Future of Undergraduate Geoscience Education & Geoscience Workforce

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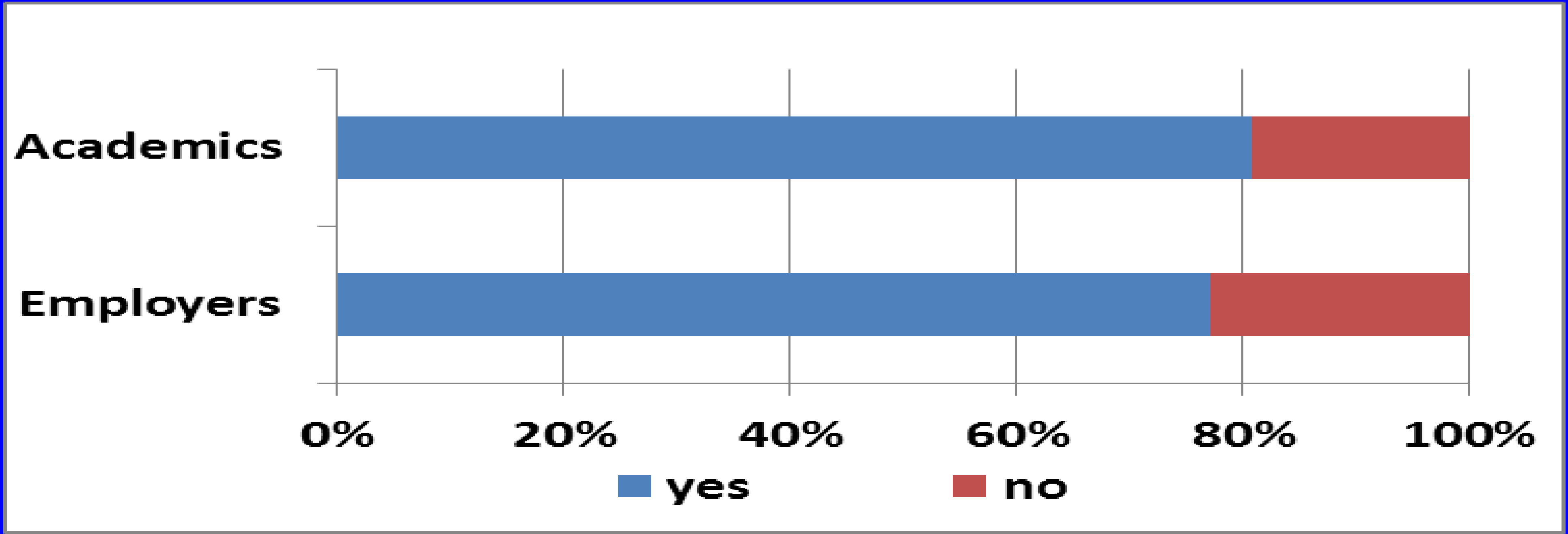
Results from project sponsored by

