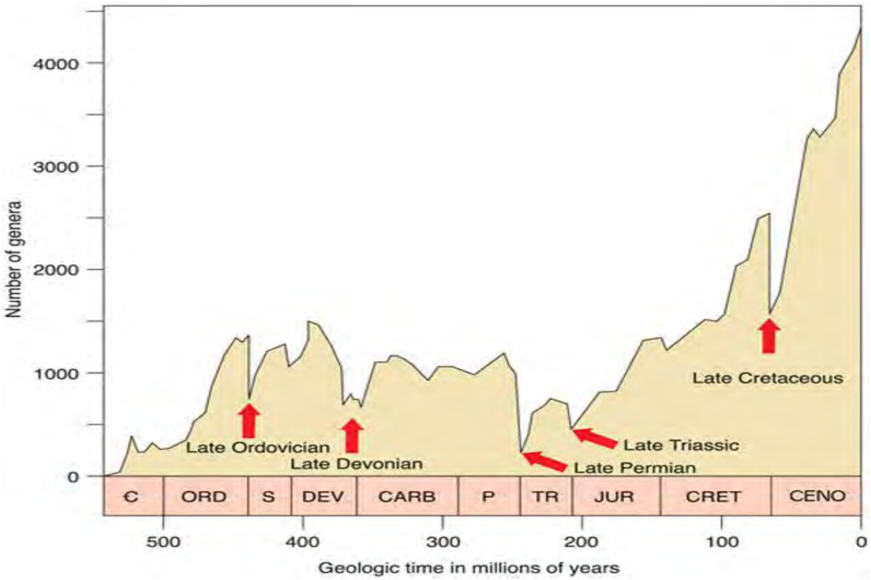
Teaching the nature of scientific (and geologic) knowledge through a "critical thinking" course on geologic time



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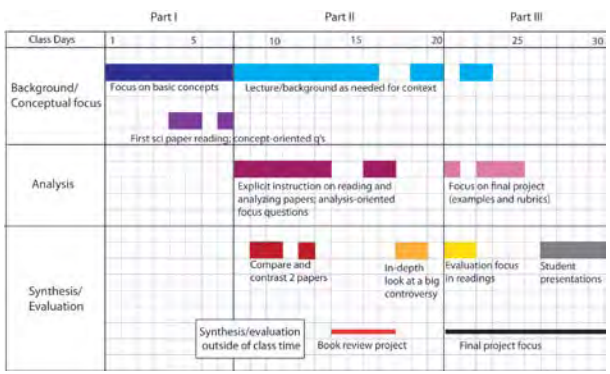
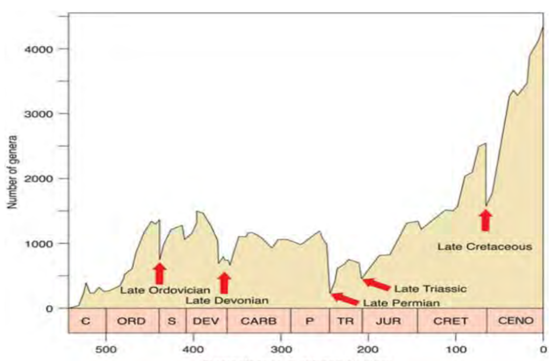
This study focuses on how competence reading primary literature relates to geologic expertise.

Linking critical thinking, the nature of scientific knowledge, and geologic time



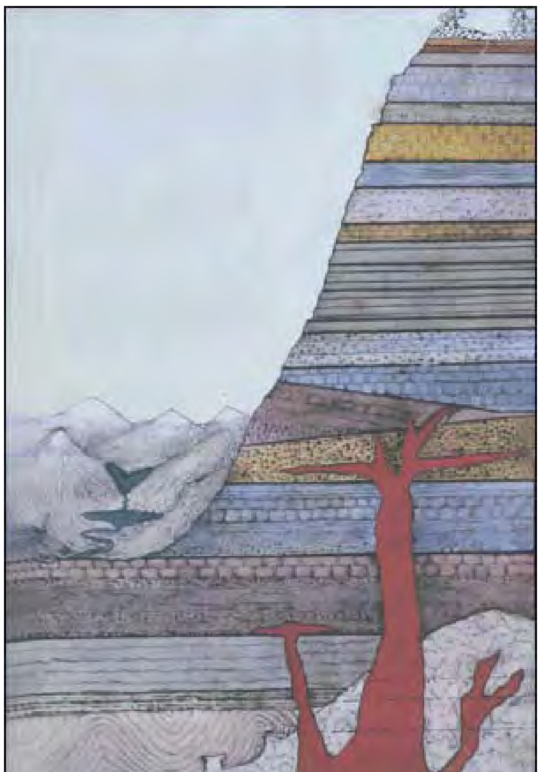
Course implementation



Student experiences, implications for instruction

The essence of critical thinking is the ability to evaluate claims.

