

*Streamlining a Modern
Geoscience Curriculum:
A Tale of Young Turks, High
Teaching Loads, and Turning
Lemons into Lemonade*

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A Changing Science

- Geosciences have changed markedly with the advent of the earth systems paradigm and broader social impacts
- Scientific progress requires integration within the discipline and across traditional departmental boundaries
- Multi-investigator, multi-institution science is increasingly the rule rather than the exception

A Challenge in Undergraduate Education

- What are the implications of these evolutionary changes for:
 - our approach to content
 - our approach to pedagogy
 - faculty professional development
 - instructional materials, labs, fieldwork
- the students who enter our field

Philosophical Challenges

- Undergraduate content has traditionally been divided into “silos”, i.e. mineralogy, paleontology, structure, etc.
- Need to vastly increase integration to respond to earth systems reality
 - facilitate and measure systems thinking
 - facilitate and measure transfer
 - facilitate and measure teamwork

Philosophical Challenges

- This means that a “core” curriculum becomes much harder to define
- Must cross-cut all areas of earth science offered by a department
- Demands significant introspection about mission, goals, objectives and programmatic and faculty strengths

Practical Challenges

- Curriculum revisions are driven by circumstance and casts of characters as much as by design
- Academic Aikido - align the department response with the existing intrinsic strengths and the internal and external stressors

Case Study - SDSU

- My former department, SDSU Geological Sciences
- My roles in this story - Assistant and Associate Professor, Undergraduate Programs Coordinator, Undergraduate Advisor, Assessment Coordinator
- University Division of Undergraduate Education - worked for one year half-time outside of the department as University Assessment Coordinator

Case Study - SDSU

- Faculty Demographics - first new hire in 10 years in 2000 - massive wave of retirements (~40% of the faculty) by 2005
- Student population in the major down from historic high of 120 majors to ~50 by 2005
- Internal Stressors
 - High teaching loads, rising research expectations
 - Unfilled positions, budget cuts
- External Stressors
 - University system-wide assessment efforts
 - University re-accreditation - WASC

2001-2002 Assessment and Accountability

- University system decided to collect data on student learning AND post-degree placement
- Disastrous strategy - became viewed as a faculty performance review and was met with resistance and cynicism
- Did prompt the development of an exit survey of graduating seniors which were administered for 2 years - produced a consistent list of "core" courses

2001-2002 Assessment and Accountability

- Faculty were also asked to produce a list of “core” courses that defined any student as an earth scientist
- Amazingly, the responses of two-years’ worth of graduating students matched the faculty list exactly
- Faculty teaching these courses were asked to list the four to five key skills students should gain from this instruction

The 2001-02 Core Courses

- Historical Geology
- Mineralogy
- Petrology
- Structural Geology
- Advanced Field
- Field Geophysics
- Sedimentology and Stratigraphy
- Paleontology and Biostratigraphy

Learning Goals 2001-02

Geology 221, Mineralogy

- learn to recognize common rock-forming minerals in laboratory hand specimen
- use different analytical techniques to construct detailed mineralogical identifications
- understand basic crystallography, including mineral symmetry, crystal chemistry, and mineral structure at the atomic level, and relationship of internal and external symmetry
- learn the optical properties of minerals and employ these properties in mineral identification
- understand the relationship of minerals found in the field to the geologic environment which formed them

Geology 306, Structural Geology

- understand the micro- and macroscopic principles, causes, and mechanisms of rock deformation
- ability to measure, map, and recognize geologic structures in the field and make meaningful predictions of the location of rock units in the sub-surface or elsewhere at the surface.
- ability to construct a cross-section of a geologic field area and interpret the deformation history of the rocks present based on field observations
- ability to visualize geologic structures in three dimensions and to understand the typical three-dimensional distribution of rocks found in the field and the deformation styles common to different tectonic environments.

Geology 508, Advanced Field Geology

- ability to integrate all geologic knowledge to solve geologic problems in the field
- advanced competency in mapping, structural and petrologic interpretations
- advanced note taking and measurement skills which maximize efficiency and completeness of data collection under field conditions.
- ability to successfully work and think critically under sometimes difficult field conditions

2001-02 Goals: Critique

- Learning goals are micro-scale - very focused on non-integrative skills, confined within their individual courses
- Non-assessable beyond content examinations - falls into the grades \neq assessment trap
- Too specific to each instructor and course and not the major, leads to a multitude (>40) of goals that are hard to link to a broader intellectual mission

2003 - A New Vision

- To broaden the intellectual reach of our goals, we drew on the work of Mary Sevina, Ed Buchwald and colleagues at Carleton College - (GSA abstracts, 2001) - on “robustly useful” skills and habits of mind as an organizing principal
- Goal was to separate intellectual “habits of mind” that cross the entire curriculum from technical/professional skills that can be localized within courses or content themes

2003 - A New Vision

- Consultations with faculty produced 12 Technical/Professional skills and 8 Habits of Mind that cross-cut the entire core curriculum and popular electives
- Asked faculty to rate these 20 skills for their courses on a sliding scale, where zero is *not at all relevant* to 3 being *critical to this course and its purpose*

Technical/Professional

Technical/Professional skills:

Students in my course learn how to...