National Science Foundation
WHERE DISCOVERIES BEGIN

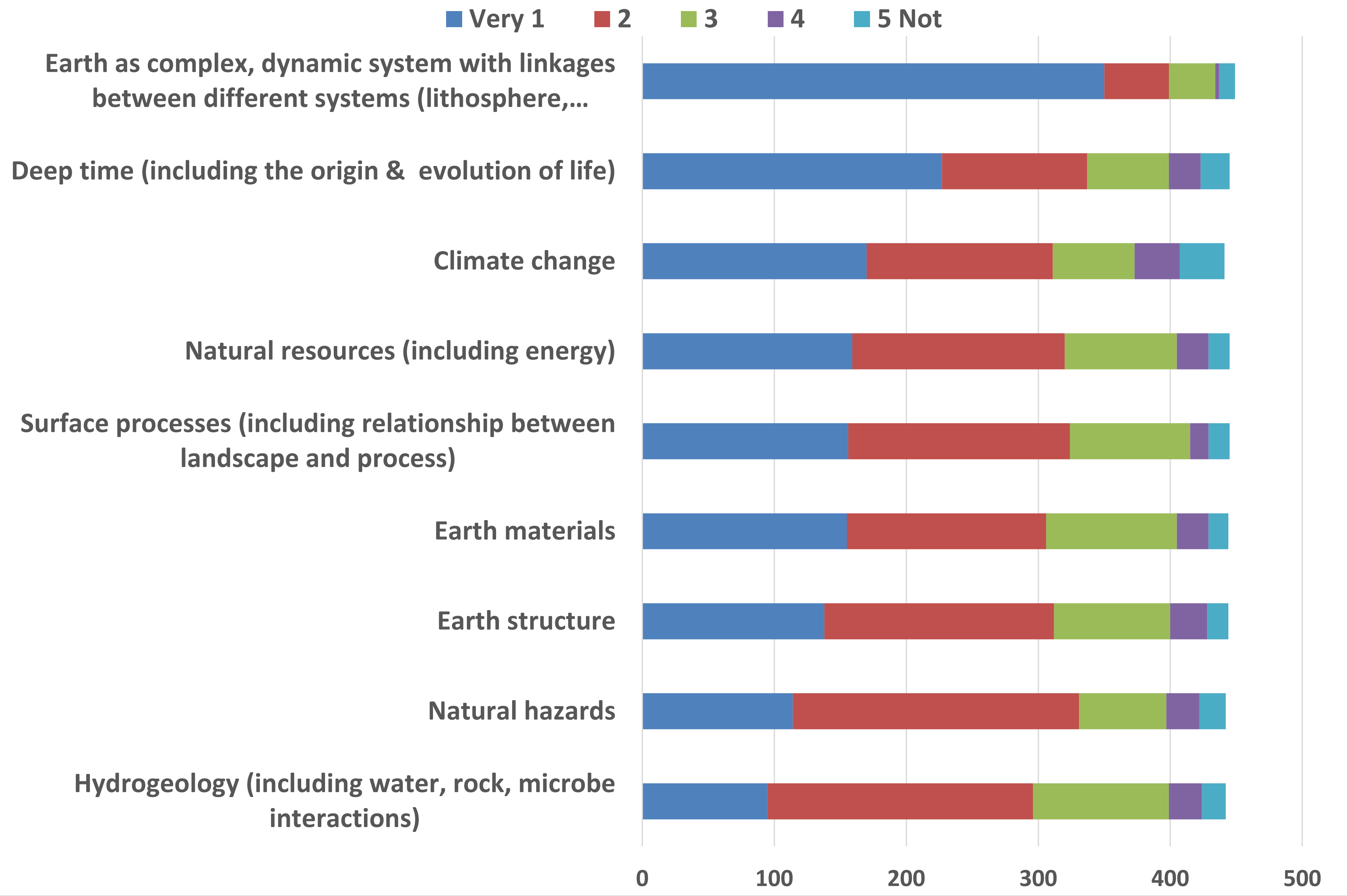
Concepts, Skills, Competencies

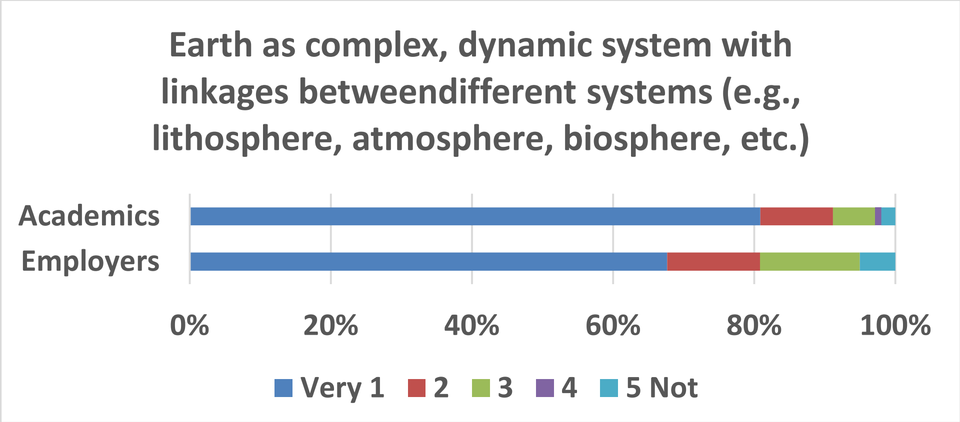
- **Major conclusion of Summit**
  - **Developing competencies, skills, and conceptual understanding**
  - **More important than taking specific courses**

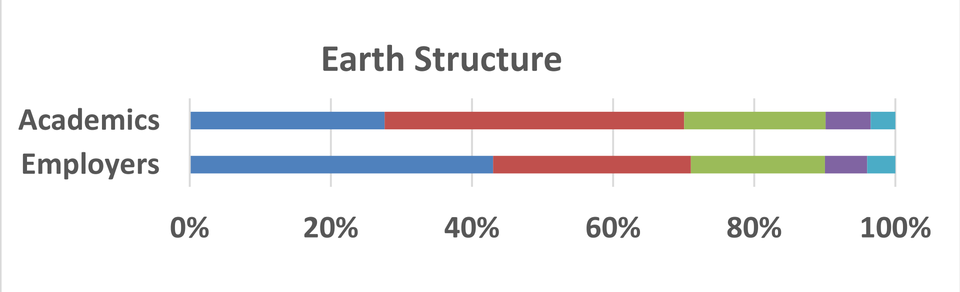
Survey Results:

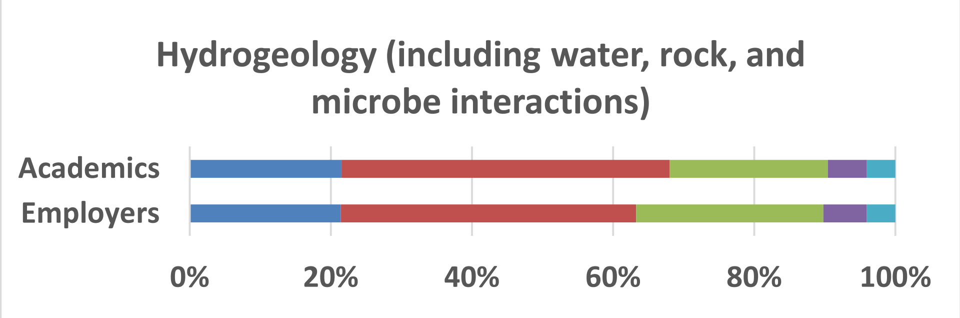


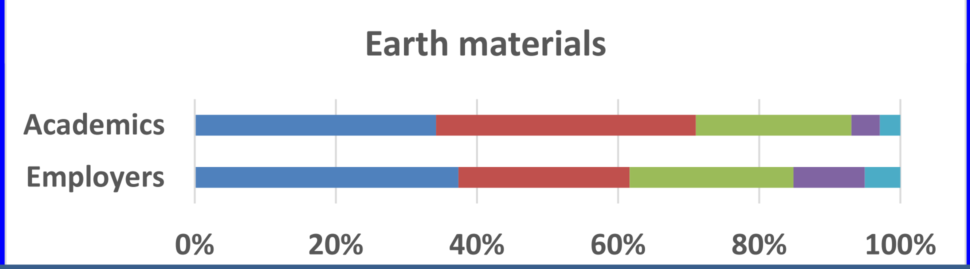
Summit Outcomes/Survey Results: Important Concepts