Critical thinking is an common educational goal at all levels.



Understanding geologic time is a key aspect of geologic expertise.

Age constraints allow evaluation of claims regarding mechanisms for geologic events and phenomena.

Goal: teach critical and geologic thinking through age constraints on events/phenomena in Earth history.

The people:

Assistant Professor
Becky Flowers
(Tectonics, thermochronology, geochronology)

Post-doc researcher in Geoscience Education
Andrea Bair
(Paleontology, biostratigraphy, geocognition)

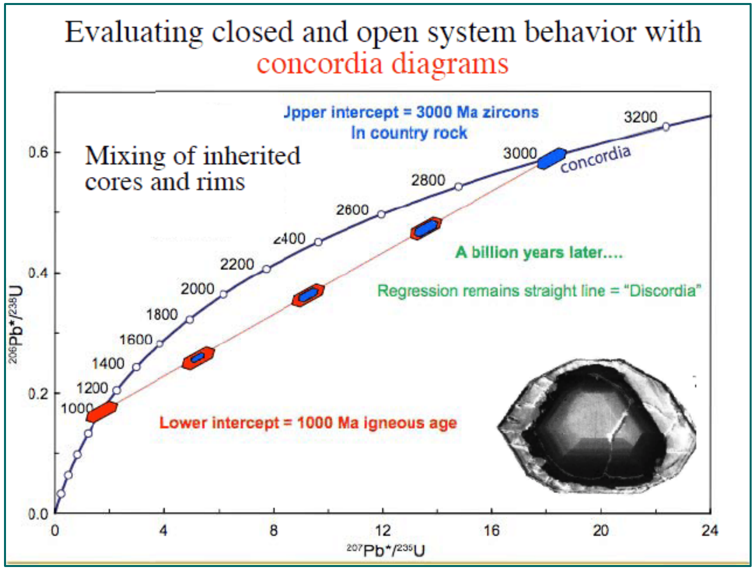
The goal:

Students participate in scientific discourse and practice by synthesizing a body of work and evaluating claims.

Focus on controversial topics:
Permo-Triassic mass extinction
Snowball earth glaciations
Grand Canyon formation

The model:

Graduate level seminar course, with more content scaffolding



Not sufficient scaffolding!

The reality check:

<u>(From pre-semester survey; in-class discussions)</u>

-Mostly geology majors, but not all

-Widely varying backgrounds

-Consistent: little experience and lack of confidence reading papers

-Focus on claims as correct or incorrect (absolutist view dominant)

-Absolute age of event known or unknown (not constrained)

<u>Two of Sandoval's (2005) four "epistemological themes":</u>

Scientific knowledge is constructed – not "out there in the world" to be discovered

Scientific knowledge varies in certainty

Focus scaffolding on aspects of scientific knowledge and practice:
-Science as an activity to construct knowledge
-Scientific knowledge is tentative (but can be evaluated)
-Primary literature is how ideas are exchanged and evolve

Implementation strategies:

1. Careful choice of appropriate topics and papers.
2. Explicit instruction and practice in reading papers critically.
3. Focus on deep understanding of one main geochronologic technique (U-Pb analysis of zircons).
4. “Contrasting cases” approach.
5. 15 assigned papers (practice with reading, writing, analysis).
6. “Staged”, thesis-focused, final synthetic research project.

Common student difficulty is picking out important points from irrelevant details.

No one gave us guidance on reading scientific papers, and we wish they had!

Explicit instruction on our suggestions for HOW to read papers and WHAT to focus on.

"Focus questions" required for most readings.

Focus questions – In general, you should keep these questions in mind to help you critically read papers:

What are the main questions the study is trying to address?

