An Earth Science Curriculum by Design

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The Department of Earth Sciences, Montana State University, recently implemented a top to bottom revision of its curriculum. We are a department that encompasses both geology and geography, and we have degree options in Geology, Geography (physical and human), GIS/Geographic Planning, Hydrology (currently on hold pending appointment of a new faculty line), Snow Science, and Paleontology. These latter two degree options are somewhat unique in the US for undergraduate degree programs, and have been hugely successful in recruiting students to the geosciences, particularly out of state students. We currently have a faculty of 11, about 270 majors, 60 graduate students (40 MS and 20 PhD), and provide a large instructional service to MSU, particularly for students from Education, Ecology, Land Resources, and the social sciences.

Our curricular changes were necessitated by both philosophical and practical considerations. Philosophically we were guided by a number of principles:

- We used the "Understanding by Design" approach advocated by Wiggins and McTighe (2005). Using "backward design", we started by determining the profile of a student who successfully completed our degree programs—what should they know, what should they be able to do? In part, this speaks to the students' professional development as they prepare for the workforce or graduate school; but also, these students are the best ambassadors of our department to industry and the community and represent the ultimate quality of our program.
- The new curriculum is better aligned with the changing nature of geoscience research and understanding. The most important shift is towards an Earth System approach, moving away from the traditional "silo-ed" disciplinary course structure.
- We have long advocated a learning sequence that emphasizes observation, description, interpretation and integration at each of our four years of instruction (Figure 1). This progression generally follows Bloom's Taxonomy of Cognitive Skills (http://www.nwlink.com/~donclark/hrd/bloom.html): knowledge, comprehension, application, analysis, synthesis, and evaluation. We also apply the "rule of 3's" (or 4's): if something is worth learning well, students need at least three exposures. So, our sequence of courses provides exposure, familiarization, competence and mastery of key concepts and skills over the four-year curriculum.
- The "cornerstones" of our curriculum (Figure 1) remain a strong background in cognate sciences (chemistry, physics, biology and math), application of the scientific method (and we understand this to mean "geologic habits of mind", see http://serc.carleton.edu/68040), an emphasis on geologic processes and

the process of doing geologic work, and a strong grounding in field instruction.
- In addition to the "core" of geoscience concepts, knowledge and skills, we are also addressing ancillary learning goals such as development of quantitative skills, communication skills (verbal, written, graphical), use of data in the classroom and modeling, systems thinking, research and research-like experiences, applications to societal issues, and interpersonal skills (cooperative and collaborative learning); these are all part of the department's assessment plan that we have prepared for institutional accreditation.

The practical drivers for this redesign of the curriculum are quite simple:
- We simply had to make more efficient use of faculty teaching efforts and teaching assistant assignments. Some courses were largely redundant (Intro Physical Geology and Intro Physical Geography covered about 80% of the same material, and have now been merged into a new Earth System Science course); other courses did not draw sufficient students to be offered (minimum of 10 undergraduates, 5 graduate students); some courses were on the books only for historical reasons, and other new courses have been introduced to address emerging new lines of research (e.g. Geomicrobiology). So we started with a clean slate.

The overall structure of our new curriculum is presented in figure 2; vertical columns show the emphasis on high level learning goals: Earth History ("deep time", evolution); Earth composition and Architecture; Surficial Processes (including water, climate); and Human Dimensions. The rows reflect the learning progressions as described above.

At the introductory level, offer a diverse suite of courses to introduce students to the range of topics covered in the Earth Sciences. The new Introduction to Earth System Science, course is required of all majors, is also required of other disciplines (Education, Ecology, Land Resources) and is available to non-majors seeking "Core Curriculum" credits. A wide array of other introductory courses are offered to stimulate interest among students including: Dinosaurs!, Planetary Geology, Oceanography, Environmental Geology, Human Geography, World Regional Geography, and a special course on Yellowstone: A Natural Scientific Laboratory. These courses are essential to recruiting students to our majors, and we highly value excellence in instruction in these courses (our faculty have earned numerous college and university teaching awards).