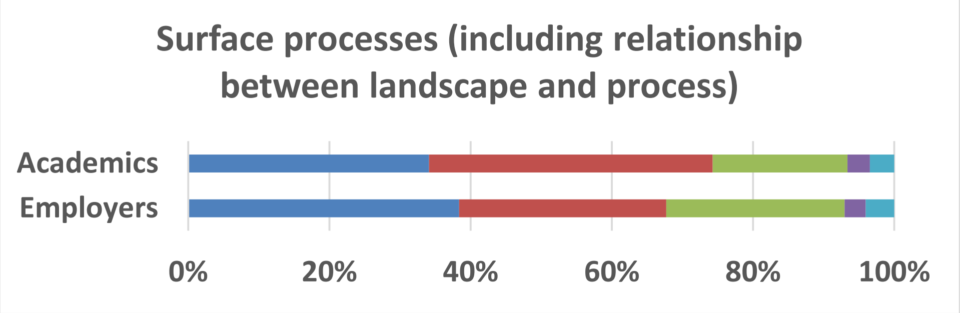


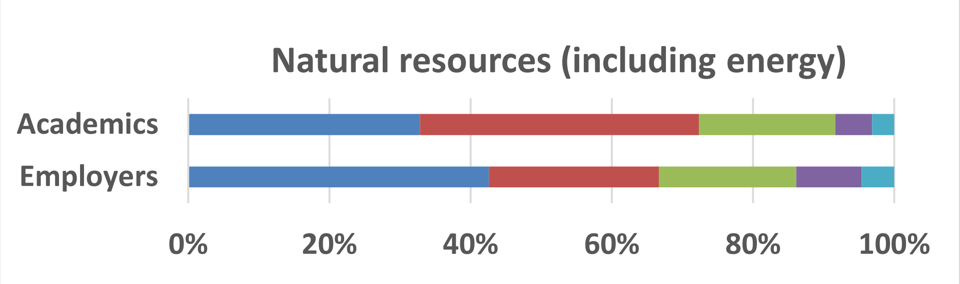


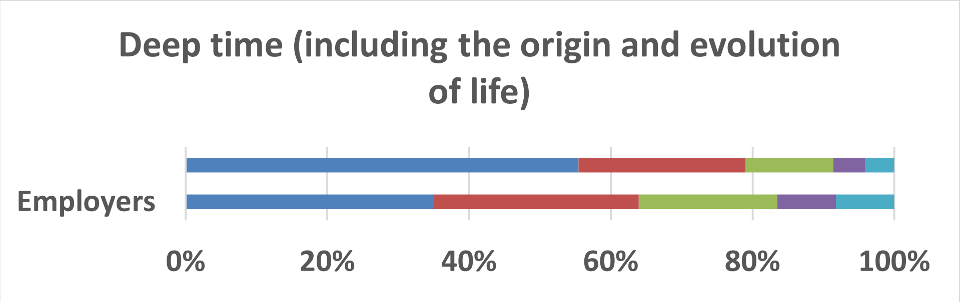


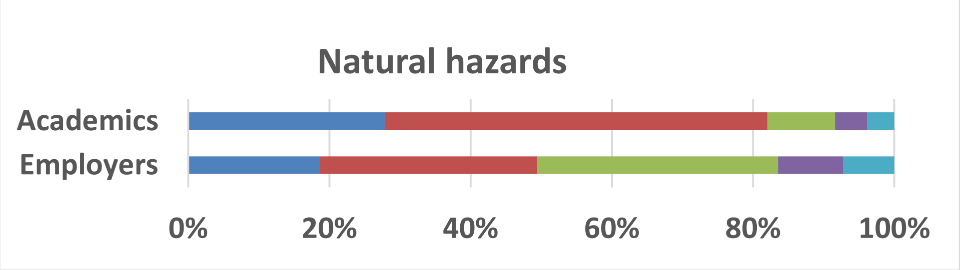


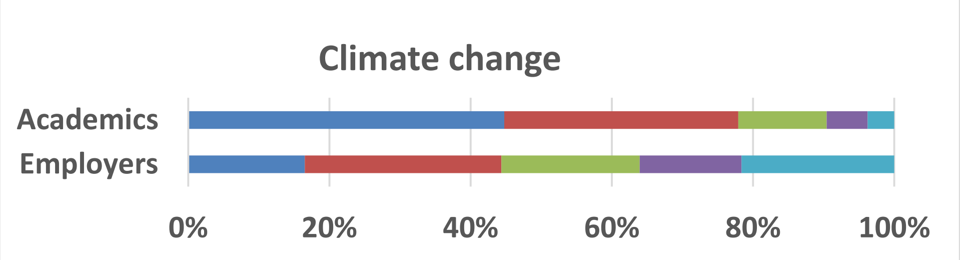












Employer Workshop added granularity

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

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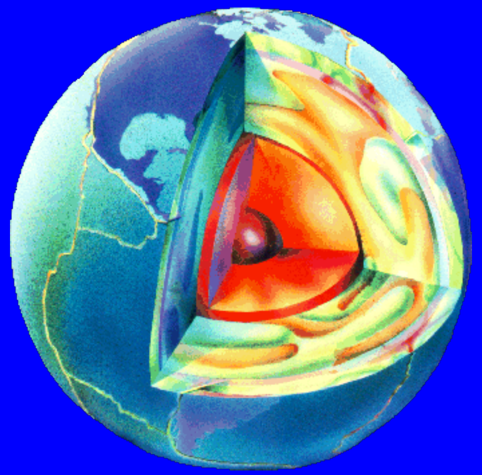
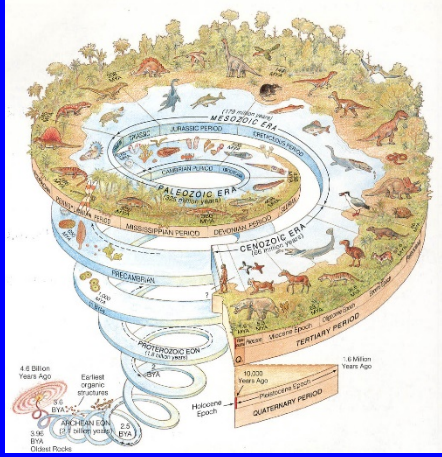
- http://www.jsg.utexas.edu/events/future-of-geoscience-undergraduate-education/   (for reports and more information)

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

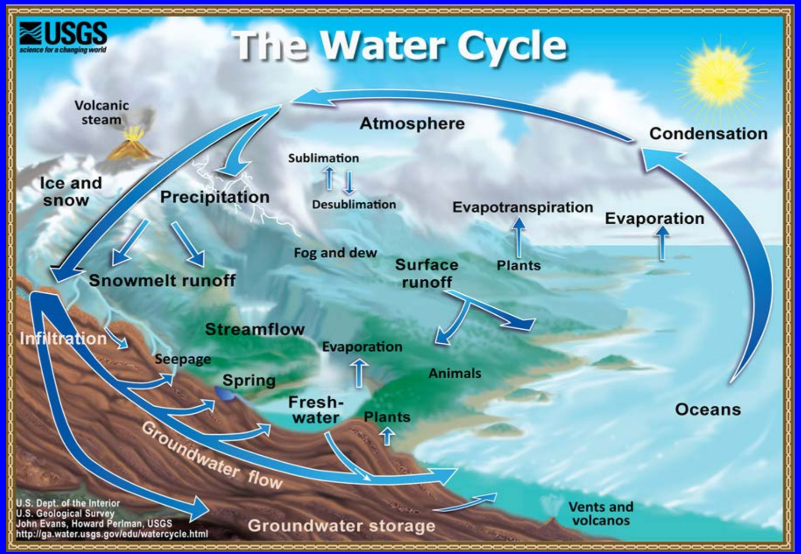
- **Structure of Earth**
  - Mechanical and compositional layers
  - Tools for defining earth structure (seismic waves, analysis of earthquakes, etc.)
- **Deformation**
  - Stress and strain
  - Rock mechanics & deformation processes
  - Fractures, faults, folds, other structural features, etc.
- **Plate 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

