Teaching Effectiveness in Project-Based Settings: Bridges and Barriers to Building Conceptual Cohesion

THE UNIVERSITY of WISCONSIN MADISON

Candace A. Walkington, Mitchell J. Nathan, Matthew Wolfgram, Martha W. Alibali, and Rachaya Srisurichan

Presentation to ITP Seminar, Nov 4, 2011

This work was made possible through the financial support of the National Science Foundation (DRL-0816406)

My Background

- Mathematician and mathematics educator
- Work with pre-service and in-service teachers
- Led 3 large classroom observation studies (*N*=83, *N*=237, *N*=994) of teaching effectiveness in mathematics and science
- Developer of observation instrument used in recent Gates/MET study (Doug Staiger)
  - Focus on PCK in math & science teaching
- Work on “Tangibility” grant at U-W – teaching practices in high school engineering classes

“Those Who Understand” (Shulman, 1986)

- In this incredibly influential paper (5,733 references), Shulman introduced the idea of *pedagogical content knowledge* (PCK).
  - What is PCK?
  - Why is PCK an important idea when considering effective teaching?

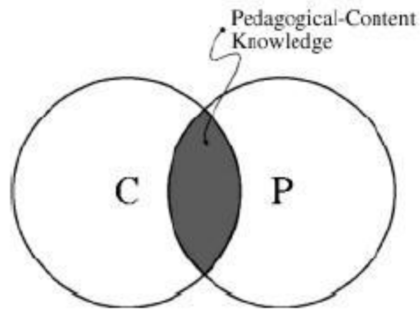


Figure 2. The Two Circles of Pedagogical Knowledge and Content Knowledge Are Now Joined by Pedagogical Content Knowledge.

Pedagogical Content Knowledge

- According to Shulman (1986), PCK or "subject matter knowledge for teaching" includes:
  - Most useful forms of representation of ideas
  - Most powerful examples & explanations
  - What makes learning topics easy or difficult
  - Preconceptions and misconceptions students bring with them to the classroom

Measuring Teaching Effectiveness

- **PCK** critical component of effective teaching – impacts student achievement (e.g., Hill, Rowan, & Ball, 2005)
- Efforts to evaluate teachers need to **look into classrooms**, examine how PCK arises during instruction, to inform policy and practice

Video: Principles of Engineering

- High school PLTW class (Principles Eng) participating in a project-based unit where they design, build, and test model bridges
- Teacher stops class from building to give short lecture on tension and compression
- "There's a problem I see with some of your bridges…"

Video: Principles of Engineering

- What does this teacher do well?
- How does this teacher demonstrate knowledge of his content area?
- How does this teacher show ***pedagogical content knowledge***?

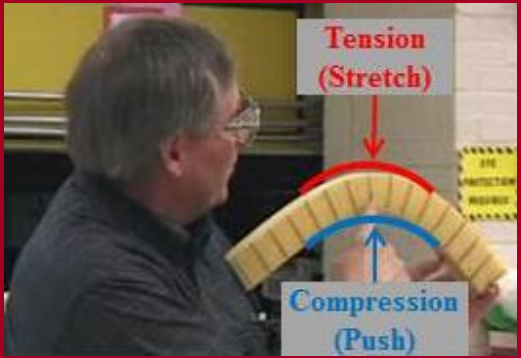
Video: Principles of Engineering

Video: Principles of Engineering

- What does this teacher do well?
- How does this teacher demonstrate knowledge of his content area?
- How does this teacher show ***pedagogical content knowledge***?

Video: Principles of Engineering

- Professional vision (Goodwin, 1994)
  - Sees that bridges will have "shear problem"
  - Encourages students to develop this skill
- Choice of representations
  - Foam block as pedagogical tool
  - Model bridge and gesture



- Explanation of concepts
  - Shear force and its relationship to T
  - Relationship between T & C in horizontal beam