We have also developed a new series of one credit "mini-courses" on Topics in the Earth Sciences (following the established model developed at the University of Michigan). In combining our Intro Physical Geology and Geography courses, we had to look for a mechanism to maintain our student credit hour generation., and these mini-courses provided the opportunity for faculty to teach courses in areas of particular interest to them without requiring a great deal of class preparation. These courses give students the opportunity to explore a given topic in some depth, as opposed to standard survey courses that are "a wile wide and an inch deep". We will offer 16 different topics in a two-year cycle (4/semester), and students can take any three to satisfy university "Core" requirements in Contemporary Issues in Science. Topics we have covered this past year include: Himalayan Geology (following David Lageson's expedition to Mt. Everest), Geology and Human Health, Military Geology, Extraterrestrial Impacts, Great Extinctions, Coral Reefs in Earth History, the Montana "Oil Boom", and Megafires. These courses have already proven to be hugely popular (all sections filled to their caps), and we will be monitoring students' progress to see if this early exposure to the Earth Sciences in these courses results in recruitment of majors.

Our second year of instruction for majors is our "Foundations" set of courses. For all geology (and hydrology, snow science, paleontology) majors, we expect that they will take Historical Geology, Earth Materials, and our sequence of two GIS courses. Earth Materials has a focus on hand sample identification of rocks and minerals, a knowledge of their occurrences in Earth, and significance in terms of interpreting Earth processes and uses in society. All our majors should be able to identify rocks and minerals and understand their contexts in the Earth system (but don't necessarily need to master topics such as crystallography and crystal chemistry emphasized in Mineralogy). We require two semesters of GIS because this is arguably the most marketable skill that students need for future graduate studies or to enter the workforce (based on feedback from recruiters). GIS applications then become possible in upper division courses such as Geomorphology, and for independent research projects. We also expect students to complete a year of inorganic chemistry, physics, and calculus by the end of their second year.

The third year of our geology major is really the "core" of geoscience professional training: Mineralogy, Sedimentary Geology and Stratigraphy, Structural Geology, and Geomorphology. Paleontologists have a similar core, including Invertebrate Paleontology, Vertebrate Paleontology, and Comparative Anatomy. Because students have already had hand sample identification in the Earth Materials course, Mineralogy now focuses more on analytical methods (petrographic microscope, XRD, SEM/EDS), and analysis of earth materials, structures, landforms and the attendant geologic processes is emphasized in the other core geology courses. All these courses have a strong field component (we are blessed with a great geologic setting so we can readily get into the field in afternoon labs and on weekends). We also believe that ALL Earth Science majors should have a fundamental understanding of Weather and Climate, so this is now a required course.

Our fourth year courses are largely a series of “enrichment” courses (commonly joint listed as a graduate course, with extra requirements for graduate students). These generally follow instructors’ research interests in topics such as Tectonics, Volcanology, Igneous Petrology, Metamorphic Petrology, Sedimentary Geology, Geophysics, Taphonomy, Macroevolution, Snow Dynamics and Accumulation. Common approaches for these upper division courses include: critical reading and review of the literature; use of modern software; in-depth class projects (field and lab); use of real-time, archived, or student-generated data; and written or oral student presentations. The geology curriculum also requires the Field Camp class as a “capstone” course, which also provides an opportunity for “end of degree” assessment of student learning outcomes. In general, these courses provide authentic geologic experiences for our undergraduates that serve to prepare them for next steps in their professional development.