1. read and interpret geological (geophysical, hydrological, etc.) maps and cross sections
2. construct geological maps and cross sections
3. identify, recognize, and understand the significance of key geological features or information (i.e. rock identification, fossil identification, seismic phase identification, etc - related to key scientific content. In skills-related courses relative to content-specific courses this may not be as central)
4. read and interpret graphical and statistical information
5. collect data and construct graphical or statistical summaries/analyses of this data
6. conduct basic field investigations using common equipment/techniques
7. conduct basic laboratory investigations using common equipment/techniques
8. write papers to communicate data and summarize findings
9. read and understand papers which communicate data and summarize findings
10. create and deliver presentations to communicate data and summarize findings
11. apply appropriate technological aids/solutions to geologic data collection and analysis, use of software and computer hardware, etc.
12. exercise and apply mathematical and basic science skills in an earth science context

Habits of Mind

Unifying concepts and Habits of Mind:

Students in my course learn to understand...

1. how to formulate multiple working hypotheses
2. equilibrium (static, dynamic, dis-equilibrium)
3. taxonomy (in the most general sense - fossils, rock types, etc. and the relations and distinctions between "taxa")
4. systems and system-scale interactions, emergent properties of systems, feedback, thresholds
5. scale (physical scale as well as scale dependence or independence of phenomena)
6. evolution and change through time
7. inverse problems and inductive thinking from sparse data
8. discrete vs. continuous properties and processes

The Results - 2003

Geological Sciences Major

Course and skills matrix - the basis of our departmental assessment plan, draft date: April 4, 2003

Key: 0 = not at all relevant to this course, 1 = touched on but not emphasized, 2 = important idea in the course but not central, 3 = critical to this course and its purpose

Color key for easy reference

0	1	2	3
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Course number (Geological Sciences XXX), and abbreviated title	Course number (Geological Sciences XXX), and abbreviated title																	
	100 Physical Geol.	200 Geol. Inquiry	221 Mineralogy	224 Petrology	300 Computer App.	306 Structure	307 Geophysics	502 Geo & FNA	508 Adv. Field	514 Geomorph.	525 Petrography	530 Geochem.	533 Geophys. Anal.	536 Sed & Strat	537 Geobiology	551 Hydrogeo.	552 Field Hydro.	560 Seismology
Technical and Professional Skills: <i>Students in this course learn how to...</i>																		
Read and interpret geological (geophysical, hydrological, etc.) maps and cross sections	2	2	No data received	1	No data received	3	No data received	2	3	3	1	0	2	3	1	2	2	0
Construct geological maps and cross sections	0	3	No data received	1	No data received	3	No data received	2	3	3	0	0	2	3	0	2	2	0
Identify, recognize, and understand the significance of key geological features or information (i.e. rock identification, fossil identification, seismic phase identification, etc - related to key scientific content)	3	1	No data received	3	No data received	3	No data received	2	2	3	3	3	3	3	3	2	3	3
Read and interpret graphical and statistical information	0	1	No data received	3	No data received	2	No data received	2	0	1	3	3	3	3	3	3	3	2
Collect data and construct graphical or statistical summaries/analyses of this data	0	2	No data received	3	No data received	2	No data received	1	1	1	3	3	3	3	3	3	3	2
Conduct basic field investigations using common equipment/techniques	0	3	No data received	1	No data received	3	No data received	1	3	1	1	1	2	3	2	1	3	1
Conduct basic laboratory investigations using common equipment/techniques	0	3	No data received	3	No data received	3	No data received	1	1	3	3	3	0	3	2	1	3	0
Write papers to communicate data and summarize findings	0	3	No data received	3	No data received	1	No data received	1	1	1	3	1	2	1	1	3	1	1
Read and understand papers which communicate data and summarize findings	0	1	No data received	2	No data received	2	No data received	2	1	1	1	2	2	0	1	1	1	1
Create and deliver presentations to communicate data and summarize findings	0	1	No data received	3	No data received	1	No data received	1	0	0	0	3	1	3	1	2	1	1
Apply appropriate technological solutions to geologic data collection and analysis, use of software and computer hardware, etc.	0	1	No data received	3	No data received	2	No data received	1	1	0	3	3	3	1	1	3	3	3
Exercise and apply mathematical and basic science skills in an earth science context	1	1	No data received	3	No data received	3	No data received	2	1	0	1	3	3	1	0	3	3	3
Unifying concepts and Habits of Mind: <i>Students in my course learn to understand...</i>																		
How to formulate multiple working hypotheses	1	3	No data received	2	No data received	2	No data received	2	3	3	3	2	2	3	3	2	2	2
Equilibrium (static, dynamic, disequilibrium)	2	1	No data received	3	No data received	2	No data received	2	1	3	3	3	0	2	2	2	2	2
Taxonomy (in the most general sense - fossils, rock types, etc. and the relations and distinctions between "taxa")	3	1	No data received	3	No data received	2	No data received	2	1	2	2	3	0	3	3	1	2	0
Systems and system-scale interactions, emergent properties of systems, feedback, thresholds	3	3	No data received	2	No data received	2	No data received	2	1	3	3	2	2	2	3	2	1	1
Scale (physical scale as well as scale dependence or independence of phenomena)	2	3	No data received	2	No data received	3	No data received	3	2	3	2	2	1	2	3	2	2	2
Evolution and change through time	3	3	No data received	3	No data received	1	No data received	3	1	2	2	3	1	3	3	1	0	1
Inverse problems and inductive thinking from sparse data	1	2	No data received	3	No data received	3	No data received	3	3	2	2	3	3	3	2	3	3	3
Discrete vs. continuous properties and processes	1	2	No data received	2	No data received	2	No data received	3	1	2	3	2	3	2	2	3	2	3

