Future of Undergraduate Geoscience Education & Geoscience Workforce

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WHERE DISCOVERIES BEGIN
Future of Undergraduate Geoscience Education

2014 Summit:
- ~200 educators representing broad spectrum of undergraduate geoscience education community
  - R1 research universities with undergraduate programs, 4-year and 2-year colleges
  - Faculty, heads & chairs, education researchers
  - Industry, government & professional society representatives (~20)
- 1st step in development a high-level community vision for the geosciences
  - Surprising collective agreement

Ongoing Community Survey
- 455 respondents
  - 354 academics (78%), 76 industry (17%), 13 government (3%), 7 other (1%), 5 professional societies (1%)
  - 85% not Summit participants

Geoscience Employers Workshop (May, 2015)
- 46 participants: 6-7 each from energy, hydro/engineering/environmental, govt. agency, prof. societies, academics; 1 mining
  - Plus ~13 NSF program directors
Concepts, Skills, Competencies

• Major conclusion of Summit
  – Developing competencies, skills, and conceptual understanding
  – More important than taking specific courses

Survey Results:
Earth as complex, dynamic system with linkages between different systems (e.g., lithosphere, atmosphere, biosphere, etc.)

Surface processes (including relationship between landscape and process)

Earth Structure

Natural resources (including energy)

Deep time (including the origin and evolution of life)

Hydrogeology (including water, rock, and microbe interactions)

Natural hazards

Earth materials

Climate change

Employer Workshop added granularity
Earth as a Complex System

• Non linear complex systems
  • Size of systems – complexity of scale and interactions
  • Feedback loops, interactions, forcings
  • Implications and predictions
• Energy, mass, fluid transport (movement and flow), residency, and cycles
• Work/changes that affect the Earth’s systems
  • Human drivers and impacts of change, Anthropocene
  • Environmental transitions
  • Scales of change
  • Using the present processes to infer past processes: Advantages/risks
• Solar system interaction
Deep Time

• **Conventional concepts of geologic time**
  • Paleontology, superposition
  • Relative vs absolute age
  • Tools to determine absolute age (radioisotopes, stable isotopes, etc.), precision of data, limitations
  • Extrapolate from lab to field

• **Impact on processes**
  • Time scales over which processes are relevant
  • Specific periods in geologic time that are critical for different processes
  • Impact of time on “Earth” events (i.e. weathering, geodynamics, resources, etc.)

• **Events and rates**
  • Duration, frequency, magnitude and residence time
  • Timing, scale, sequencing and rates of change

• **Temporal reasoning**
What is climate change? Geologic scale vs. present change
- Significant climate change in geologic past
- Relevant space and time scales
- Continental vs local scale change
- Proxy records
- Rate of climate change; rapid change

Driving forces and causal mechanisms
- External forcing vs. internal forcing
- Dependence upon spatial and temporal scale and feedbacks
- Impact of plate tectonics, atmosphere-earth interactions, etc.
- Human-induced climate change

Carbon cycle

Difference between weather and climate

Impacts of climate change
- Water resources, hydrologic cycle, other climate change effects
- Biosphere implications, ocean acidification, sea level rise
- Implications on soil, agriculture
- Economics and social aspects of climate change
- Climate element to environmental consulting and hydrogeology as well as petroleum exploration
Natural Resources

- Understanding of what is included in “natural resources”
  - Economic geology (commodities and finite resources)
  - Energy, water, minerals, geologic materials
- Solid vs. liquid resources, geographic distribution, uses
- Ecosystem services, analysis of renewable and non-renewable (finite) resources
- Resource dependency and limits
  - Finite resource or commodity
  - Understanding your environment (where do our materials, energy, and medicines come from)
  - Ore and fossil fuel supply and demand and getting it to market
  - Time and space scale of formation and depletion, sustainability
  - Economics and viability of resources
  - How things are made
    - Process from ore to refined product
    - Process from fossil fuel to energy or material objects
Surface Processes

- Sediment deposition & erosion
  - Stream/River flow, morphology, deposition, erosion, effect of floods
  - Transport relationships (all surface processes)
  - Magnitude and frequency relationships of surficial deposits
  - Subsurface analogs

- Terrestrial and marine surface interactions
  - Biological, chemical, and physical interactions
  - Rates of chemical and physical changes

- Landscape alteration (geomorphology)
  - Surface mechanical and chemical processes
  - Karst formation
  - Glacial till and overburden thickness

- Habitability, sustaining life
  - Ties to natural hazards
Earth Materials

• What is a rock, mineral? Rock cycle
• Rocks: physical and chemical properties
  • How measure, scale of measurement
  • Mechanical characteristics
  • Scales of heterogeneity
  • How change over time
• Processes that form rocks and minerals
  • Processes and conditions of formation
  • Localizing mechanisms for deposits
  • Fluid dynamics, flow and fluid chemistry
  • Role of microbiology and organisms
• Resource applications, organic-inorganic materials
Earth Structure

- **Structure of Earth**
  - Mechanical and compositional layers
  - Tools for defining earth structure (seismic waves, analysis of earthquakes, etc.)