We are in the first year of implementation of this new curriculum. Initially there was some resistance from some of the faculty had adopted a stance of "if it ain't broke, don't fix it" as we already had a pretty solid undergraduate curriculum. But the redundancies in some course work, gaps in other areas, and need to optimize teaching staff efforts won the argument. Downstream benefits are realized as course pre-requisite requirements are uniformly applied, and students are better prepared to enter our upper division courses. Foundational skill sets are uniformly developed in lower division courses and faculty can expect to build on this early work in the upper division classes as well. Teaching assistants that were once assigned to redundant introductory courses are now available to help teach labs in many of the upper division courses for the first time. Early reviews from students are largely favorable as they realize that these changes will position them well for future opportunities. To prepare students for these changes, and to explain the underlying need and reasoning, I gave the first departmental colloquium of the year on the "State of the Geosciences, State of the Department"; it was very helpful for the students to have the trajectory of their coursework explained in the context of our evolving Science and expectations for the workforce of the future. We are working out a few wrinkles as some students are a bit challenged to reconcile the old and new degree requirements, but we are working through this in our advising efforts. Faculty seem to be happier in the alignment of courses, because it has actually reduced teaching loads to a degree, and has given us flexibility to provide TA support in some courses at the upper division which we were not previously able to provide. The curriculum is in better alignment with the university's Strategic Plan, and we think it also is in better alignment with the changing nature of the geosciences as a discipline. The proof of success of this new plan will ultimately be reflected by the success of our students as they enter the workforce or grad school. I'll keep you posted!

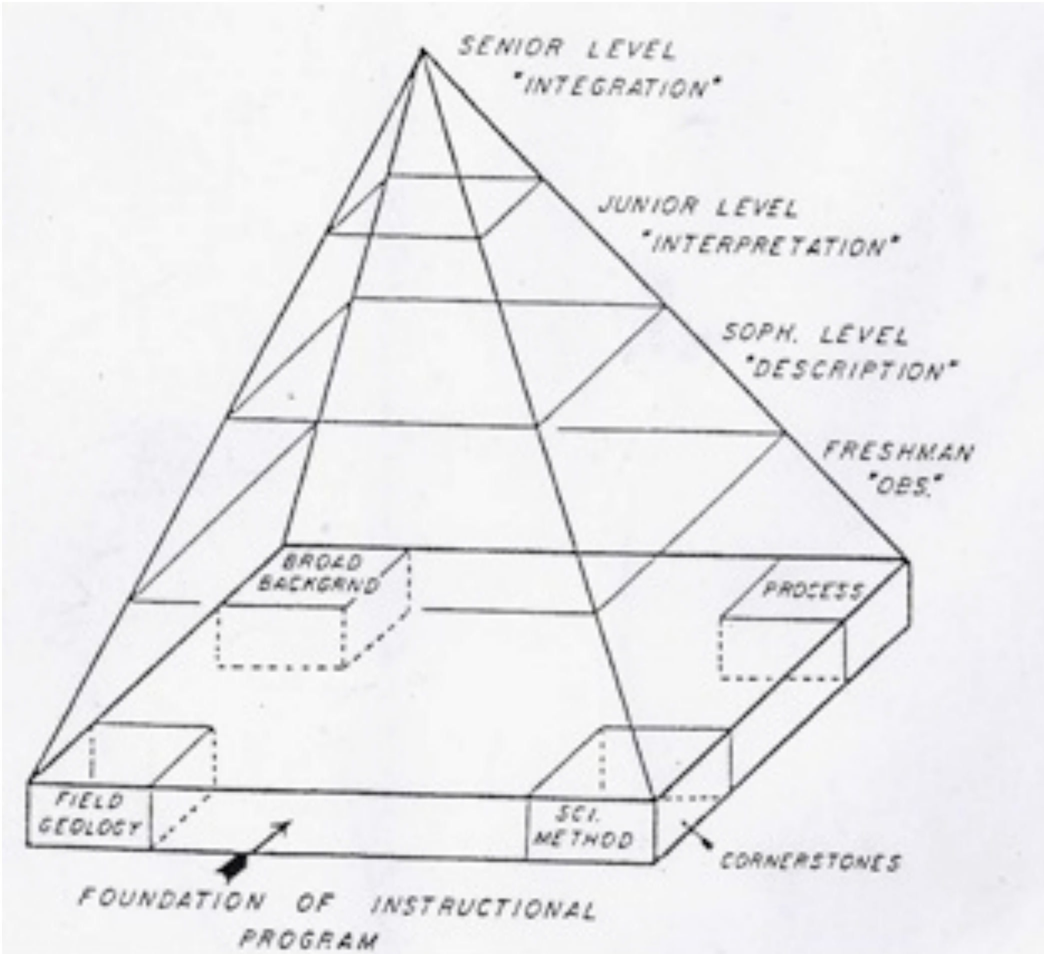

Figure 1: Learning "pyramid" for the Dept. of Earth Sciences, Montana State University, that illustrates levels of skill development (observation, description, interpretation and integration) built on the foundations of a broad scientific background, the methods of (geo)science, Earth processes, and field geology. Figure originally drafted by David Lageson.