Hydrogeology

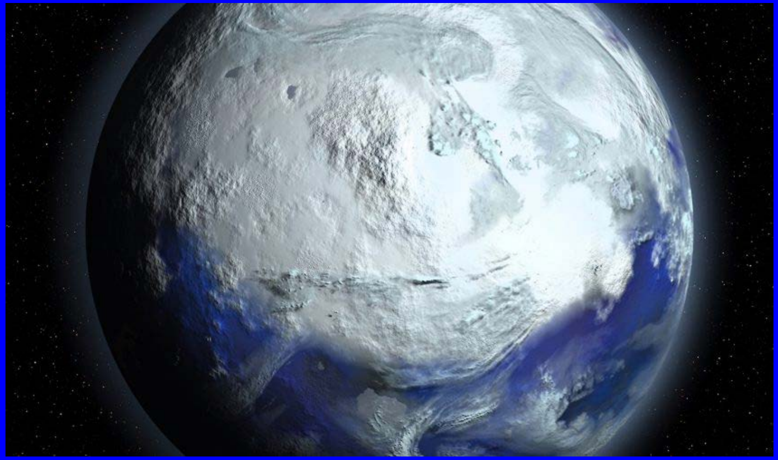
- Water cycle
- Groundwater/aquifers, confined vs unconfined aquifers
  - Phase behaviors
  - Saturated vs unsaturated conditions
  - Scales of heterogeneity in space and time
  - Contaminant transfer
- Biogeochemistry and aqueous geochemistry
  - Microbe interactions
  - Nutrient cycling
- Subsurface-surface 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



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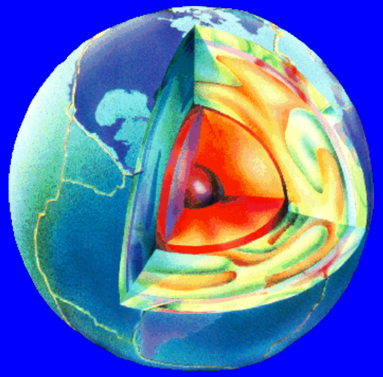
- What is climate change? Geologic scale vs. present change
  - Significant climate change in geologic past
  - Relevant space and time scales
  - Continental vs local scale change
  - Proxy records
  - Rate of climate change; rapid change
- Driving forces and causal mechanisms
  - External forcing vs. 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, Anthropomorphic Climate Change, Natural Hazards
  - Influence of geology on society
  - Influences of society on earth processes

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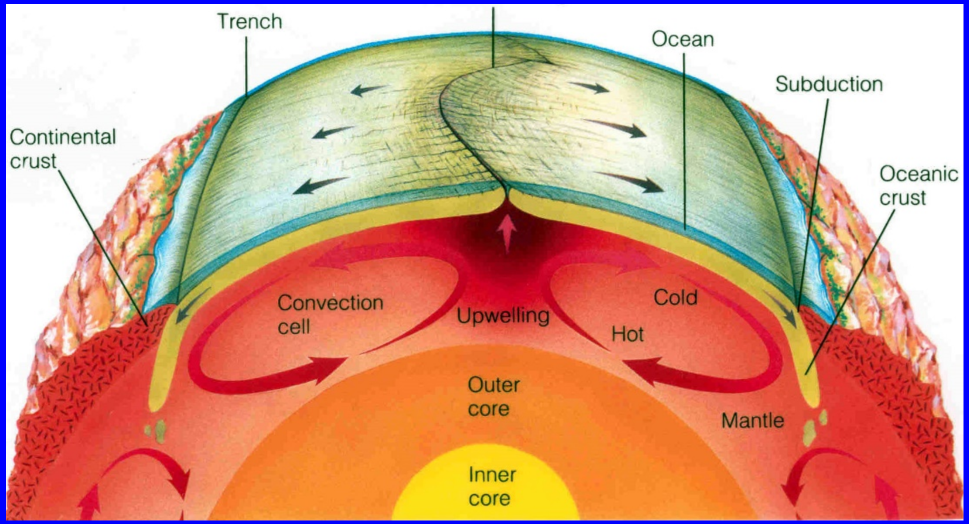
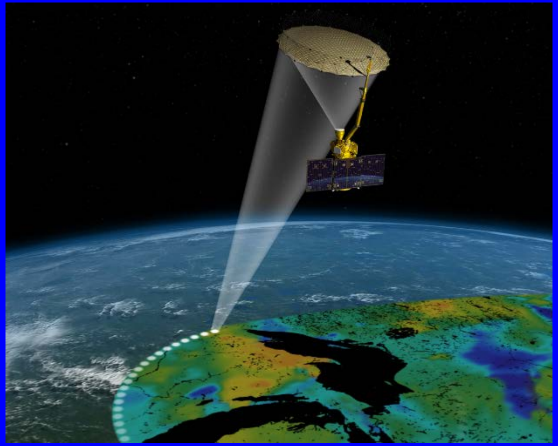
Processes

