Geoscience Workforce & the Future of Undergraduate Geoscience Education

What does it mean to be a geoscientist? Is there a core curriculum?

Earth Educators' Rendezvous

Boulder, CO

July 14, 2015

Results from project sponsored by

National Science Foundation
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

Summit for Heads & Chairs – Jan. 2016

Geoscience Workforce today & in the future…

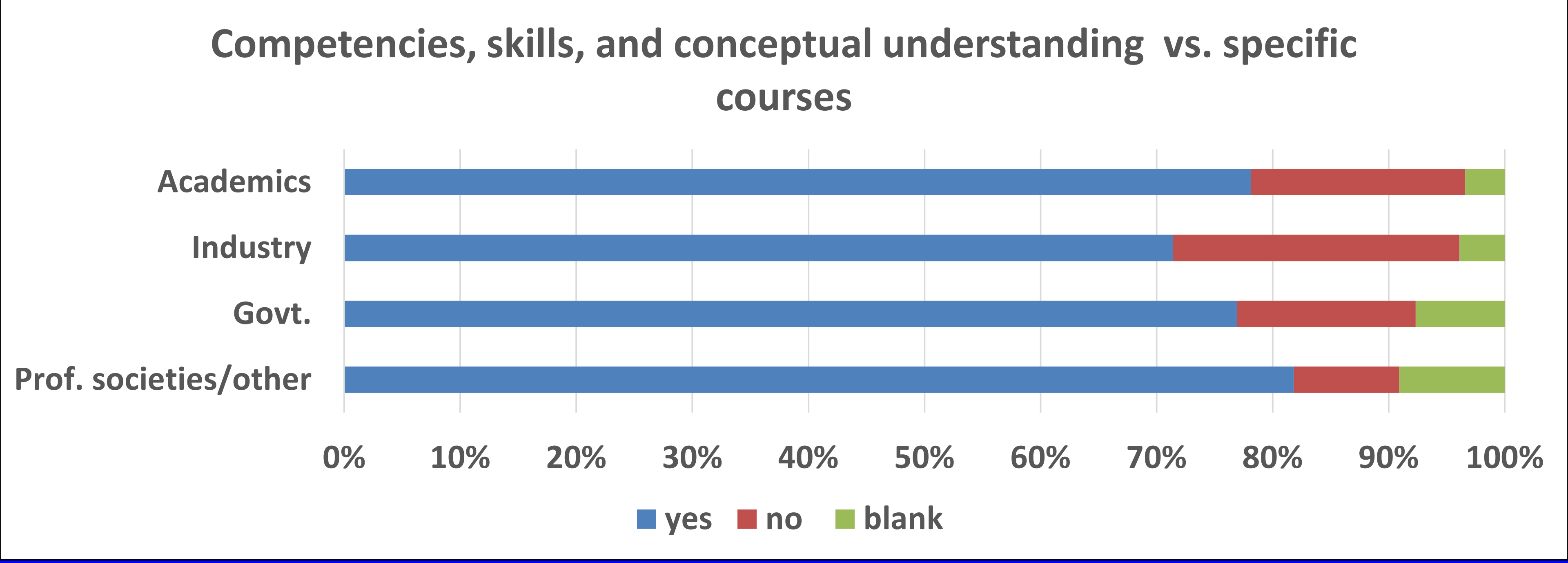
- **Need for multi-disciplinary approaches to problems**
  - **More integration of different types of datasets**
  - **Cross disciplinarily teamwork**
- **Different paradigms – thinking about rocks in fundamentally different ways**
- **Different types of jobs for geoscientists**
- **Technological advances – changing skill sets**
  - **More digital & modeling skills**
  - **Black box mentality without understanding how works**
- **BIG DATA – manage, use, model; statistical analysis**
- **More interaction between business & society**
  - **Economics/law/business practices/ethics/risk/environment**
- **Cultural diversity**