Pre-College Engineering

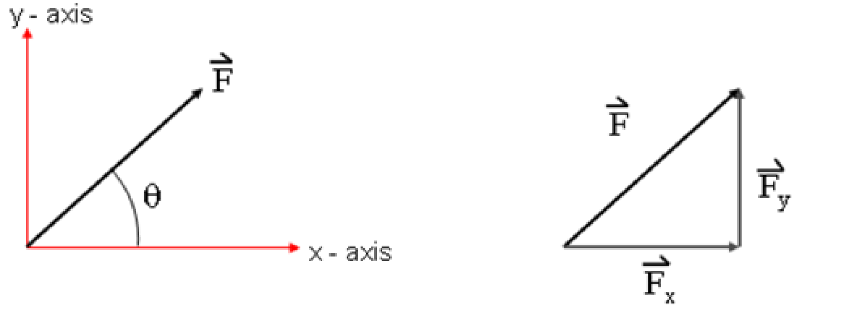
- How does participation in PLTW courses impact achievement in math & science?
  - Tran & Nathan, 2010: Slightly smaller gains in mathematics, no difference in gains in science
- Why aren't students exhibiting more math and science gains from these courses?
  - Lack of explicit integration, both in curriculum (Nathan et al., 2008; Prevost et al., 2009, 2010) and in ***classroom interactions***

What is the Mathematics and Science in the Bridge Project?

- Forces of tension and compression
  - Trigonometric Properties
  - Algebraic Equation Solving
  - Vector Addition

$\tan \theta = opp / adj$

$\theta = \tan^{-1}(opp / adj)$



- These concepts are often presented in abstract or decontextualized forms on standardized tests

Classroom Observation

- Classroom observation to examine how PCK is used for math & science integration
  - Understand "effective teaching" in these settings
  - Look for missed opportunities for integration
- **Can a skilled teacher weave mathematics and science concepts into engineering lessons?**
  - "Teachable moments"
  - Leverage PCK to improve achievement

Video: Principles of Engineering

Let’s look at this video again…

- Do you see any weaknesses in this episode?
- Do you think the integration of mathematics and science into this engineering lesson has been successfully carried out?
- What are some of the challenges for this integration?

Video: Principles of Engineering

Video: Principles of Engineering

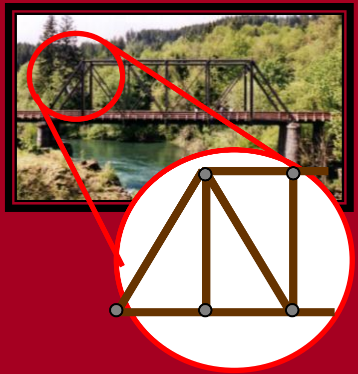
Let's look at this video again…

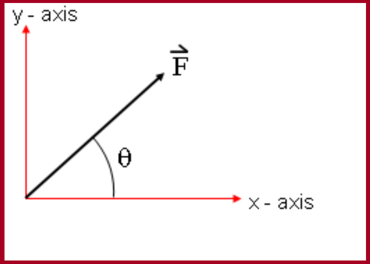
- Do you see any weaknesses in this episode?
- Do you think the integration of mathematics and science into this engineering lesson has been successfully carried out?
- What are some of the challenges for this integration?

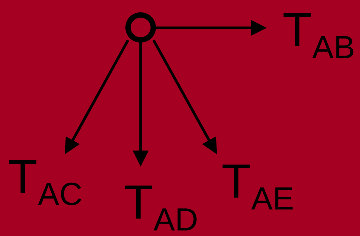
Video: Principles of Engineering

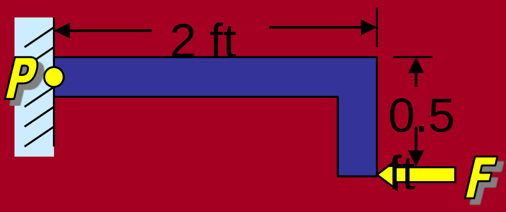
- **Direct instruction** – effective if learners *actively* construct knowledge (Schwartz & Bransford, 1998)
- **Little interaction** – how does teacher know if students understand explanation?
- **Complexity** of project-based environments makes learning math and science concepts difficult and precarious

Where are the Math and Science Concepts?

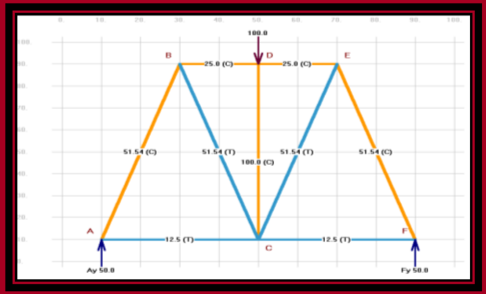








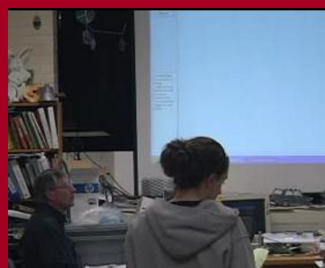
$F_x = F * \cos \theta$
$F = ma$
$\Sigma F_y = W + N$



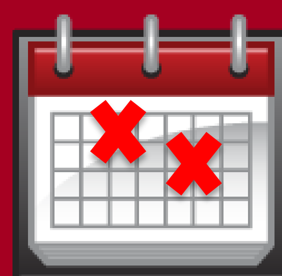
Where are the Math and Science Concepts?