- **Deformation**
  - Stress and strain
  - Rock mechanics & deformation processes
  - Fractures, faults, folds, other structural features, etc.

- **Plate Tectonics, including**
  - Basin formation
  - Episodic nature, planning perspectives, uncertainty

- **Structural controls on resource accumulations**
Hydrogeology

- **Water cycle**
- **Groundwater/aquifers, confined vs unconfined aquifers**
  - Phase behaviors
  - Saturated vs unsaturated conditions
  - Scales of heterogeneity in space and time
  - Contaminant transfer
- **Biogeochemistry and aqueous geochemistry**
  - Microbe interactions
  - Nutrient cycling
- **Subsurface-surface water interactions**
- **Economics and public policy**
  - Groundwater quality
  - Regulatory standards
Employer Workshop: Systems Thinking

How systems work and interact

- **Atmosphere** – Climate, Weather, Ocean-atmospheric circulation
- **Hydrosphere** – Ocean, Ice, Surface water, Groundwater
- **Lithosphere** – rock cycle, deformation, structure, tectonics
- **Pedosphere/surface** – Geomorphic, Erosion, and Surface Processes, Landscape evolution
- **Biosphere** - Paleontology, Ecosystems
- **Solar/Earth Interactions** – Tidal, Climate; planetary geology
- **Human/Societal Coupled to Earth** – Natural Resources, Energy, Anthropomorphic Climate Change, Natural Hazards
  - Influence of geology on society
  - Influences of society on earth processes
Processes

- **Thermodynamics** – energy, kinetics, diffusion, heat, mass transfer, fluid flow
- **Geochemical Cycles** – C, H₂O, N, P
- **Geomechanics/Stress State/Rheology**
- **Geological Time/Earth Evolution**
- **Plate Tectonics/Geodynamics**
- **Tectonic Processes**
- **Depositional Processes**
- **Crystallization Processes**
Tools

- Statistics/Uncertainty/Probability
- Mathematics (differential equations, linear algebra)
- Field Methods
- Geography and spatial thinking
- Seismology/Geophysical sensing
- Potential Fields
- Remote Sensing
- Analytical/Numerical Modeling
- Age Dating
- Instrumentation
- Cartography
Summit Outcomes/Survey Results: Science Skills

- Critical thinking/problem solving skills
- Communicate effectively to scientists & non-scientists
- Ability to access and integrate information from different sources and to continue to learn
- Understand and use scientific research methods
- Have strong quantitative skills and ability to apply
- Work in interdisciplinary teams and across cultures
Be technologically versatile (i.e. Google Earth, tablets, smartphones, apps)

Have strong computational skills and the ability to manage and analyze large datasets

Have strong field skills and a working knowledge of GIS

Integrate data from different disciplines and apply systems thinking

Work with uncertainty, non-uniqueness, incompleteness, ambiguity and indirect observations

Readily solve problems, especially those requiring spatial and temporal (i.e. 3D and 4D) interpretations

Make inferences about Earth system from observations of natural world combined with experimentation and modeling

Summit Outcomes/Survey Results: Geoscience Skills

Very 1    2   3   4   5 Not
Work with uncertainty, non-uniqueness, incompleteness, ambiguity and indirect observations

Academics
Employers

Readily solve problems, especially those requiring spatial and temporal (i.e. 3D and 4D) interpretations

Academics
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Academics
Employers
Employer Workshop: Geoscience Thinking

- **Earth Science habits of mind/geoscientific thinking**
  - Temporal and spatial thinking – 3D & 4D
  - Systems thinking – Earth as system of interacting parts & processes
  - Geologic reasoning and synthesis

- **Problem solving in the context of an open and dynamic system**
  - Understand context of problem
  - Identify appropriate questions to ask
  - Visualize and solve problems in 3- and 4-D
  - Work on problems with no clear answers
  - Understand the importance of scale
  - Managing uncertainty in problem solving
  - Have a passion for solving problems

- **Work by analogy, inference and the limits of certainty**
- **Intellectually flexible - applying skills in new scenarios**
<table>
<thead>
<tr>
<th>Skill List (A-awareness (had in class); P-proficiency (had to use/apply); M-mastery (project, etc. requiring demonstration of ability); E-expert (MS or PHD))</th>
<th>Level of Mastery</th>
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<tbody>
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Technical Skills

• **Problem Solving with real data**
  • Data collection and interpretation, use and application of data
  • Begin with understanding of how data will answer question, purpose of collecting data
  • Evaluation of data, data quality
  • Understanding data and uncertainties
  • Make predictions with limited data
  • Use of appropriate methods, reading and interpreting graphs