Ranked Skills

Technical/Professional skills:

Primary Importance:

identify, recognize, and understand the significance of key geological features or information (i.e. rock identification, fossil identification, seismic phase identification, etc - related to key scientific content. In skills-related courses relative to content-specific courses this may not be as central)

read and interpret geological (geophysical, hydrological, etc.) maps and cross sections

Secondary Importance:

read and interpret graphical and statistical information

collect data and construct graphical or statistical summaries/analyses of this data

conduct basic laboratory investigations using common equipment/techniques

read and understand papers which communicate data and summarize findings

Tertiary Importance:

apply appropriate technological aids/solutions to geologic data collection and analysis, use of software and computer hardware, etc.

exercise and apply mathematical and basic science skills in an earth science context

construct geological maps and cross sections

Ranked Skills

Unifying concepts and Habits of Mind:

Primary Importance:

inverse problems and inductive thinking from sparse data.

scale (physical scale as well as scale dependence or independence of phenomena)

Secondary Importance:

how to formulate multiple working hypotheses

evolution and change through time

equilibrium (static, dynamic, dis-equilibrium)

discrete vs. continuous properties and processes

Tertiary Importance:

systems and system-scale interactions, emergent properties of systems, feedback, thresholds

A Good Start...

- The 2001-2003 efforts provided a solid conceptual base and an internal consensus for assessment work and curriculum realignment
- Provided measurable skills disembedded from content
- Was presented as a model to other departments in the College of Science

...and then the roof fell in

- 3 new hires joined the department
- massive retirements finalized (6-8 faculty out of 14, depending on how one counts “early retirement” packages offered during horrible budget years)
- WASC accreditation loomed, new Dean of Undergraduate Studies swings into action - required departments to state goals, objectives, and an overall mission statement

New Stressors and Responses - 2004-05

- 40% of core courses redesigned, updated and taught by new, untenured faculty
- Major staffing shortfalls forced coordination of teaching as never before
- What should students know coming into my course, and how can we make sure that happens
- Evolution: Change in response to environmental stress - streamlining of assessment activities and course sequence and scope

The Young Turks Take Action

- Beer and pizza brainstorming sessions
 - how to reconceptualize our core sequence in response to the drive to form a departmental mission
 - how to ensure student-centered coherence and comprehension
 - how to save our own skins teaching-wise and workload-wise

Administrative Vision

- Division of Undergraduate Studies
 - in charge of student learning outcomes assessment guidance
 - set forth challenges for each department
 - write a mission statement
 - produce three to five student learning goals - large scale
 - write two measurable/observable outcomes for each goal and state the assessment timing and strategy

Our Solution

- Conceptualized by the Young Turks, vetted by strategic allies in the senior professorate, sold as a complete package to the whole faculty
- Assessment made painless - coordinated by a department faculty member in exchange for release time - all embedded assessments in existing course assignments

Our Solution

- Content Threads (Learning Goals)
 - Earth History and Systems, emphasis on Life on Earth and Sedimentary Systems
 - Field-Based Geologic/Geophysical investigations, emphasizing Earth Structure and Dynamics
 - Earth Materials and Composition in all parts of the Geosphere

Our Solution

- Geoscience Methods, Norms and Epistemology (Learning Goals)
 - Nature and Collection of Evidence in the Earth Sciences
 - Geoscientific Data Interpretation: Methods and Paradigms