Making Free-Body Diagrams

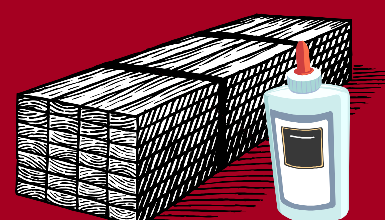
Using Bridge Modeling Software

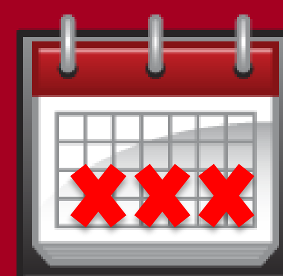


Lecture on Tension and Compression



Building Bridges with Raw Materials





Stressing Bridges with Weights

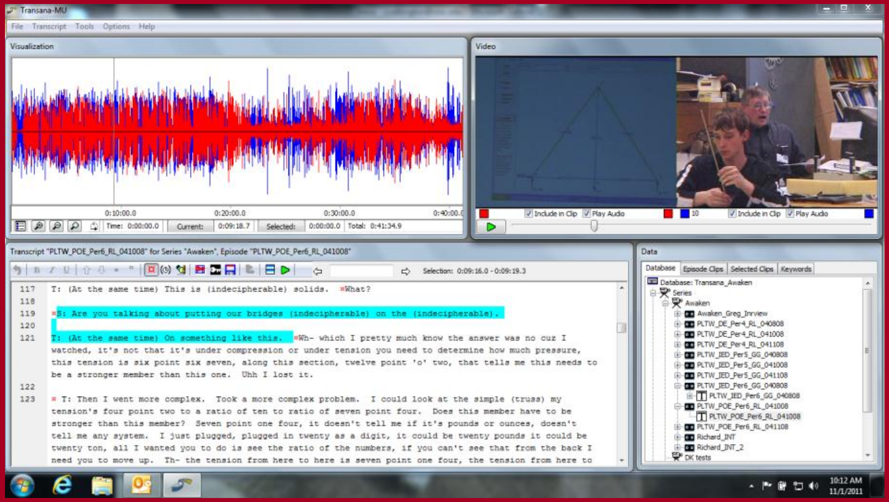
The Challenge

- In project-based classrooms, like pre-college engineering, formal math and science concepts are scattered across:
  - Different activities
  - Different time points
  - Different physical and social settings
  - Different tools and representations

- Often only ***implicitly*** realized (Nathan, Tran, Phelps & Prevost, 2008; Prevost et al., 2009, 2010)
- **How can an "effective" teacher use PCK to overcome these challenges?**

Methodology

- Video observations of students participating in 3 PLTW foundations courses (~30 class periods)
- Lessons divided into “clips” representing classroom activities and contexts (Transana)
- Clips coded for pedagogical moves of the teacher, and evidence of student learning



Cohesion Production

- Teachers do try to overcome these challenges
- Use pedagogical moves that promote ***cohesion*** of math & science concepts across the diverse representations, contexts, and events
  - An understanding how key concepts arise in different forms over the course of a project
  - “Seeing” the mathematical and scientific ideas that underlie each activity
  - Make connections

Cohesion Production

- We identified 3 key ways in which teachers can use PCK to produce cohesion:
  - Identification
  - Projection
  - Coordination

Cohesion Production

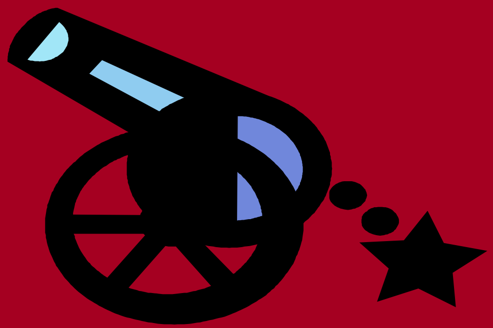
- We identified 3 key ways in which teachers can use PCK to produce cohesion:
  - **Identification**
  - Projection
  - Coordination

The teacher explicitly labels a **key concept** or **term** that is part of the current activity.