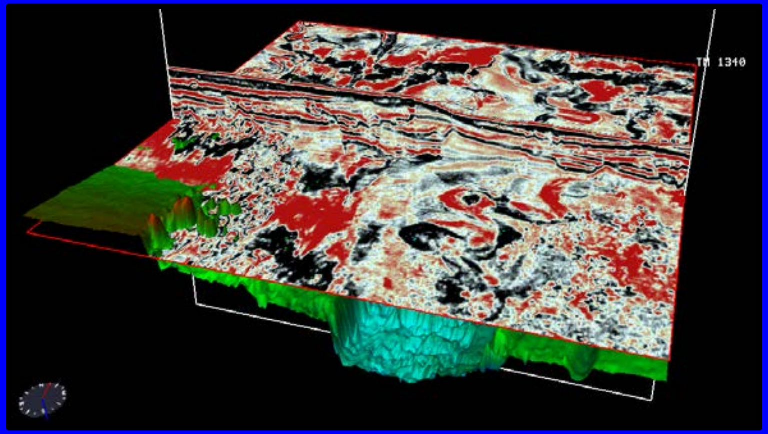
- **Thermodynamics** – energy, kinetics, diffusion, heat, mass transfer, fluid flow
- **Geochemical Cycles** – C, H_2O, N, P
- **Geomechanics/Stress State/Rheology**
- **Geological Time/Earth Evolution**
- **Plate Tectonics/Geodynamics**
- **Tectonic Processes**
- **Depositional Processes**
- **Crystallization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



