Future of Undergraduate Geoscience Education & Geoscience Workforce

Sharon Mosher
Organizing Committee Chair
Jackson School of Geosciences
University of Texas at Austin

Results from project sponsored by
Concepts, Skills, Competencies

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

**Survey Results:**

![Survey Results Graph]

- Academics
  - Yes: 80%
  - No: 20%

- Employers
  - Yes: 90%
  - No: 10%
Summit Outcomes/Survey Results: Important Concepts

Earth as complex, dynamic system with linkages between different systems (lithosphere, ...)

Deep time (including the origin & evolution of life)

Climate change

Natural resources (including energy)

Surface processes (including relationship between landscape and process)

Earth materials

Earth structure

Natural hazards

Hydrogeology (including water, rock, microbe interactions)
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

Hydrogeology (including water, rock, and microbe interactions)

Natural resources (including energy)

Deep time (including the origin and evolution of life)

Natural hazards

Climate change

Employer Workshop added granularity
2014 Summit, Survey & Employer Workshop

• **Concepts:**
  – Traditional Earth Science – most cover (deep time, earth materials, structure, surface processes, etc.)
  – Other geoscience – some cover, variable extent (climate, hazards, resources, hydrogeology)

Employers added granularity, plus emphasized

  – Systems Thinking
  – Understanding processes
  – Linkages, feedbacks, driving forces
  – Impacts

  • [http://www.jsg.utexas.edu/events/future-of-geoscience-undergraduate-education/](http://www.jsg.utexas.edu/events/future-of-geoscience-undergraduate-education/) (for reports and more information)
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
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
  - Natural hazards – earthquakes, landslides, volcanoes
  - Episodic nature, planning perspectives, uncertainty

- **Structural controls on resource accumulations**
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

Wax Lake Delta, LA
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
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
Climate Change

- **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
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, Anthropomorphemic 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
Work in interdisciplinary teams and across cultures

Have strong quantitative skills and ability to apply

Understand and use scientific research methods

Ability to access and integrate information from different sources and to continue to learn

Communicate effectively to scientists & non-scientists

Critical thinking/problem solving skills
Be technologically versatile (i.e. Google Earth, tablets, smartphones, apps)

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

Integrate data from different disciplines and apply systems thinking

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

Have strong field skills and a working knowledge of GIS

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
- Employers

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

- Academics
- Employers

Integrate data from different disciplines and apply systems thinking

- Academics
- Employers

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

- Academics
- Employers

Have strong field skills and a working knowledge of GIS

- Academics
- Employers
Have strong quantitative skills and ability to apply

Academics

Employers

Critical thinking/problem solving skills

Academics

Employers

Ability to access and integrate information from different sources and to continue to learn

Academics

Employers

Communicate effectively to scientists & non-scientists

Academics

Employers

Work in interdisciplinary teams and across cultures

Academics

Employers

Be technologically versatile (i.e. Google Earth, tablets, smartphones, apps)

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**
  • Work by analogy, inference and the limits of certainty
  • Have a passion for solving problems

• **Intellectually flexible - applying skills in new scenarios**
• Critically evaluate literature, critical thinking
• Experience with authentic research, collection of new information

• **Preparation for life-long learning**
  • How to learn and use new technology and software
  • Ability to learn and apply new concepts, ideas and data
<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>
</tr>
</thead>
<tbody>
<tr>
<td>Critical thinking/problem solving skills</td>
<td>P</td>
</tr>
<tr>
<td>Communicate effectively to scientists &amp; non-scientists</td>
<td>P</td>
</tr>
<tr>
<td>Readily solve problems, especially those requiring spatial and temporal (i.e. 3D and 4D) interpretations</td>
<td>M</td>
</tr>
<tr>
<td>Make inferences about Earth system from observations of natural world combined with experimentation and modeling</td>
<td>M</td>
</tr>
<tr>
<td>Work with uncertainty, non-uniqueness, incompleteness, ambiguity and indirect observations</td>
<td>M</td>
</tr>
<tr>
<td>Ability to access and integrate information from different sources and to continue to learn</td>
<td>M</td>
</tr>
<tr>
<td>Understand and use scientific research methods</td>
<td>P</td>
</tr>
<tr>
<td>Have strong quantitative skills and ability to apply</td>
<td>P</td>
</tr>
<tr>
<td>Integrate data from different disciplines and apply systems thinking</td>
<td>P</td>
</tr>
<tr>
<td>Have strong field skills and a working knowledge of GIS</td>
<td>M, P</td>
</tr>
<tr>
<td>Work in interdisciplinary teams and across cultures</td>
<td>P</td>
</tr>
<tr>
<td>Have strong computational skills and the ability to manage and analyze large datasets</td>
<td>P</td>
</tr>
<tr>
<td>Be technologically versatile (i.e. Google Earth, tablets, smartphones, apps)</td>
<td>M</td>
</tr>
</tbody>
</table>
Preparation for “real world” professional projects and/or future research

Critical thinking & problem solving

- **Problem Solving with real data, non-unique answers**
  - Understand context of problem
  - Identify appropriate questions to ask, data to collect, methods to use
  - Be able to collect data, analyze quality, interpret and apply
  - Make predictions with limited data
  - Understand & manage uncertainties
  - Visualize and solve problems in 3- & 4-D
  - Understand the importance of scale
  - Work on problems with no clear answers, high ambiguity
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**
High level quantitative skills increases employability & resiliency

• Higher level math & computer programming skills
  – Probability, statistics, uncertainty analysis & risk assessment
  – Differential equations/linear algebra
  – Computer programming, modeling
Data Analysis Skills

- **BIG DATA**
  - Integrate multiple large datasets
    - Different types - disciplines
    - Model, statistical analysis
    - Use visual models, modeling tools (Stella, Modflow, Matlab, etc.), simulations
    - Integrate technical, quantitative skills, programming, application development

Geoscience ANALYST - Mira Geoscience

Leapfrog3D: NUMERIC MODELLING

Cross-Domain Visualization, Exploration, and Analysis Capabilities
Enthought Canopy Geoscience
Cross-disciplinary Teamwork on Interdisciplinary Projects

• Project management in team settings
  • Working in teams with different backgrounds, specialties, experience, personalities
    • Being a leader & follower; listening, sharing
  • Goal setting
    • Solution-oriented approaches
  • Time management
  • Conflict resolution
    • Managing problems on the front end

Fieldwork builds these skills
– **Communication skills**

– Written & verbal scientific communication
  • Tailored to several different audiences
    – Scientists, educated non-scientists, engineers, potential funders, management & general public

– **Listening skills**
Non-technical Skills

- **Ethics**
  - Codes of conduct
  - Awareness of implicit biases

- **Interpersonal skills - ability to work with different...**
  - Personalities, emotional makeup, viewpoints
  - Specialties, educational backgrounds, abilities

- **Professionalism**
  - Business acumen
  - Risk management
  - Leadership

- **Global perspective**
  - Different cultures

- **Understanding societal relevance & implications**
Effective Ways of Developing Skills/Competencies/Concepts

Experiential learning

Constant engagement/opportunities to practice skills/use concepts

- Problem solving; using and analyzing real data in classes
  - ASBOG test as a source of problem-oriented activity
- Integrate written/oral intensive courses in programs
- Collaborative, integrative, interdisciplinary team projects
- Integration and interactive use of technology
  - Visualization, simulation, modeling, use of real data

Substantial experiences

- Fieldwork and field experiences
- Capstone, problem/project oriented courses
- Independent research experiences/projects, Senior Theses
- Internships or REUs

Active collaboration between academia and the outside employers