In this way, the teacher ***identifies*** the content for the students, making its presence explicit.

Cohesion Production

- We identified 3 key ways in which teachers can use PCK to produce cohesion:
  - Identification
  - **<u>Projection</u>**
  - Coordination

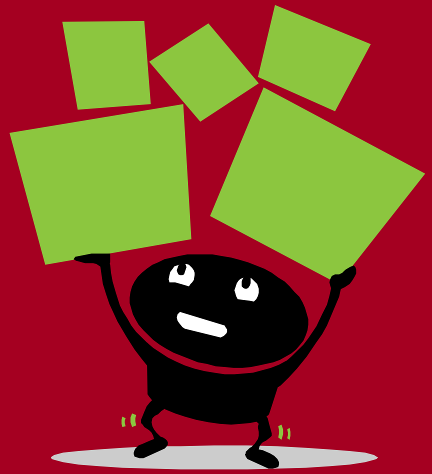


The teacher references a past or future activity, to show students how different parts of the unit sequence are related.

In this way, the teacher ***projects*** the math or science content backwards or forwards.

Cohesion Production

- We identified 3 key ways in which teachers can use PCK to produce cohesion:
  - Identification
  - Projection
  - **Coordination**



The teacher links one representation of the key concepts to another – for example, the teacher relates an equation to a sketch.

In this way, the teacher ***coordinates*** different representations of the math and science content.

Cohesion Production

Look at your transcript. Can you find:

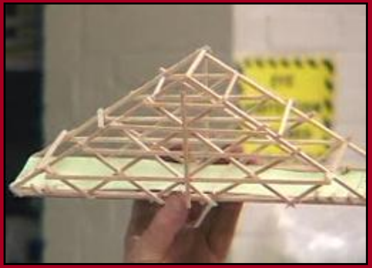
- Identification?
  - The teacher explicitly labels a **key concept** or **term** that is part of the current activity
- Projection?
  - The teacher references a **past/future activity**, to show relation bt different parts of lesson sequence
- Coordination?
  - The teacher **links or relates** one representation of a key concept to another

Cohesion Production

- **Identification**
  - The teacher uses the terms “tension,” “compression,” and “shear force,” and discusses how they are related

- **Projection**
  - The teacher projects backwards to computer simulation, and forwards to testing the bridges

- **Coordination**
  - The teacher relates the foam block to the model bridge



Summary: Clip 1

- Teacher uses ***PCK*** to foster ***cohesion*** of the key math and science concepts
  - Using identification, projection, coordination
- Unclear if these pedagogical moves are taken up by students
  - Cohesion must be ***co-produced***
- What are the implications for **student learning** of mathematics and science?