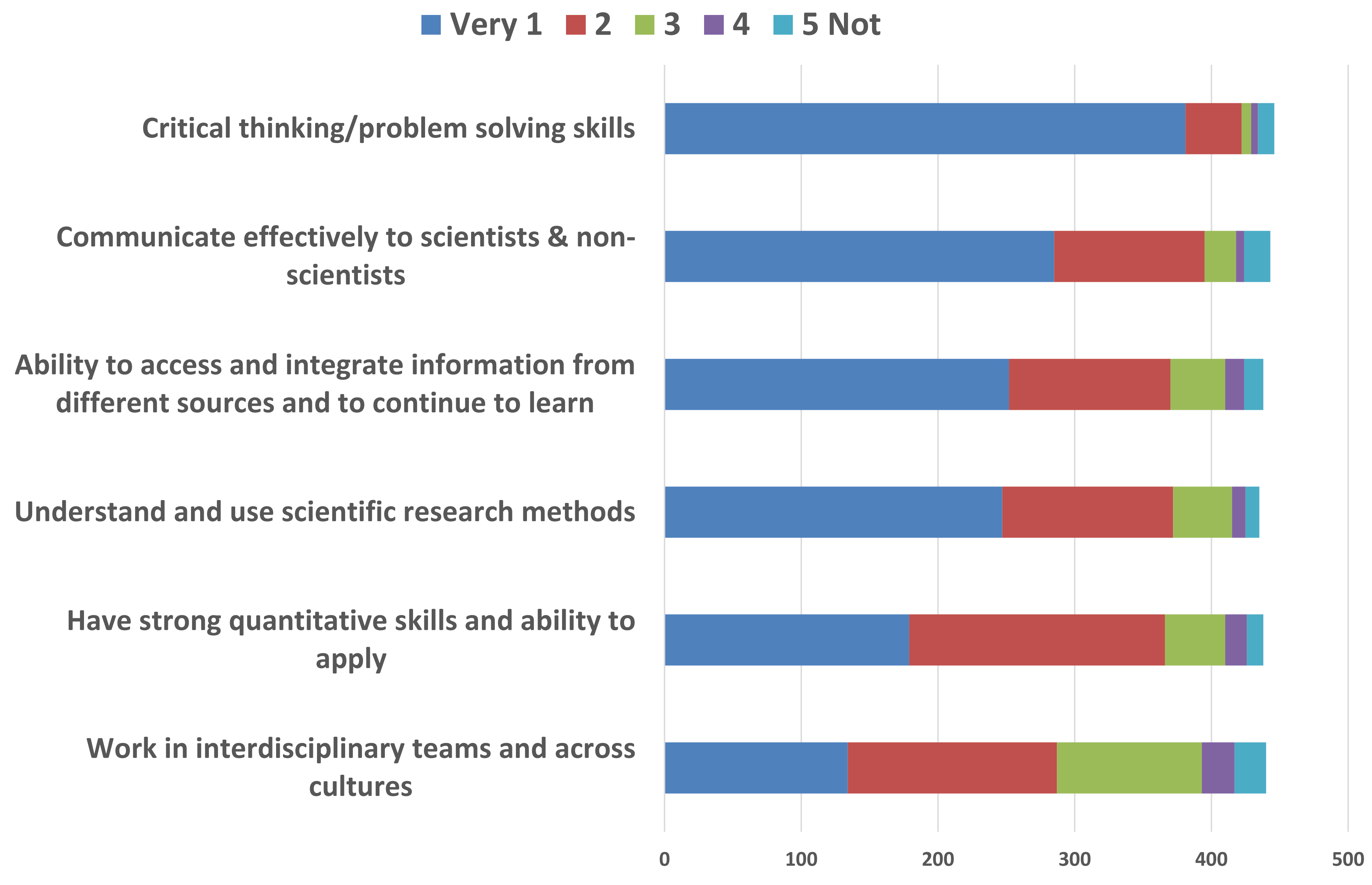
Tools

- 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

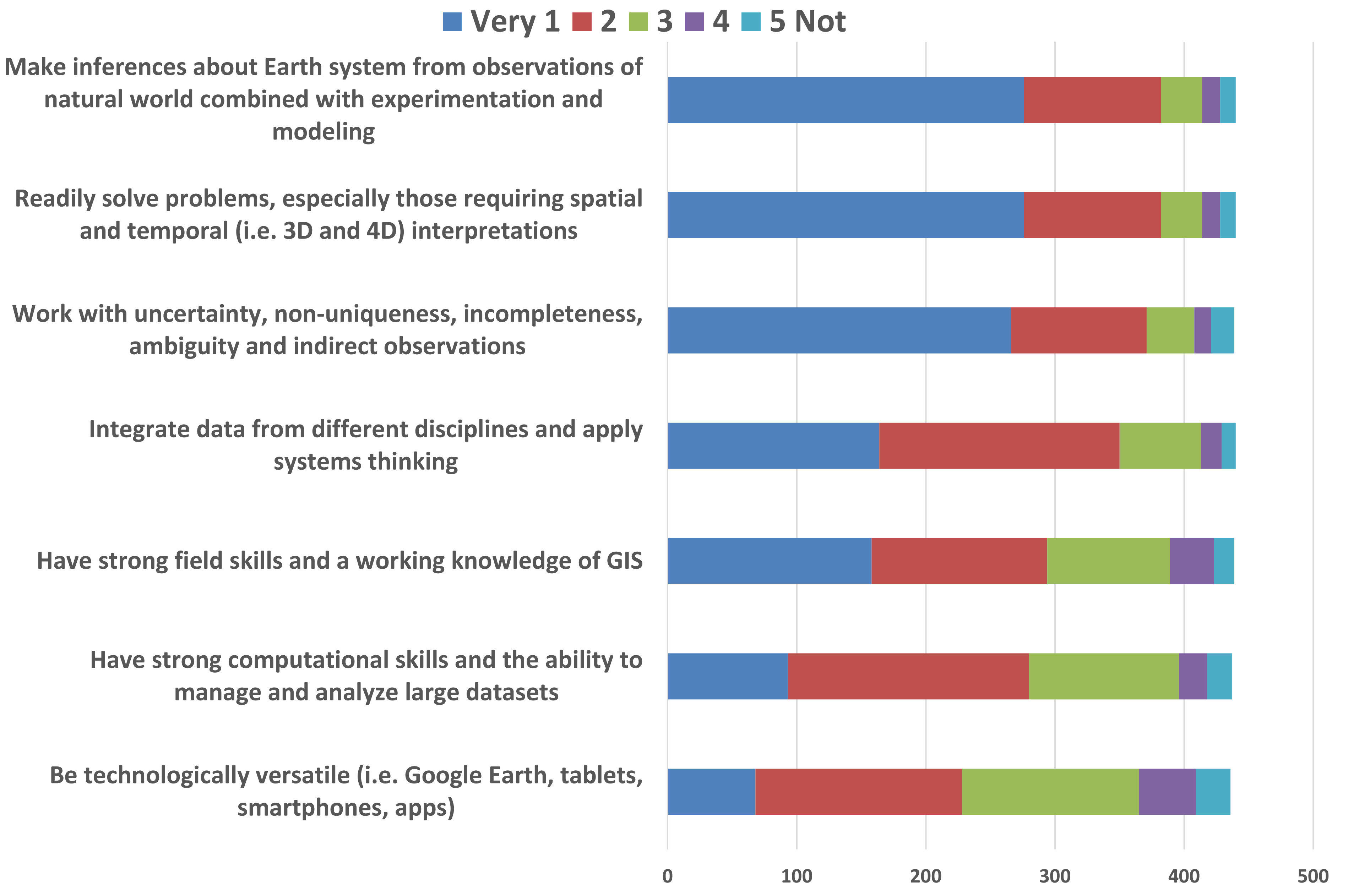


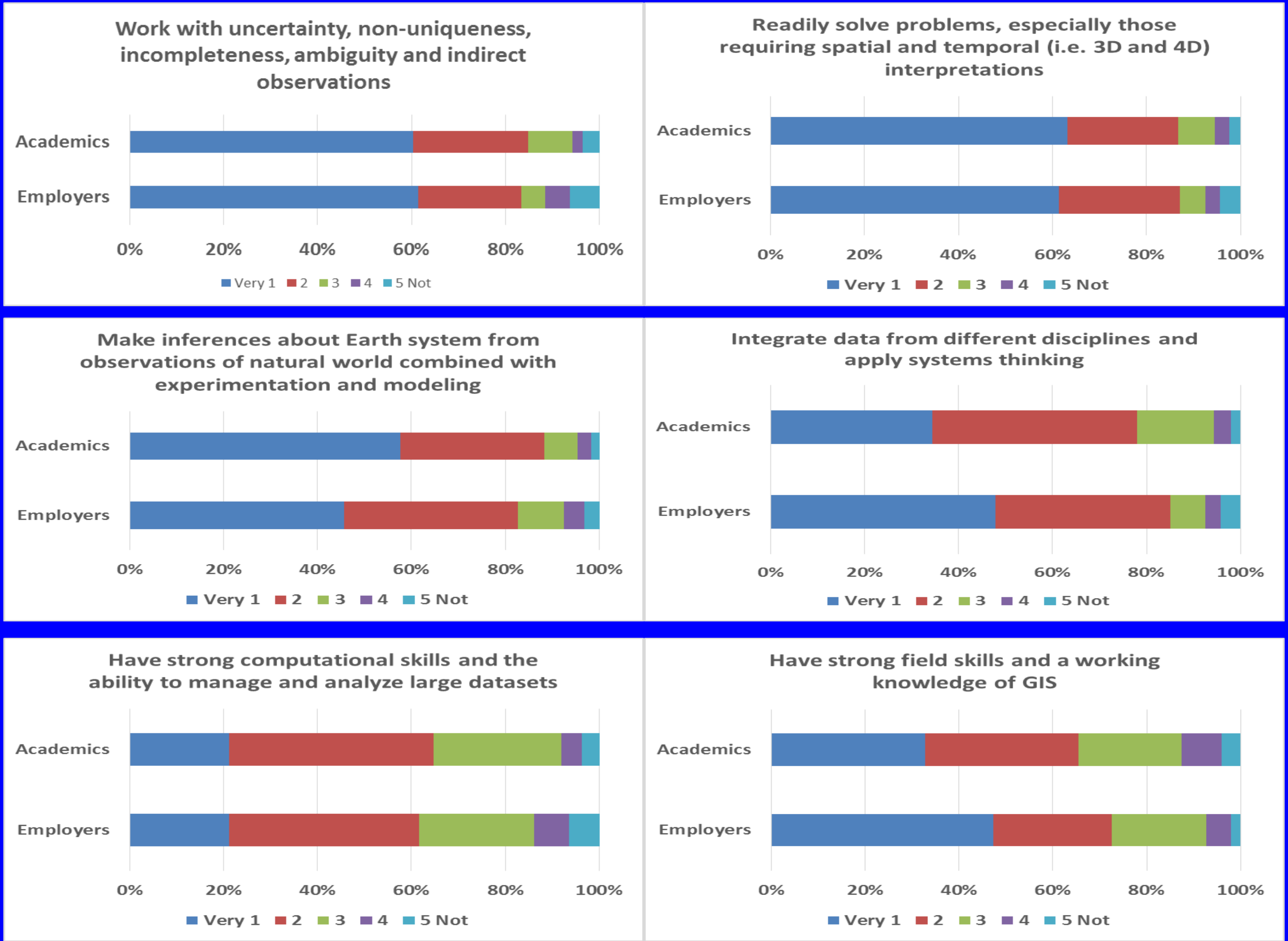


Summit Outcomes/Survey Results: Science Skills



Summit Outcomes/Survey Results: Geoscience Skills




Work with uncertainty, non-uniqueness, incompleteness, ambiguity and indirect observations
Academics
Employers
0%
20%
40%
60%
80%
100%
Very 1
2
3
4
5 Not
Readily solve problems, especially those requiring spatial and temporal (i.e. 3D and 4D) interpretations
Academics
Employers
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Very 1
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5 Not
Make inferences about Earth system from observations of natural world combined with experimentation and modeling
Academics
Employers
0%
20%
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Integrate data from different disciplines and apply systems thinking
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Very 1