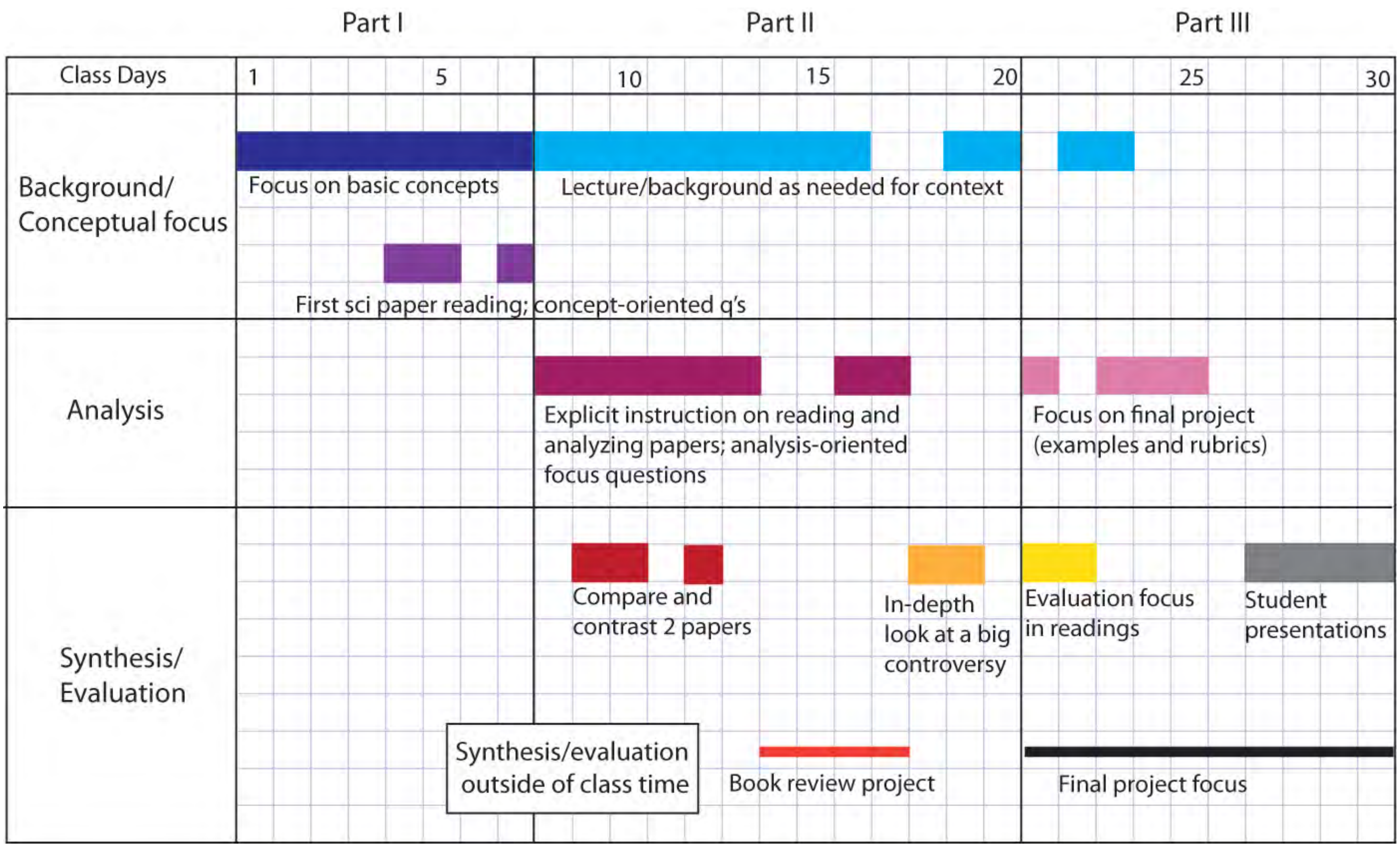
What are the methods used?

What are the results (what are the data generated from the methods?)

What are the conclusions/interpretations the authors are making from the results?

Do the data (results) support the conclusions (as best as you can assess)?

Instruction and assessment grouped as *background*, *analysis*, and *synthesis/evaluation*.



We made extensive use of models, examples, and rubrics.

In-class activity: headward erosion

Case study activity: How can we date when (and at what rate) the Niagara River carved its modern canyon?