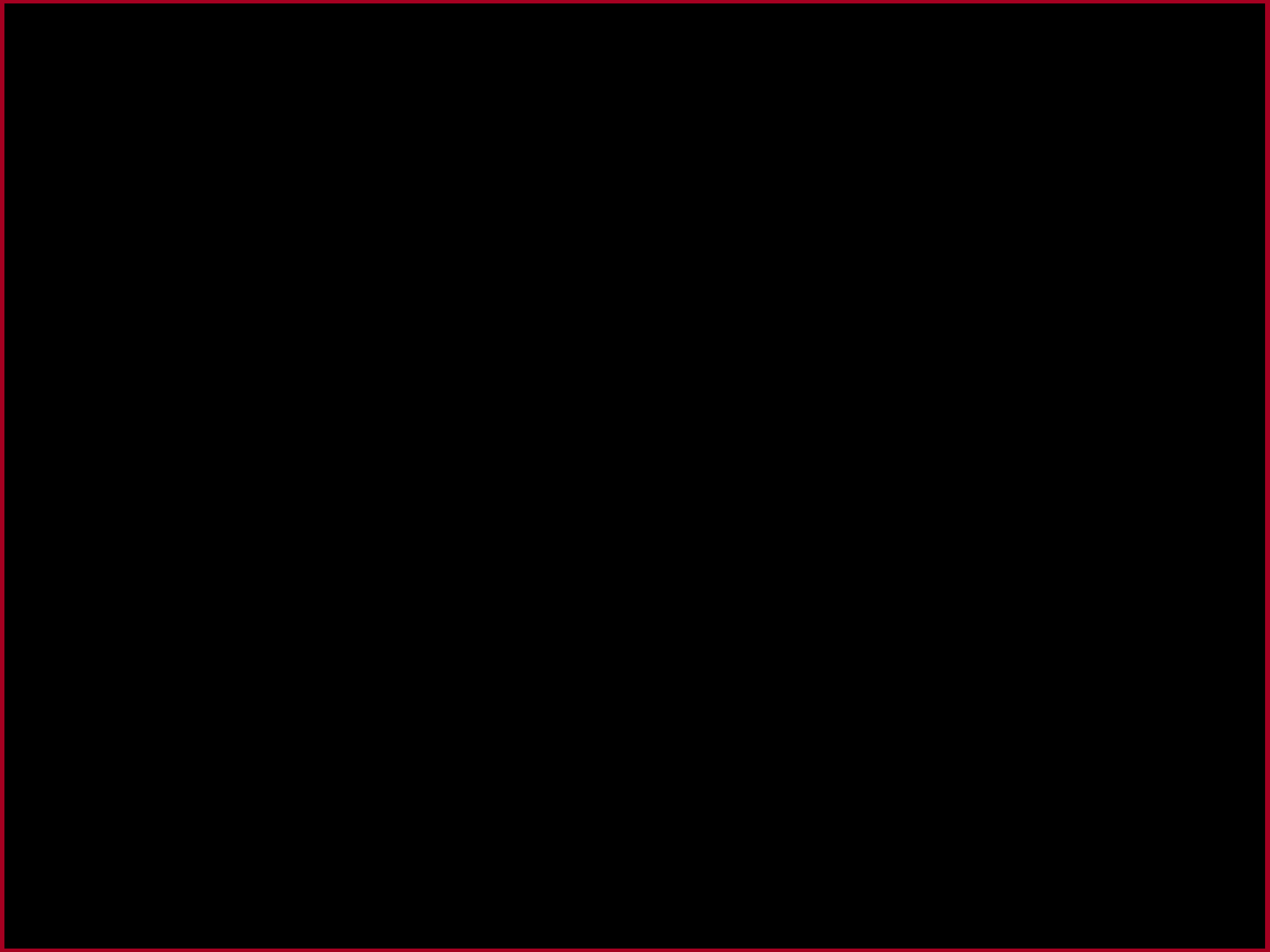
Bridge Testing – Clip 2

- Students are testing their bridges by stressing them with weights
- First group is about to test their bridge
- Bridge has a piece of paper lying flat on top of its base – elicits discussion

Bridge Testing – Clip 2

- Do you see the teacher using ***identification***, ***projection***, or ***coordination***?
- Does the teacher seem to be successful in establishing ***cohesion*** of the mathematics and science concepts for students? Why or why not?

Bridge Testing – Clip 2



Bridge Testing – Clip 2

- Do you see the teacher using ***identification***, ***projection***, or ***coordination***?
- Does the teacher seem to be successful in establishing ***cohesion*** of the mathematics and science concepts for students? Why or why not?

Bridge Testing – Clip 2

- **Identifies** key concepts (T & C) during a "teachable moment"
- **Backwards projection** to lecture – brief, does not re-invoke action or explanation
- **Downwards force = compression** is weak criterion for understanding concept
- **Cohesion** not clearly established: *"I was thinking that it would be under tension"*

