Our quest for control and certainty in the classroom can sometimes masquerade as intellectual rigor. The truth is, thinking critically and independently requires risk-taking. Finding acceptable ways to “exploit error” and to “manage correctness” will be key. This session models what we can do to bring students into messy “inquiry” processes without ignoring valuable traditions of formal knowledge.
True or False?

“My research is too advanced and technical for my undergraduate students to participate in meaningfully.”
“My research is too advanced and technical for my undergraduate students to participate in meaningfully.”

1. It’s true to say that beginners (on average) will have trouble with advanced research (and publishing), based on lack of sufficient knowledge.

2. It’s false to say that the type of thinking used to carry out advanced research is unattainable for a beginner.
What’s it like to be a beginner?

If you have a background in or recent familiarity with physics or geology, please take the role of silent observer in the next discussion.
Revisiting the old karate problem

A karate expert hits downward with his bare hand on a stack of 3 two-inch thick solid concrete blocks supported at both ends.

Describe the physical process of what happens to the blocks. (i.e.: Envision the breakage in extreme slow motion: precisely where does it begin; how and why?)

*If you have a background in physics, please take the role of silent observer of your group’s conversation*
Here are 4 of the concepts that may be related to this problem. Incorporate any of these terms that seem useful into your prediction and description.

- Tensile stress (like pulling on a wire from both ends)
- Compressive stress (like putting weight or force on something)
- Shear stress (putting pressure on an object in opposing directions: the pressure exerted by scissors in cutting paper)
- Elasticity (an object’s capacity to return to its original shape after receiving stress)
Characterize the conversation your group experienced when working on the first version of the problem.

What happened in the second conversation, when you were asked to revisit your prediction using the formal concepts?
What I did...

1. Converted a procedural application question (“Explain how these 3 kinds of stress are involved in breaking a concrete block”)... 

...to an inquiry (thought experiment): “What would happen, how and why?”

Authentic inquiry: Student is asked to “set” the problem, judging which factors are likely to be relevant, and what information is missing or has to be assumed.
Setting the problem...
(deciding what to include and exclude in the inquiry)

...is the cornerstone of knowledge-making in any discipline.

(e.g., Literature: which imagery should we focus on? Which details of the story will be relevant to a good interpretation?)

(e.g., sociology: which data or combination of data can be used to reveal significant patterns of behavior)
What I did (part 2)

1. Converted a procedural question to an inquiry question

2. Asked you to translate your analysis into more precise scientific language

Compare “normal” teaching practice: vocabulary is provided first, then applied procedurally like peanut butter on bread
The Inquiry Model

Question
How do stacked hard objects break when put under stress?

Data
We see the blocks breaking

Significance
extractable concepts and principles
The Inquiry Model

Question ← ————— ————— ————— ————— ————— Data ← ————— ————— ————— ————— ————— Significance

“Procedural instruction” short-circuits the brain’s knowledge-making process by omitting Question and Data stages of knowledge-making.

e.g.,

“Here are 3 types of stress involved in breaking cookies. Now explain how it works with blocks.”

“Here is a definition of X. Remember this for future use.”
Inquiry made simple

Question <--------> data <--------> significance

Inquiry can take place anywhere, in any direction by isolating any of these and asking students to work toward the others.

- What data will be generated to answer X question?
- What does this raw data signify?
- What does this representation of data signify?
- What question generated this data?
- What new questions are generated by this significance?
- What kinds of data might have been used to generate this significance?
Learning through inquiry is **knowledge making**…

**For beginners:** (re)making knowledge for myself that others have already made

**For experts:** making new knowledge for the discipline
Inquiry’s essential tool: ERROR

Manufactured error
(used by teachers to make grades)

Vs

Authentic error
(used by experts to make knowledge)
Manufactured error = failure to replicate pre-ordained correctness

- Learner’s information does not match the teacher’s
- Discrepancies in information have no value to learner

Student responses:
- I gave the wrong answer, so either I’m clueless as to what you’re looking for, or you tricked me.
- You say my answer is not correct. What’s the right one, professor?

