EAR-1347209: The Future of Undergraduate Geoscience Education

Geoscience Employers Workshop Outcomes:

A Geoscience Employers Workshop was held May 27-28 in Washington D.C. to get input on the developing community vision for the geosciences. The 46 participants included an even distribution of employers from the petroleum industries; hydrology, engineering and environmental consulting companies; and federal agencies that employ geoscientists, along with representatives from some of the geoscience professional societies. One participant represented the mining. The first breakout session asked them to identify the skills competencies and conceptual understandings needed by undergraduates for future employment. Subsequently the results from the Summit and survey were presented, and several breakout sessions focused on comparison of their initial views and that of the Summit and survey. Overall there was strong agreement amongst the employers, with little variation based on type of employer, and strong agreement with the developing vision from the Summit and survey. In addition to their own views, they also provided needed granularity to the concepts and skills identified by the Summit. Lastly, they discussed ways to implement or develop these skills and competencies in students, the role industry and other employers should take to help the academic community, and how to develop better academic-industry partnerships. The specific results are summarized below.

Important concepts identified by the employers:

1) 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

2) Processes
- Geochemical Cycles – C, H_2O, N, P
- Thermodynamics – energy, kinetics, diffusion, heat, mass transfer, fluid flow
- Geomechanics/Stress State/Rheology
- Geological Time/Earth Evolution
- Plate Tectonics/Geodynamics
- Tectonic Processes
- Depositional Processes
- Crystallization Processes

3) Tools
- Statistics/Uncertainty/Probability
- Mathematics (differential equations, linear algebra)

- Cartography
- Geography and spatial thinking
- Field Methods
- Potential Fields
- Remote Sensing
- Age Dating
- Instrumentation
- Analytical/Numerical Modeling
- Seismology/Geophysical sensing

The employers also provided more granularity for each of the general concepts identified by the Summit.

Earth as a Complex System:

- Nonlinear 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

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

<u>Natural resources:</u>

- 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

<u>Surface Processes:</u>

- 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 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 and 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 interactions
- Economics and public policy
    - Groundwater quality
    - Regulatory standards

Important skills and competencies identified by the employers:

<u>Geoscience thinking</u>

- Earth Science habits of mind/geoscientific thinking
  - Temporal and spatial thinking
  - Systems thinking
  - Geologic reasoning and synthesis
- Problem solving in the context of an open and dynamic system
  - Asking appropriate questions
  - Understand context of problem
  - Problem solving in 3- and 4-D
  - Ability to work on problems with no clear answers
  - Managing uncertainty in problem solving
  - Have a passion for solving problems
- Working by analogy, inference and the limits of certainty
- Intellectually flexible - applying skills in new scenarios

<u>Technical Skills:</u>

- Problem Solving with data
  - Data collection and interpretation, use of data and application
  - Evaluation of data, data quality, purpose of collecting data, begin with understanding of how data will answer question
  - Understanding data and uncertainties
  - Make predictions with limited data
  - Use of appropriate methods, reading and interpreting graphs
- Quantitative/Math skills
  - Differential equations/linear algebra
  - Probability and statistics (so understand risk)
  - Understanding of scale
  - Computer programing skills (be able to think about how to solve a problem computationally)
- Experience with authentic research, collection of new information
- Critically evaluate literature, encourage critical thinking

<u>Field and Technology Skills:</u>

- Field Skills
  - Field camp and/or Field mapping experiences
  - Improves spatial cognition, creative problem solving, teamwork, geoscience synthesis
  - Data supports field skills are unique and essential, difficult to replicate or substitute
- GIS – Most essential for building large data sets
- 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

<u>Non-technical Skills:</u>

- Oral and written communication competency
  - Science writing and verbal communication; knowing your audience
  - Public speaking
  - Listening skills
- Project management
  - Ability to work in teams
    - Be a leader and follower
    - Don't divide work; iterative process between students with different backgrounds/disciplines
  - Goal setting
  - Conflict resolution (open minded – answer may lie in the conflict space)
  - Managing problems on the front end
  - Solution-oriented approaches
  - Time management
- Professionalism, interpersonal skills
  - Ethics, ethical awareness and conduct
  - Business acumen and risk management
  - Cultural interactions, cultural literacy, emotional literacy, learning styles, awareness of implicit bias
  - Leadership
  - Career awareness/resume/interview preparation
- Global perspective
- Understand societal relevance