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Have strong computational skills and the ability to manage and analyze large datasets
Academics
Employers
0%
20%
40%
60%
80%
100%
Very 1
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5 Not
Have strong field skills and a working knowledge of GIS
Academics
Employers
0%
20%
40%
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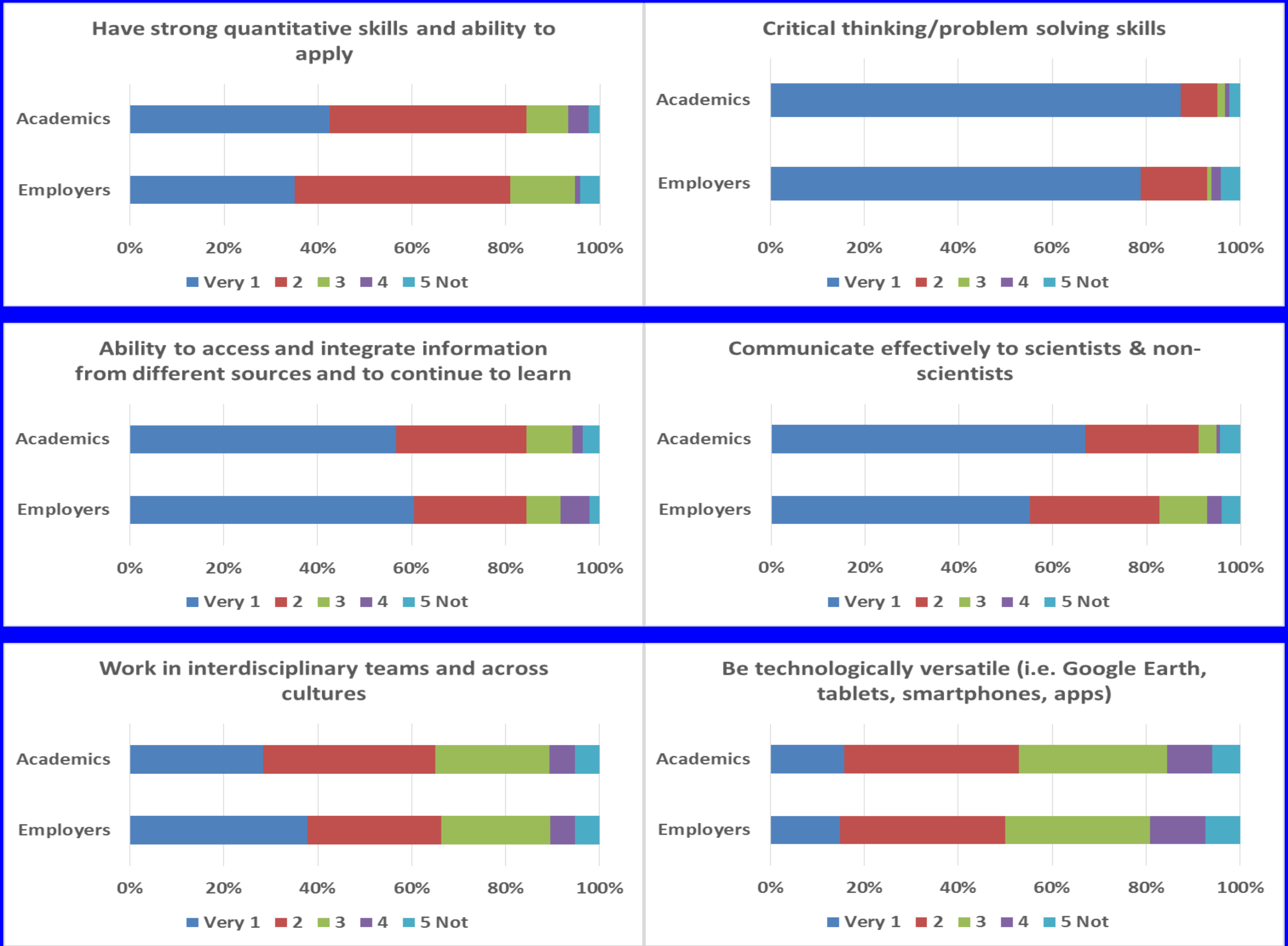

Have strong quantitative skills and ability to apply
Critical thinking/problem solving skills
Ability to access and integrate information from different sources and to continue to learn
Communicate effectively to scientists & non-scientists
Work in interdisciplinary teams and across cultures
Be technologically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

earthday.jpg

- 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

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

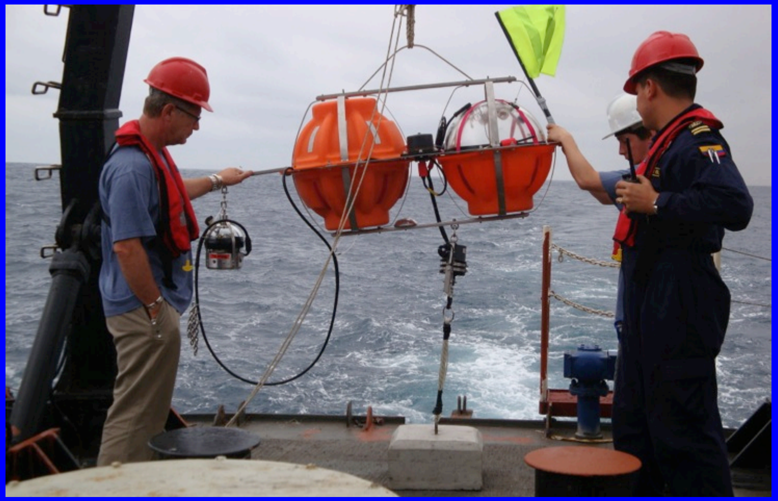
Preparation for "real world" professional projects and/or future research