Our Solution

- We identified measurable/observable objectives for each goal that could be revisited at progressive levels of skill and sophistication as students moved upwards through the curriculum
- Measured in existing assignments
- Explicit attempt to leverage use of the same field areas and the realities of co-enrollment and sequence

Shared Field Investigations

- A Key Strategy
 - Maximizes faculty/student ratio
 - Maximizes transfer - students study material for two courses in one location
 - Minimizes duplication of field time
 - Rainbow Basin - Intro Field and Mineralogy
 - Fossil Canyon - Intro Field and Historical

Shared Field Investigations

- A Longitudinal Strategy
 - Students return to work the same field area again in a later class
 - Maximizes metacognition and confidence - students perceive the growth in their own understanding
 - Utilizes peer teaching approaches, relieves instructional load on faculty and TAs
 - Rainbow Basin - Intro Field/ Mineralogy and Structural Geology

Making it all work - The Matrix

- We constructed a chart illustrating the “horizontal” and “vertical” relationships between content thread and student progression
- Made explicit the scope and sequence of each course - driven by assessment
- Eventually made explicit the staffing and timing of each course offering to avoid pre-/co-requisite interference

The Matrix

Curricular Sequence Theme	Year 2		Year 3		Summer - Geol 508 Advanced Field Geology – Option 1	Year 4		Summer - Geol 508 Advanced Field Geology – Option 2
	Fall	Spring	Fall	Spring		Fall	Spring	
Earth History and Systems, Sedimentary Rocks and Life on Earth	Geol 105 Historical Geology	Geol 536 Sedimentology and Stratigraphy	Elective/GE	Geol 537 Geobiology Paleontology		New 500-level Earth Systems	Geol 498 Senior Thesis/ Elective	
Field Methods and Geologic Investigation, Earth Structure and Dynamics	Geol 200 Geologic Inquiry	Geol 300 Quantitative Analysis	Geol 306 Structural Geology	Geol 307 Geophysics		New 500-level Geotectonics	Geol 498 Senior Thesis/ Elective	
Earth Materials and Composition, Igneous and Metamorphic Rocks	Geol 221 Mineralogy	Geol 224 (324) Petrology	Geol 530 Geochemistry	Elective/GE		Elective/GE	Geol 498 Senior Thesis/ Elective	

The Matrix with Teeth

Curricular Sequence Theme	Year 2		Year 3		Summer - Geol 508 Advanced Field Geology - Option 1	Year 4		Summer - Geol 508 Advanced Field Geology - Option 2
	Fall	Spring	Fall	Spring		Fall	Spring	
Earth History and Systems, Sedimentary Rocks and Life on Earth	Geol 105 Historical Geology Leighton/ Schellenberg 1230-1345 TTH 1400-1640 T	Geol 536 Sedimentology and Stratigraphy Abbott <i>1100-1150 TTH</i> <i>1300-1540 T</i>	Elective/GE	Geol 537 Geobiology Schellenberg/ Leighton <i>1000-1115 MW</i> <i>1400-1640 M</i>		New 500-level Earth Systems	Geol 498 Senior Thesis/ Elective	
Field Methods and Geologic Investigation, Earth Structure and Dynamics	Geol 200 Geologic Inquiry Riggs 0930-1110 T 0930-1210 TH	Geol 300 Quantitative Analysis Mellors <i>0930-1045 or</i> <i>0900-1015 TTH</i> <i>1300-1540 TH</i>	Geol 306 Structural Geology Girty 0800-0850 MW 0800-1040 F	Geol 307 Geophysics Jiracek <i>1000-1115 TTH</i> <i>1200-1440 T</i>		New 500-level Geotectonics	Geol 498 Senior Thesis/ Elective	
Earth Materials and Composition, Igneous and Metamorphic Rocks	Geol 221 Mineralogy Kimbrough 1000-1050 MW 1400-1640 MW	Geol 324 Petrology Pietruszka <i>1000-1050 MW</i> <i>1400-1640 MW</i>	Geol 530 Geochemistry Pietruszka <i>1000-1050 MW</i> <i>1400-1640 M</i>	Elective/GE		Elective/GE	Geol 498 Senior Thesis/ Elective	

Lessons Learned

- Curriculum revision must be viewed as systemic change
- Backwards design based on desired outcomes is crucial
- Faculty must buy in completely, but the vision typically comes from a committed core

Issues

- Scheduling can be rigid - not much room for experimental meddling in core courses in terms of duration and timing
- Potentially vulnerable to faculty departures and staffing changes, but in the presence of strong leadership can make the department very resilient to these changes
- Difficult for out-of-sequence students to be integrated

Parting Thoughts

- It's worth it, but it takes time and energy - there are no quick fixes
- Take a student-centered approach
- Look for synergies and economies of scale - minimize duplication of effort
- Seek a shared vision for the ideal geoscience major's skill set
- Work with your own strengths
- Be evidence-driven - convince the skeptics with data, not hunches