Ranking of importance of skills identified by Summit:

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)	Level of Mastery
Critical thinking/problem solving skills	P
Communicate effectively to scientists & non-scientists	P
Readily solve problems, especially those requiring spatial and temporal (i.e. 3D and 4D) interpretations	M
Make inferences about Earth system from observations of natural world combined with experimentation and modeling	M

Work with uncertainty, non-uniqueness, incompleteness, ambiguity and indirect observations	M
Ability to access and integrate information from different sources and to continue to learn	M
Understand and use scientific research methods	P
Have strong quantitative skills and ability to apply	P
Integrate data from different disciplines and apply systems thinking	P
Have strong field skills and a working knowledge of GIS	M,P
Work in interdisciplinary teams and across cultures	P
Have strong computational skills and the ability to manage and analyze large datasets	P
Be technologically versatile (i.e. Google Earth, tablets, smartphones, apps)	M

<u>Additional Employer discussion:</u>

- Difference between Explicit versus Tacit Knowledge
  - To what extent to you give this versus they discover themselves
  - Transferability of Skills and Competencies
- Integrated Culture between Academia and Industry
  - Advisory boards
  - Workshops and engagement
- Geoscience as a Service to Society
  - Discussion topic with students for recruitment and retention
  - Looking at the big picture
- Balance between Geoscience Knowledge and Professional Skills
  - Where to draw that line
    - Should there be requirements or a certification before completion
    - Should curriculum prepare students for ASBOG exam?
  - External forces

<u>Experiential Learning:</u>

- Vehicles for Practical Problem Solving
  - Constant engagement in opportunities to practice skills and use concepts
  - Field experiences
  - Internships

  - Senior thesis, research projects
  - Project based courses
- Technical skills being at the forefront
- Getting internship etc. experience – the earlier the better, the more often the better
- Use games to teach & reward innovation and creativity

Ways employers can help:
- Provide opportunities for end to end learning: conceptualization, collection of data, analysis, and presentation
- Providing samples and data
- Problem oriented short courses
- Collaborative research projects between employers and academia
- Judging student activities
- Supporting field experiences – providing funds and representatives for teaching
- Sabbatical programs – both ways; Faculty fellowships
- Internships – earlier and more often the better
- Virtual internships, classes, and field experiences
- Campus teaching awards or pedagogical development
- Geoscientists without Borders – raise profile of the science and profession

Training
- Importance of practical applications and problem solving embedded in the curriculum
- Opportunities for instruction by professional partners
  - Professors of practice, invited experts
  - Short courses, webinars, practicums, pop-up and micro (AGI) courses in core competencies
  - Annual industry symposia, career days with emphasis on problem solving skills and essential component
  - Opportunities for partnerships with curriculum developers
- Working through industry - instructional barriers that might exist with proprietary barriers with data and software

Opportunities:
- Tech Transfer as a part of greater community engagement meeting the mission of both the institution industry
- Added value of local, more frequent engagement and ties to broader impacts
- Growing/expanding stakeholders, growing campus consortiums and partnerships towards similar goals

Measuring effectiveness and competencies:
- Accreditation of programs and practicality of course (engineering model; ASBOG)
- Collection of courses, practicums with appropriate assessments
- Need stronger articulation of measures of competence
  - elate to specific employer needs
  - explicitly tie skills and applications to courses
  - acknowledging one size does not fit all

Additional thoughts:

- Models, tools, and resources already exist for how to develop the whole student and prepare them for employment
  - Cutting Edge website
  - ASBOG test as a source of problem-oriented activity for the classroom and as an incentive
  - Assessment, accreditation (demonstrable and measurable)
- But success requires
  - More active collaboration between academia and the outside employers
  - Ranging from formal courses to informal mentoring of students faculty
  - Culture changes needed for faculty to place greater value on the benefits of active collaboration
  - Faculty need to be incentivized to increase experiential learning into classroom/curriculum
  - Incorporation of the non-technical skills into the geoscience curriculum or proactively include or advise students to take courses/experiences related to those non-technical skills (e.g. business, ethics, etc.)
- Solutions
  - Professional societies leading active discussions about these collaborations
  - Increased industry – academia interaction
  - NSF funding for research to demonstrate outcomes of these collaborations – we are missing opportunities community