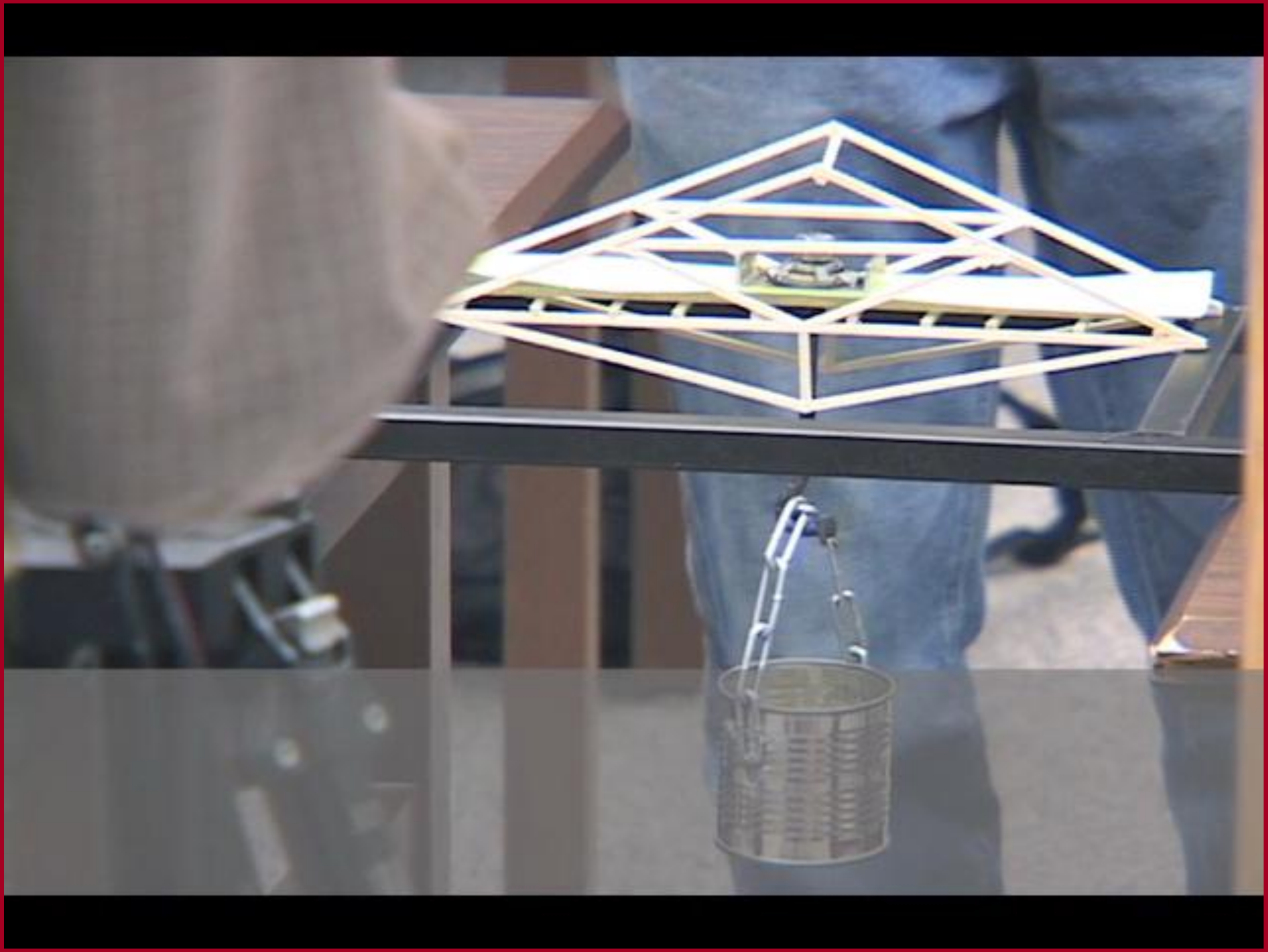
Bridge Testing – Clip 3

- Immediately after previous clip
- Students have begun loading weights on first model bridge
- Teacher asks for **prediction**:
  - *"Can you see what's going to happen to your bridge? An engineer has to have vision."*

Bridge Testing – Clip 3

- Do you see the teacher using ***identification***, ***projection***, or ***coordination***?
- Does the teacher seem to be successful in establishing ***cohesion*** of the mathematics and science concepts for students? Why or why not?

Bridge Testing – Clip 3



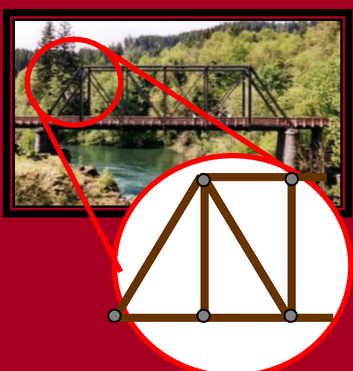
Bridge Testing – Clip 3

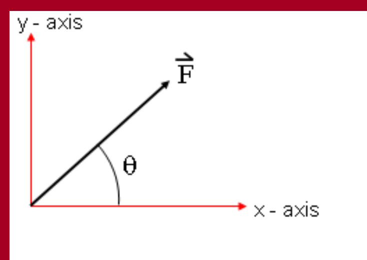
- Do you see the teacher using ***identification***, ***projection***, or ***coordination***?
- Does the teacher seem to be successful in establishing ***cohesion*** of the mathematics and science concepts for students? Why or why not?