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**

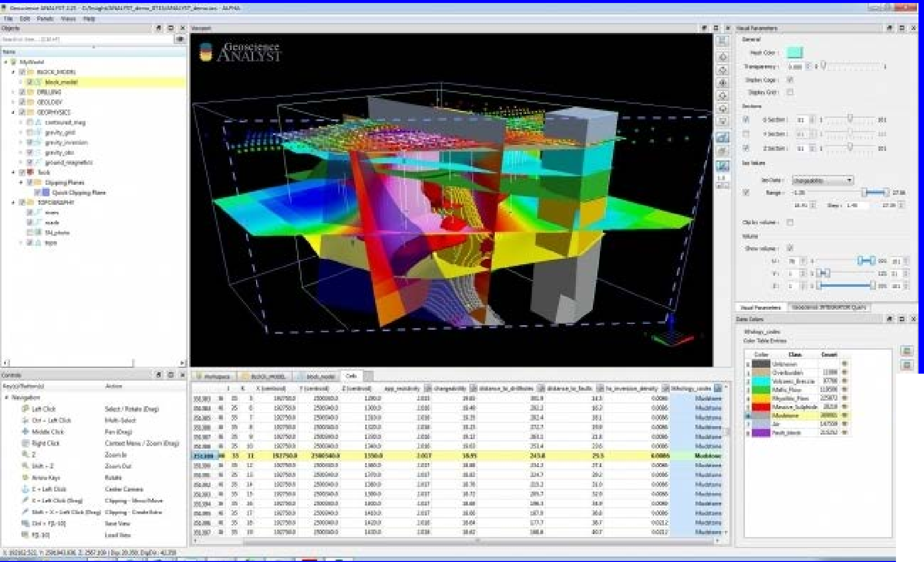


High level quantitative skills increases employability & resiliency

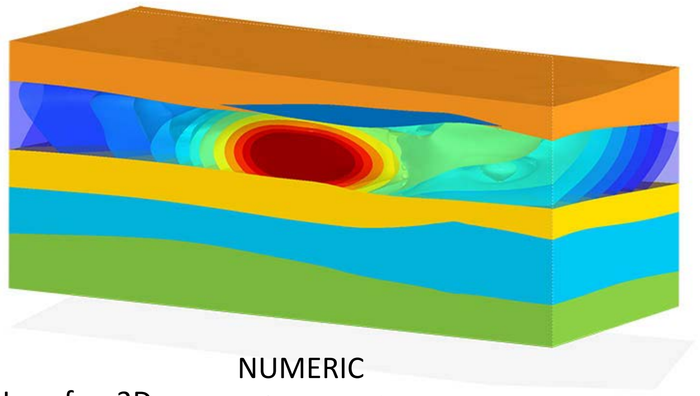
- Higher level math & computer programing skills
  - Probability, statistics, uncertainty analysis & risk assessment
  - Differential equations/linear algebra
  - Computer programming, modeling

Data Analysis Skills

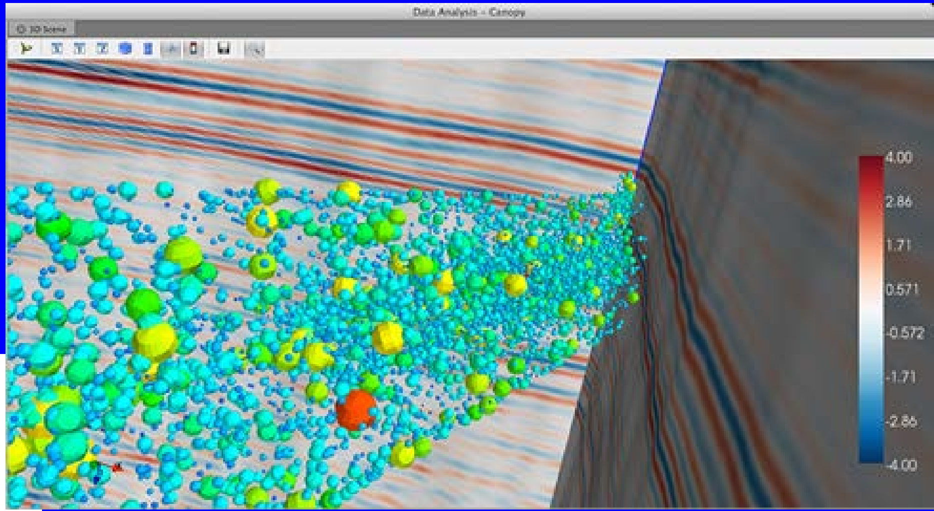
- **BIG DATA**
  - **Integrate multiple large datasets**
    - **Different types - disciplines**
    - **Model, statistical analysis**
  - **Use visual models, modeling tools (Stella, Modflow, Matlab, etc.), simulations**
  - **Integrate technical, quantitative skills, programming, application development**



Geoscience ANALYST - Mira Geoscience



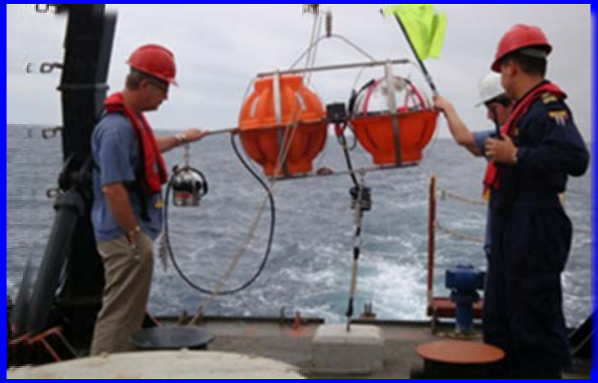
Leapfrog3D: NUMERIC MODELLING



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

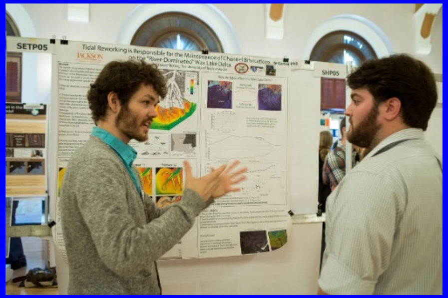
- Understanding societal relevance & implications

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