• **Quantitative/Math skills – integrate into geo courses throughout**
  • Differential equations/linear algebra
  • Probability and statistics (so understand risk)
  • Computer programming skills (think about how to solve a problem computationally)

• **Experience with authentic research, collection of new information**
• **Critically evaluate literature, encourage critical thinking**
Technology Skills

• **Data Analysis Skills**
  - Ability to handle and analyze Big Data
  - Use of visual models, modeling tools (Stella, Modflow, Matlab, etc.)
  - Integration of technical and quantitative skills, programming, application development

• **Technological diversity (need skills and training beyond point, click, and type) – i.e. not just black box**

• **Preparation for life-long learning**
  - How to learn and use new technology and software
Field Skills

- **Field Camp and Field Experiences**
  - Improves spatial cognition, creative problem solving, teamwork, geoscience synthesis
  - Field skills are unique and essential, difficult to replicate or substitute

- **GIS** – Most essential for building large data sets
Non-technical Skills

• **Project management in team setting**
  • Ability to work in teams
    • Be a leader and follower
    • Iterative process between students with different backgrounds/disciplines
  • Goal setting
  • Solution-oriented approaches
  • Time management
  • Conflict resolution (open minded – answer may lie in the conflict space)
  • Managing problems on the front end

• **Interpersonal skills**
  • Ethics, ethical awareness, codes of conduct
  • Awareness of implicit biases
  • Emotional literacy, learning styles
  • Leadership
  • Ability to work with different personalities
Non-technical Skills Needed

• **Communication skills**
  – Written & verbal scientific communication
  – Knowing audience
  – Public speaking
  – Listening skills

• **Professionalism**
  – Business acumen
  – Risk management
  – Career awareness/resume/interview preparation

• **Global perspective**
  • Cultural interactions, cultural literacy

• **Understanding societal relevance**
Effective Ways of Developing Skills/Competencies/Concepts

- Experiential learning – incentivize faculty to increase use
  - Constant engagement in opportunities to practice skills and use concepts
  - Project based courses
  - Collaborative, integrative team projects
  - Interdisciplinary projects
  - Fieldwork and field experiences
  - Exercises using and analyzing real data
  - Internships or REUs – the earlier and more often the better
  - Research experiences/projects
  - Senior Theses
  - ASBOG test as a source of problem-oriented activity for the classroom and as an incentive
  - Use games to teach & reward innovation and creativity
  - Integration and interactive use of technology
    - Visualization, simulation, modeling, use of real data
- More active collaboration between academia and the outside employers
Do your undergraduates have the opportunity for the following activities?

- **Independent research (theses or major projects)**
- **Other research projects or experiences involving real data and analysis**
- **Traditional field camp**
- **Other types of field courses including field methods courses**

[Bar chart showing distribution of required, optional, and no opportunities for each activity]
From what you know about your department, which of the below teaching methods are used by faculty in your department?

<table>
<thead>
<tr>
<th>Method</th>
<th>5 -none</th>
<th>4 - a few</th>
<th>3 -some</th>
<th>2 -most</th>
<th>1 - nearly all</th>
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<tbody>
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<td>Inquiry based labs</td>
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<td>Frequent use of small group discussion, whole class discussion or in-class exercises</td>
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<td>Learning through practice with feedback – teaching with using real data &amp; research</td>
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<td>Students engaged in collaborative learning in class (e.g. Think-Pair-Share; team...)</td>
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<td>Opportunities for reflection and refinement (e.g. Retrieval practice, Minute papers, Concept...)</td>
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<td>Blended learning (classroom lectures/activities combined with partial online delivery of...)</td>
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<td>Explore before learning</td>
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<tr>
<td>Entire classes designed around collaborative team based projects</td>
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<tr>
<td>Flipped classrooms (lectures online; in-class time exercises, projects or discussions)</td>
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Legend:
- 5 - none
- 4 - a few
- 3 - some
- 2 - most
- 1 - nearly all
From what you know about your department, how do your colleagues (or you) use technology in teaching?

- Modeling and simulation
- Use of large datasets
- Visualization - passive observation
- Interactive visualization
- Integrating Google Earth with maps
- Student-driven investigation facilitated by technology
- Student-driven investigation with real-time “instantaneous” feedback
- Virtual fieldtrips
- Social networking, educational games or crowdsourcing
From what you know about your department, how do your colleagues (or you) use technology in teaching in the field?

- Instructor provides information for field (e.g. maps/cross sections overlain on Google Earth, DEMs overlain on photographs, remote sensing...)
- Using ARCGIS or other similar software
- Mapping on tablets, IPADs or phones
- Student develops information for field (e.g. remote sensing interpretations, etc.)
- Not at all – but teaching is done in the field
- Not at all – no teaching done in the field