DEPT EARTH SCIENCES, MONTANA STATE UNIV., UNDERGRADUATE COURSE MATRIX

(Required Courses ONLY Offered in the Dept. of Earth Sciences, exlusive of Independent Study, Thesis, etc.)

Unifyiing Themes:	Earth History, Deep Time, Evolution	Earth Composition and Architecture	Surficial Processes, Water, Climate	Human Dimensions
Degree Option:	Paleontology Option	Geology Option	Hydrology, Snow Options	Geography Options, Including GIS Minor
Upper Division Electives (4xx)				
Capstone Courses	GEO 429 Field Geology			GPHY 425 Geog Thought
Major "Enrichment" Courses (4XX)	GEO 417 Taphonomy	GEO 433 Tectonics	Other electives from	GPHY 431 Historical Geog
Cognitive Skill Level: Analysis and Synthesis	GEO 411 Vert Paleo	GEO 440 Volcanology	LRES, CE, Poli Sci....	GPHY 461 Tourism Plan
Mastery of content and concepts	GEO 413 Macroevol	GEO 408 Meta Pet		GPHY 441R Mountain Geog
	GEO 419 Field Paleo	GEO 406 Igneous Pet.		GPHY 445 Regional Geog
		GEO 480 Petroleum		GPHY 480 Water and Soc.
		GEO 480 Geophysics		GPHY 480: American West
	GEO 407 Sedimentary Petrology			GPHY 446 East Asia
		Geohydrology		GPHY 411 Biogeography
		GEO 445 Glaciology		
		ERTH 450R Snow Dynamics		
				GPHY 426 Remote Sensing
				GPHY484 Applied GIS
Major "Core" Courses by Option (3xx)	GEO 310 Invert Paleo	GEO 302R Mineralogy		GPHY 321 Urban Geog
Cognitive Skill Level: Interpretation (process, history...)	GEO 330 Paleo Lab Technique	GEO 309 Sed and Strat		GPHY 322 Economic Geog
Competence with content and concepts	GEO 316 Comp Vert Anatomy	GEO 315 Structural Geol		GPHY 325 Cultural Geog
	GEO 312 Dinosaur Paleo			GPHY 357 Fund App Map
				GPHY 365 Geog Planning
	GPHY 384 Advanced GIS			
	ERTH 303 Weather and Climate			
	ERTH 307 Geomorphology			
"Foundations" Courses (2xx)-- Concepts/Skills required of ALL E Sci Majors AND Allied Depts.	All Majors are expected to fulfill prerequisites in cognate courses: Chemistry 141, Chemistry 143, Physics 220, Physics 222, STAT 332, Math 171 Calc I, Math 172 Calc II, (Math 273, 274 Diff Equations			Stat 216, 217;
Cognitive Skill Level: Description	GEO 211 Historical Geology			1 year foreign Language
Familiarization with content and concepts	GEO 205 Earth Materials			
	GPHY 284 Intro to GIS			
Introductory Courses (1xx)	ERTH 101 IN Earth System Science			GPHY 121D Human Geography
Cognitive Skill Level: Observation, inquiry, discovery	ERTH 102 CS Topics in Earth Science			GPHY 141D Geog of World Regions
Initial Exposure to content and concepts	GEO 103 CS Environmental Geology			
	GEO 111 IN Dinosaurs	GEO 140 IN Planetary Geology	GEO 105 IN Oceanography	
		ERTH 212R Yellowstone Scientific Lab		

Figure 2: Course matrix for undergraduate degree programs in the Dept. of Earth Sciences, Montana State University