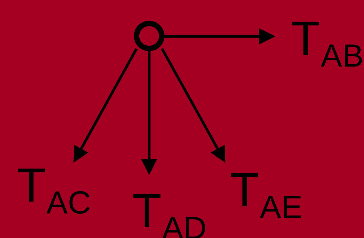
Bridge Testing – Clip 3

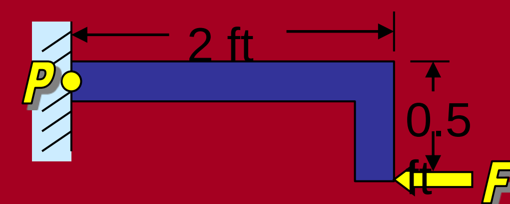
- Students give non-scientific predictions, focused on **current representation** (“gonna break,” “gonna snap,” hold half, fail at center)

Where Is the Mathematics?

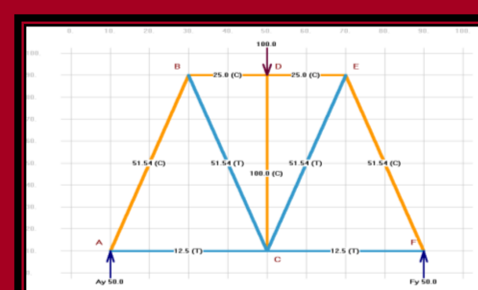








$F_x = F * \cos \theta$
$F = ma$
$\Sigma Fy = W + N$



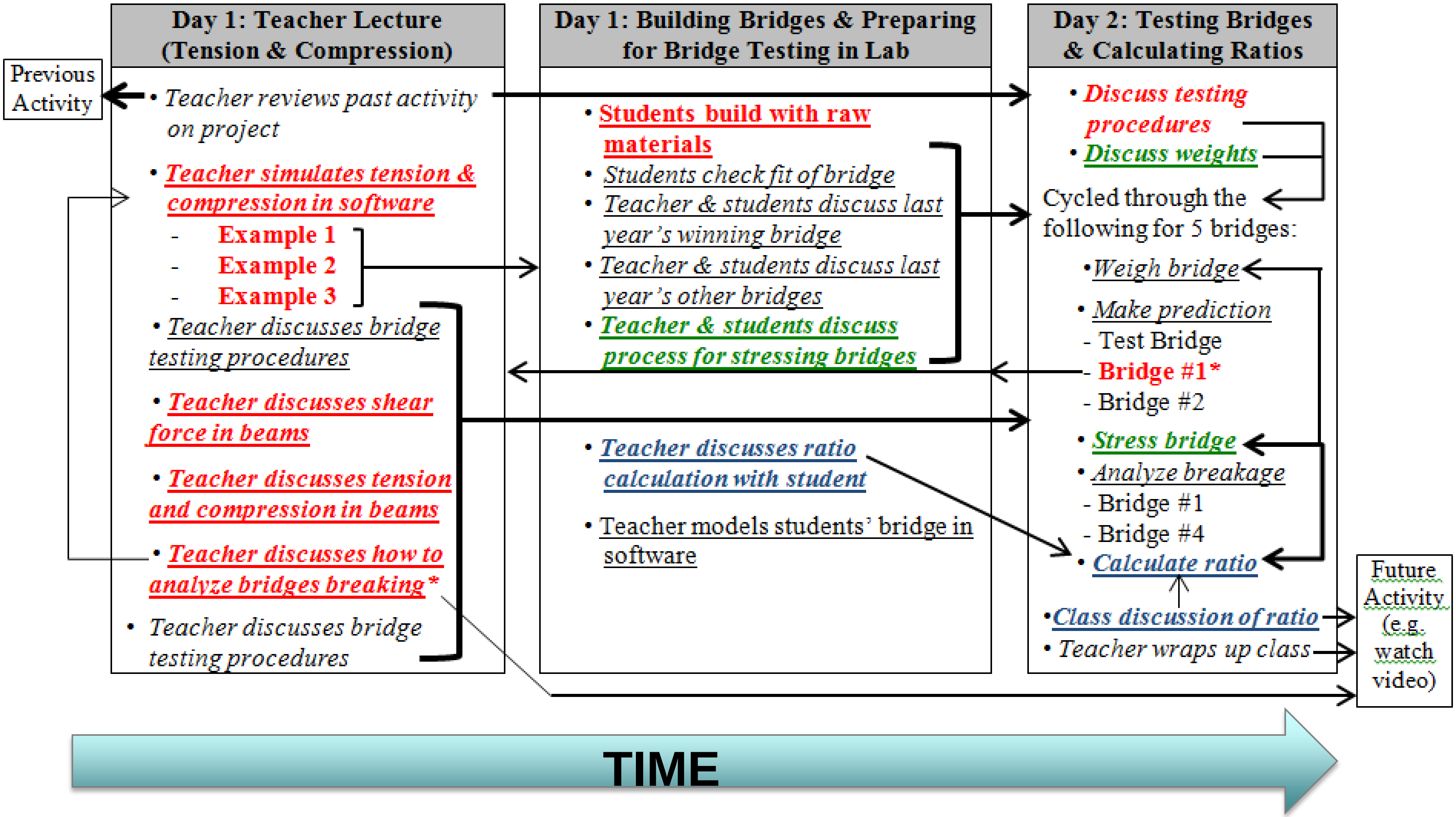
Bridge Testing – Clip 3

- Students give non-scientific predictions, focused on **current representation** (gonna break, gonna snap, hold half, fail at center)
- Teacher **identifies** key concepts (T & C)
- One student takes up this move
  - *“We designed it so it would compress…”*
- **Cohesion** not well-established
  - *“What do we get if we win?”*

Analysis of Bridge Unit

- Missed opportunities for cohesion production during critical "**teachable moments**" in the unit
- Also look on a macro-level at how teacher and students connect different parts of the unit using **identification**, **projection**, and **coordination**
- "Map out" all project activities, and see what connections are made, and where opportunities for **cohesion** are missed

Bridge Building Case



Arrows show **Projection**

Colors show **Identification** (**red = tension & compression**)

Underlines show **Coordination**

Overview of Unit

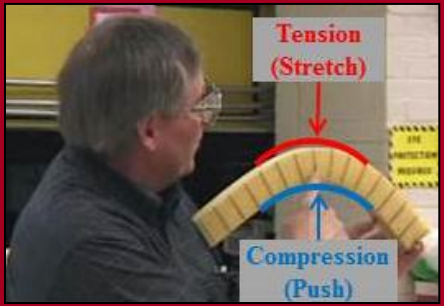
- Students and teacher orient themselves towards motivating capstone events – 56% of projections
  - Bridges breaking
  - Calculating strength-weight ratio to determine winner
- Few projections to earlier, more abstract content
  - Equations, diagrams
  - Valued on standardized tests of achievement
- As bridge testing proceeds, the math and science concepts of tension and compression are not identified again

Discussion

- Technical education courses, like PLTW, may not always promote achievement on standardized math and science assessments
