Research on Transfer of Learning & Implications for Instruction

Sanjay Rebello

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

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

What We Do

RESEARCH
PILOT & FIELD TESTING
CURRICULUM DEVELOPMENT

What is Transfer?

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

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

Research Question

How do students transfer their knowledge from one situation to a new situation?

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), Throndike (1906)
Example: Interview on Optic Fibers

From what I understand, it's a, it's almost a series of
reflections. … I'm pretty sure it's reflected light all
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-
lke, 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); dSessa & Wagner (2005);

Model of Transfer
(Basic View)

WORKING MEMORY

External Inputs

READ-OUT FILTER

Information in scenario

The nature of
knowledge to be
used in sense-
making

WORKING MEMORY

Epistemic Mode

LONG TERM MEMORY

Prior Knowledge

Epistemic Mode

Control

Primed

Activated

Prior Knowledge

Model of Transfer
(Complex View)

SENSORY FILTER

INPUT INFORMATION STREAM

‘WORKBENCH’

Read Out Input

Epistemic state,
motivation, emotion
and other variables

EXECUTIVE CONTROLLER

PRIOR KNOWLEDGE

ASSOCIATION

READ-OUT INFORMATION

EXECUTION CONTROLLER

PRIOR KNOWLEDGE

ASSOCIATION

INPUT INFORMATION STREAM

OUTPUT

ACTIVATION

Model of Transfer

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.

'Vertical'
- Constructing a new model to make sense of a situation.
- Association between knowledge elements to create model.

New knowledge elements incorporated in model, others are discarded.

Theoretical Framework

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

'Vertical' Transfer
- "Accommodation" of new experiences
- "Assimilation" of new experiences

Alignment with Others' Views

<table>
<thead>
<tr>
<th>'Horizontal'</th>
<th>'Vertical'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Road 1, Class C 2 Transfer</td>
<td>High Road 1, Class A 2 Transfer</td>
</tr>
<tr>
<td>Assimilation of new experiences 3</td>
<td>Accommodation of new experiences 3</td>
</tr>
<tr>
<td>Involves Deductive reasoning: 'Model Deployment' 4</td>
<td>Involves Inductive reasoning: 'Model Development' 4</td>
</tr>
<tr>
<td>Uses 'Applicative' knowledge 5</td>
<td>Uses 'Interpretive' knowledge 5</td>
</tr>
<tr>
<td>Focus on 'Efficiency' 6</td>
<td>Focus on 'Innovation' 6</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 9</td>
<td>Choosing, using and constructing multiple internal representations 9</td>
</tr>
</tbody>
</table>

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?

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

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.
**Research Question**

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

*Cui et al. (2005)*

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**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)

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**Research Plan**

- **Semi-structured Interviews**

  - **‘Horizontal’ Transfer**
    - Textbook-like Problems
  
  - **‘Vertical’ Transfer**
    - ‘Contrasting Cases’
    - ‘Jeopardy’ Problems

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**‘Contrasting Cases’**

Continuous vs. Discrete

When do you use integration in a problem?

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**‘Jeopardy’ Questions**

Construct a physical situation that is described by the following expression

\[
2 \times \int \left[ \frac{1}{2} \left( 8.99 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2 \right) \left( 2 \times 10^{-10} \text{ C} / \text{m} \right) \left( 5 \times 10^{-2} \text{ m} \right) \cos \theta \right] d\theta
\]

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**Student Interview Results**

- **Textbook-like Problems**
  - no difficulty in recalling the required calculus knowledge.
  - difficulty setting up the problem.

- **‘Contrasting Cases’**
  - used similarity of textbook problems to decide when to use integration.
  - had difficulty determining variables and limits of integration.

- **‘Jeopardy’ Problems**
  - 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.

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"I know how to integrate it, but it is just figuring out what to integrate, that is the hard part... which is really general... which is really general... but... I look for pieces of terms that I recognize... they will tell me 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."

"I am not confident if I set up the problem right or wrong... so many numbers and constants to take into account, I get confused, I lose the objective of what I am actually looking for... as soon as I set it up, there is no problem."
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.

Students told me that they even do not want to try...something I never understood myself, because that is the problem that you encounter in everyday life, but for some reason, translating a word problem into a mathematical problem is 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.

"Student...told me that I do not have enough background to actually know where they are generally used."

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

SUMMARY

'Horizontal' Transfer: Students have no difficulty recalling model to solve calculus problems. Difficulty mapping physics problem variables into model.

'Vertical' Transfer of knowledge: Students have difficulty deciding when to activate appropriate model. Difficulty in deconstructing model or constructing 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.

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

PILOT & FIELD TESTING

CURRICULUM DEVELOPMENT

Typical Methodology

Curriculum Design

Determine students' prior knowledge

Design interventions to change knowledge

Clinical Interviews

Curriculum Design & Development

Pilot- & Field-Testing

Alternative Methodology

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

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.

Engelhardt et al. (2004)
**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.
  - 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)

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**Modeling Cycle**

- Exploration
- Concept Construction
- Application
- Model Development
- Model Deployment

- Build new knowledge based on exploration, Hands-on & instructor guided.
- Make predictions.
- Hands-on.
- Activate prior knowledge.
- Apply newly knowledge in different contexts.
- Hands-on design tasks.

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**Another Representation…**

What we currently try to do…
- Mostly 'Horizontal'

What we should try to do…
- Mostly 'Vertical'

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**‘Microscopic Friction’ Study**

Students' Initial Model of Microscopic Friction

- Friction is due to mechanical interactions
  - meshing up of bumps and valleys
  - rubbing of atoms
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
Wooden Surface-Sandpaper
Graphing of Friction vs. Surface Roughness

Model Deployment

??COGNITIVE DISSONANCE??
Can't explain observations with metal blocks using present model.

Model Development

Graphing of Friction vs. Surface Roughness

Final Model

Wooden Block-Sandpaper Activity

Friction

Metal Blocks & Paper-Transparency Activity

Friction

Increasing Roughness

Increasing Smoothness

Revisit Graph.
Findings

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

BEFORE

- Increasing Friction
- Increasing Roughness

AFTER

- Increasing Friction
- Increasing Smoothness
- Increasing Roughness

Findings

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

BEFORE

- Increasing Friction
- Increasing Roughness

AFTER

- Decreasing 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>
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<tr>
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<tbody>
<tr>
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<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 / bonding of close atoms

Quantitative Evaluation

- Multiple-Choice Test
  - Students asked to make predictions in various situations

- Pretest-Posttest Control Group
  - 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)

Quantitative Results

PRE-TEST & POST-TEST

CONTROL (N=24)  EXPERIMENTAL (N=32)

% Correct Responses

PRE-TEST: 31% ± 15%  30% ± 10%
POST-TEST: 47% ± 12%  69% ± 9%

CONTROL vs. EXPERIMENTAL
(N = 24)  (N =32)

% Correct Responses

PRE-TEST: 16% ± 10%  39% ± 7%
POST-TEST: 21% ± 12%  55% ± 15%

* t-test: p value (Control vs. Experimental Gain) ≤ 0.0001 (two-tailed)
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 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.

THANK YOU