Purpose: Evaluate a simple model of knickpoint migration/headward erosion with ages for fossil clams formerly living in the channel by determining 1) location of the knickpoint at different times and 2) the rate of headward erosion of the knickpoint

Prospectus rubric

Rubric for research prospectus

Instructions: CIRCLE the point value you feel is appropriate fo

Question/dimension	Exemplary
1. Statement of problem/question to be addressed	There is a clear, single problem/question stated. Concise and clear statement of a single problem/question to be addressed (1-2 sentences in the text, also stated in title). **6 pts**
The problem/question to be addressed is:	
2. Statements of how problem/question is SIGNIFICANT and PROBLEMATIC a. SIGNIFICANCE	There is a clear statement of WHY the problem/question is significant. **3 pts**
The significance of the problem/question is:	
b. PROBLEMATIC	There is a clear statement of WHY the problem/question is problematic. **3 pts**
The problem/question is problematic (or unknown, or poor	

Example research prospectus

Geology 4500 – Critical Thinking in Earth Sciences

Research prospectus 2

Paper title: Timing and causes of the late Pleistocene megafaunal extinction in Australia

Across the world, many large terrestrial animals (>44kg) became extinct during the late Pleistocene (~50,000 to 10,000 years before present). Historically, two end-member causes of this extinction are proposed: climate change, and human influence (both direct through hunting, and indirect through environmental change.) It is challenging and controversial determining which of these causes, or their combination, and what mechanisms acted to kill off megafauna preferentially. Is the cause of this pattern similar among the different continents? If so, it could provide a powerful natural experiment for understanding patterns and processes driving evolution and extinction of large terrestrial organisms. Knowledge of past climatic and human influences on extinction is of particular interest in contextualizing current and future human and climatic impacts on organisms.

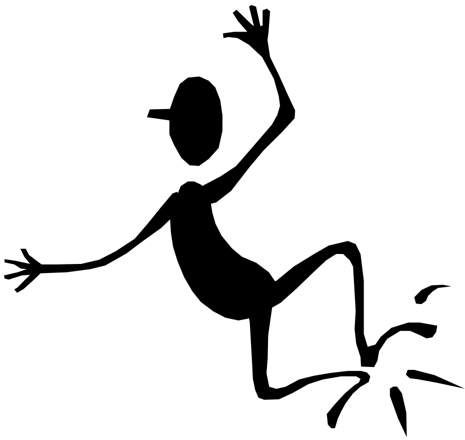
Sorting out causes first involves establishing reliable chronologies of 1) appearance of modern *Homo sapiens* on the continent, and 2) last appearance of megafaunal species. The timing of the megafaunal extinction event in Australia has been challenging to establish, as has any consensus on likely causes, because reliable and comprehensive chronologies have been lacking. For Australia, it has proven particularly difficult to constrain ages because the critical time period is just beyond the range of conventional radiocarbon dating of ~35,000 to ~50,000 years. Recent work has sought to clarify timing using Accelerator Mass Spectrometer (AMS) dating of carbon and U-series techniques.

Two recent review papers set the context. Barnosky et al. (2004) review pertinent literature on the timing and potential causes of the megafaunal extinction on the different continents, identify major challenges in each case, and recommend future directions for productive research. Rather than focusing on the state of the evidence, Koch and Barnosky (2006) review the plethora of proposed extinction mechanisms.

We assessed student learning and views through surveys, interviews, qualitative analysis of student work, and observations on in-class discussions.

<u>Before:</u>
-Little experience and lack of confidence reading papers.
-Absolute age of event known or unknown (not constrained).
-Focus on claims as correct or incorrect (absolutist view dominant).

<u>After:</u>



What is the most valuable thing you learned in this course?

ALL students responded their *<u>improved confidence</u>* (and in many cases *<u>competence</u>*) in reading papers was most valuable!

<u>Interview</u>: " I use the focus questions from this course every time I read a scientific paper now."

Practice READING papers first seems to help students WRITE effectively about them later on.

Before:

-Little experience and lack of confidence reading papers.

-Absolute age of event known or unknown (not constrained).

-Focus on claims as correct or incorrect (absolutist view dominant).