Judgment and evaluation are professor’s responsibility
**Authentic error** = resulting from a quest to understand

Student: *my thinking on this question was not confirmed by observation, experiment, reading, analysis or calculation*

Questions emerging from authentic error:
- What went wrong?
- I wonder why...?
- What might I try now?
- How will I “learn my way out” of this dead-end?

Student is responsible for judgment and evaluation.
Perceived *risk of error* is the intellectual *and* emotional key to learning to think in the discipline

Risk of Discovery (Joyful risk) associated with authentic trial and error:

*I’m taking a risk in order to know more; my errors are interesting, and lead me to more questions. If I’m wrong, let me try it again with new tools and more information.*

Risk of Incorrectnessness (Fearful risk) associated with error as “mistake” (manufactured error):

*I’m risking an answer because I am forced to, but my mistakes terrorize me because I will feel inadequate or cheated if I’m not right.*
How do we change the culture of fearful risk to that of joyful risk?
Inversion of the learning sequence introduces needed risk

Traditional classroom:
Decisions and judgments are encouraged only after receiving "ample" information. Speculation and Guessing are discouraged.

Critical thinking classroom:
Decisions and judgments (guesses and hypotheses) are forced prematurely, creating frustration and the need for information

(Ignorance is not only an opportunity...it is a necessity)
Critical Thinking develops through **productive frustration** that results from having tried to do something.

Why didn’t my web catch that child?
Why won’t this peg fit in this hole?
Why don’t these chemicals interact the way I expected?
Why didn’t you understand what I just said in French?
Why doesn’t my solution seem believable (even to myself)?
Why is the author telling this story in such a confusing way?
Why doesn’t the professor just tell us the answer?
Productive Frustration is created through **staged** inquiry

The role of the instructor is to “stage” (frame and structure) opportunities in which students struggle to develop “original” solutions.

“Stage”: **AS IF** this problem has never been solved before

“Original”: **AS IF** no one has ever had this idea before
A common type of “staged inquiry”

Prediction of Data

What data will be generated in answering question X?
Question X

How do children go about solving problems?

If you have a formal background in elementary education or cognitive development in children, please take the role of observer in the following discussion.
The case of the “neo-scientists”

(Inhelder & Karmiloff-Smith *Cognition* 3,3 195-212)
The case of the “neo-scientists”

60 Children: ages 6, 7, 8

Task: Children are asked to balance numerous wooden blocks of various shapes on a fixed, rigid, narrow, horizontal, metal bar set just above the floor.

Special conditions:
- some of the blocks are just plain blocks;
- others are conspicuously weighted off-center (i.e. with a weight attached to one side);
- others are weighted off-center, but not conspicuously (i.e. with a weight hidden inside the block)
What do you think will happen?

Work in teams at your table.

Estimate success/failure rates for the children and be prepared to justify your predictions.

Be sure to indicate whether your estimates apply to the entire group of children, or to any subsets you think are relevant in the outcomes.
2. Predict what you think the children’s “process” to balance blocks will be. In your prediction draw a **flow chart** showing the **physical and mental steps** of this process.
Work in groups.

You are no longer the participants in the discussion of the case. You are now observers visiting this workshop.

Describe what just happened:
◆ What did the facilitator ask participants to do?
◆ How did the participants respond?
◆ Describe and characterize the interaction among participants in the groups.
The essential role of Incomplete Information

- invites curiosity and inquiry, like a puzzle
- activates productive frustration
- forces students to “set” the problem and decide how to proceed
- forces judgments that make assumptions visible
- allows for assessment of the thinking process.
…and finally:

Limiting information allows the activity to focus on concepts rather than on “answers.”
An expert is...

...someone who is paid to give a complete explanation of reality, but never has enough information to do so.

