIMENTAL (N=32)
- 30%  ± 10%
- 47%  ± 10%
Quantitative Results

CONCLUSIONS

- 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 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.

THANK YOU