- ***Complexity*** of project-based environments makes establishing ***cohesion*** of core concepts challenging
- Students have a tendency to focus on **concrete forms**, **competition**, and **exciting capstone events**

Discussion

- Teachers must actively involve students in ***cohesion production***
  - ***Identification, Projection, & Coordination***
- Teachers must identify & take advantage of ***teachable moments*** for integration
- These moves all involve application of **PCK** – integration does not happen "naturally"

Limitations

- Believe cohesion-producing behaviors effective for math/science learning, but needs **empirical verification**
- In future work, camera following the students to look for **evidence of learning**
- Standardized classroom observation instruments can link teaching behaviors to teacher valued-added (**MET study**)
  - Connections made by teacher

Implications

- Importance of **classroom observation** for measuring teacher effectiveness
  - How **teacher knowledge** is used during instruction to promote student learning
  - Missed opportunities and "teachable moments"
  - Witness **instances of learning** beyond what's measured on standardized assessments
  - Generate **new** questions and hypotheses

Implications

- **Classroom observations** offer **rich** and **generative** view of teaching - inform professional development, curriculum design, and policy
  – Train teachers to look beyond "expert blind spot," promote **reflection** & **integration**
  – Design curricula that promote and support outcomes valued on assessments
  – Evaluate teachers in a way that provides quality feedback – build and develop **PCK**

Implications

Value-added measures, used in isolation, are a "**black box**" that does little to help us understand or improve teaching and learning

To understand effective teaching and its impact on student achievement, we need to **look into our classrooms**

Thank You!