If you have “enough information” to solve a problem, you may not really need an expert to help you.
Difficulty:

Teaching through “gaps” in information makes students (and instructors) uncomfortable!!!

Students say,

“If the professor does not tell me the answers, she’s not doing her job!!!”

“I don’t like it when the professor answers my question with another question.”

“Your test was tricky (=unfair) !!!”

(See William Perry’s Scheme of Ethical and Intellectual Development)
Time to present your predictions.
Back to the case of the “neo-scientists”

1. Estimate success/failure rates for the children and be prepared to justify your predictions. Indicate whether your estimates apply to the entire group of children, or to subsets.

2. Predict what you think the children’s “process” to balance blocks will look like. In your prediction, list the physical and mental steps of this process, or draw a flow chart.
Meta-moment

What I did to “problematize” the psychology content

- Removed the data (i.e. the results of the research were stripped from the research question)
- Asked participants to predict data (success rates)
- Asked participants to detail and give reasons for their prediction (flow chart)
Results of the experiment (FINALLY!!!)

1. Children all began by balancing blocks at their geometric center

2. When this failed, they placed blocks more and more precisely and systematically at their geometric center

3. They were surprised when this didn’t work

4. Younger children (6yrs) continued the same pattern, finally declaring the project impossible
Results (cont.)

Older children (7-8)

– Began to de-center the blocks, beginning with conspicuously weighted blocks

– Gradually and \textit{reluctantly} began to make corrections on inconspicuously weighted blocks

– Took more time balancing the inconspicuously weighted blocks

– Finally, started \textit{pausing before} each item, roughly assessing its weight distribution by lifting it, then placed the block at the point of balance without attempting to balance it at the geometric center at all
The Good News

Children naturally use the scientific method!

Question under exploration: where do blocks balance?

Hypothesis at work = all blocks balance at the geometric center
Trial = gather data to test hypothesis
Error or Success = data generated
New trial = statement of new or revised hypothesis
etc.

Surprises caused by unexpected data lead to revision of hypotheses (critical thinking!!!), even at a very young age.
The Bad News

- Complete beginners lack perseverance and flexibility—are easily frustrated.

- New “theories in action” (Schon) are only *reluctantly* adopted by “future experts” even in the face of clear evidence.
The Really Bad news

We don’t need to teach students scientific thinking...

...BUT...many common educational practices succeed in de-activating (de-motivating) this instinct by providing too much information too early, and too few opportunities to fail without punishment (i.e. with purely formative feedback).
The Scientific Method is the codified process of making knowledge by extracting value from error and failure

1. Observe and Question
2. Make a hypothesis or prediction
3. Collect data, test, observe more closely, study
4. Reflect, consider alternate theories, revise hypothesis/prediction
5. Repeat as needed

Error/Failure $\rightarrow$ valuable data has been collected
Error/Failure $\neq$ lack of success
As university instructors we are trying to “stage” the Scientific Method for students (NO MATTER THE DISCIPLINE)

This means:
We provide a framework (stage) in which students must struggle to make decisions BEFORE they are given sufficient information to “determine” correct answers
What all good experts do…

Formulate questions and statements (hypotheses) to determine a direction for research

Attempt to predict the data (via hypothesis) that will be collected (“thought experiments”)

Make “educated guesses” about significance based on limited, minimal or even no data

Speculate, estimate, “guesstimate” and imagine….
What we really want our beginners to be:

The “Neo-Expert” ...

...is allowed to think “like an expert” in the discipline, even when coping with inadequate technical knowledge and experience

...floats solutions to see how they sound, and tests them by studying, imagining, or collecting more data

...is motivated to persevere, even through inevitable early set-backs and errors
“We do not need competency skills for this life. We need *in*competency skills, the skills of being effective beginners.”

Peter Vaill, Learning as a Way of Being

When do we ever stop being beginners?
Next up...

Mastering the Interactive Lecture

(Don’t Let Tradition Stop Student Thinking)