After:

What about implementation helped? (identified by students)

- Repetition: read many papers, a routine for doing so in the course
- Guided by “reading questions”: designed to help identify major components of paper and analyze it
- Peer discussion on paper and reading questions in class: improved, deeper understanding (“stuff other people picked up that I didn’t”)

Two of Sandoval's (2005) four "epistemological themes":

Scientific knowledge is constructed – not "out there in the world" to be discovered.

Before:
-Absolute age of event *known* or *unknown* (not constrained).
Ex: "You can't know the age of faults."

After:
Students discuss *constraints*; some recognize that *knowledge is negotiated* (argumentation important)***

Scientific knowledge varies in certainty.

Before:
-Focus on claims as *correct* or *incorrect* (absolutist view dominant).
Ex: "But who is right?"

After:
(More) students focused on evaluation of claims within context.
Ex: "Is this technique widely accepted?"

Social aspect of research practice and development of scientific knowledge appreciated.

Conclusion: what is the duration of the PETM?

Farley and Eltgroth → ~120 kyr

Röhl et al. → ~170 kyr

Guisberti et al. → ~231 kyr

Three time intervals with no solution

Need a consistent means of measuring global event

Should confirm data with multiple types of sites globally.

Conclusions:

There is no one unifying theory for the P/T extinction

While a relative age for the P/T has been found, more work must be done to further narrow down the error of the date before any theories can truly be right
The relatively poor nature of the Permian rock record makes finding the cause even more difficult

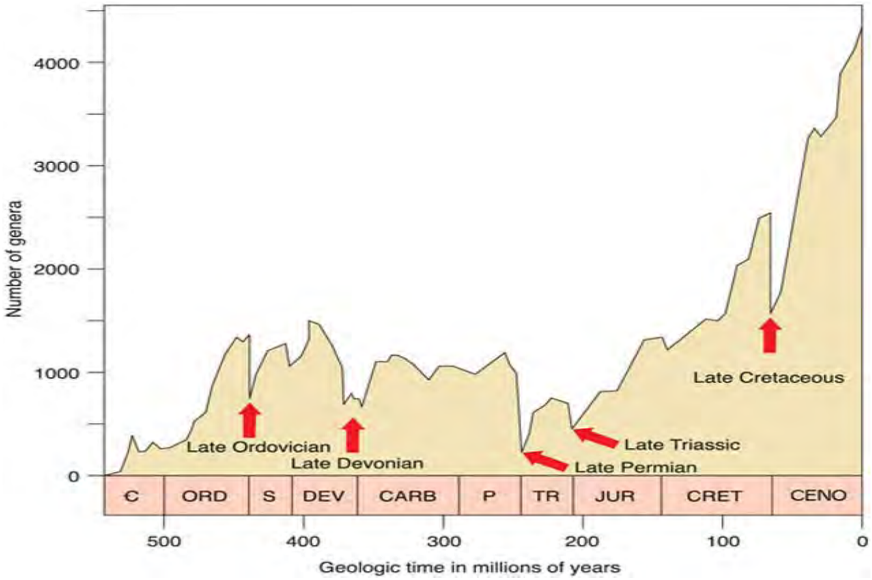
<u>Key questions for each theory</u>

Siberian Traps: how to find scientific/rock record evidence that outgassing produced enough carbon to sufficiently damage biosphere

Bolide impact: determining whether Bedout is an actual impact crater, if not check validity of Wilkes Land crater

Combination theory: Finding a reliable method of tying together the various methods(volcanism, methane release, ocean anoxia, sea level fluctuations, etc.) with the rock record and P/T date

Chart from "The Earth Through Time" by *Harold L. Levin*



Take-home message on how reading and analyzing papers relates:

-Highlights *tentative nature* of scientific claims.

-Highlights *social aspect of constructing scientific claims* (knowledge is constructed and negotiated).

-High student engagement – viewed as useful skill.

Most students DO NOT develop these ideas through their undergraduate experiences

(Sandoval 2005: don't learn it through inquiry alone either)

Implementation that seems to matter most:

Reading and understanding papers:

Repetition/practice, explicit instruction on reading, peer discussion

Other aspects:

Large number of papers, "contrasting cases" approach, scaffolding with copious feedback

(a few) Remaining questions:

Transferability to other courses?

Instructor expertise critical? Geologic time particularly integrative?

Assessment tool for "critical thinking"? (transfer to other contexts)

Would grad students benefit from similar experience?