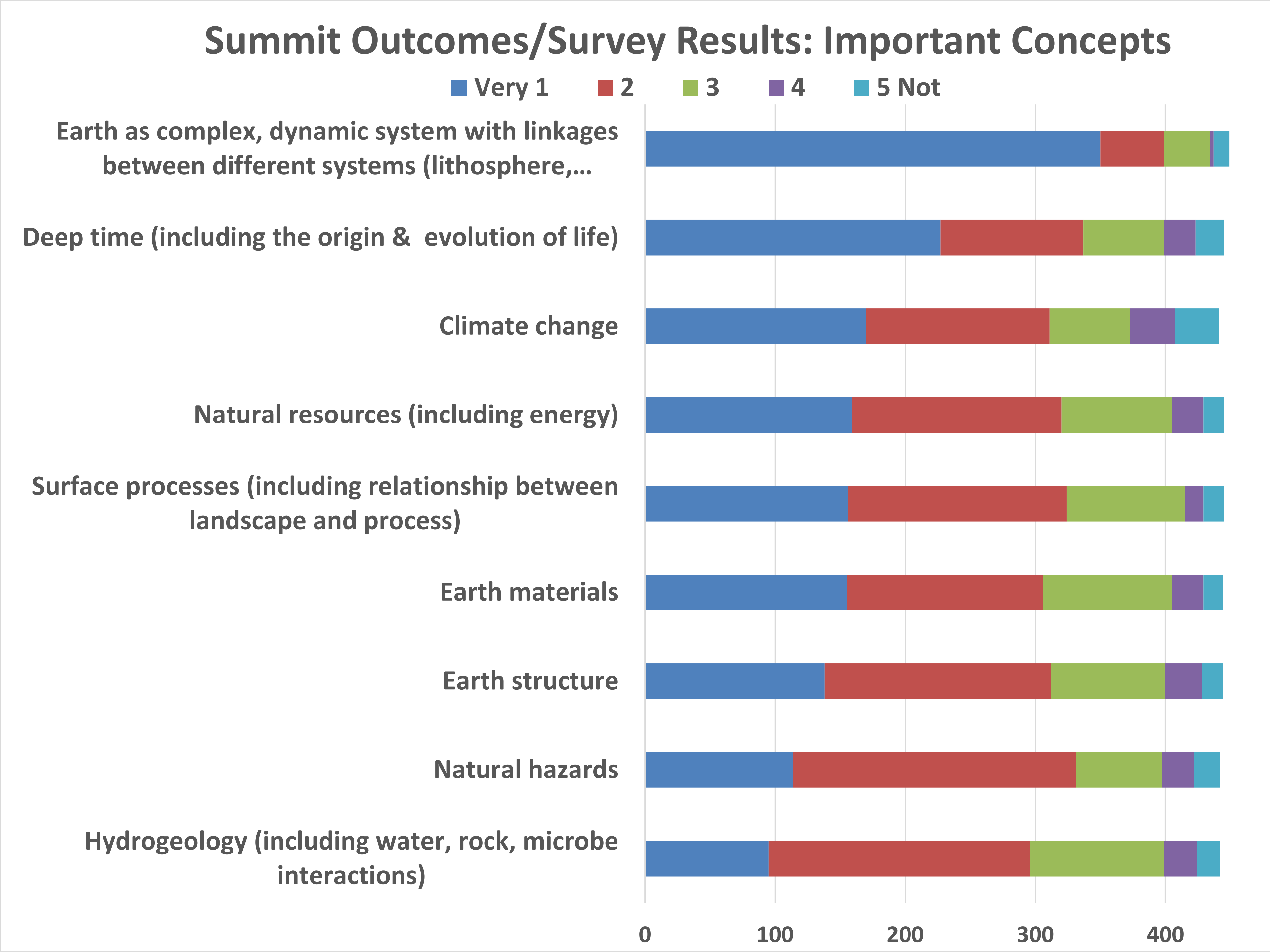
As the workforce changes – student learning must change

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
Very 1
2
3
4
5 Not
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)
0
100
200
300
400

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

- **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**

Tools

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

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

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

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 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

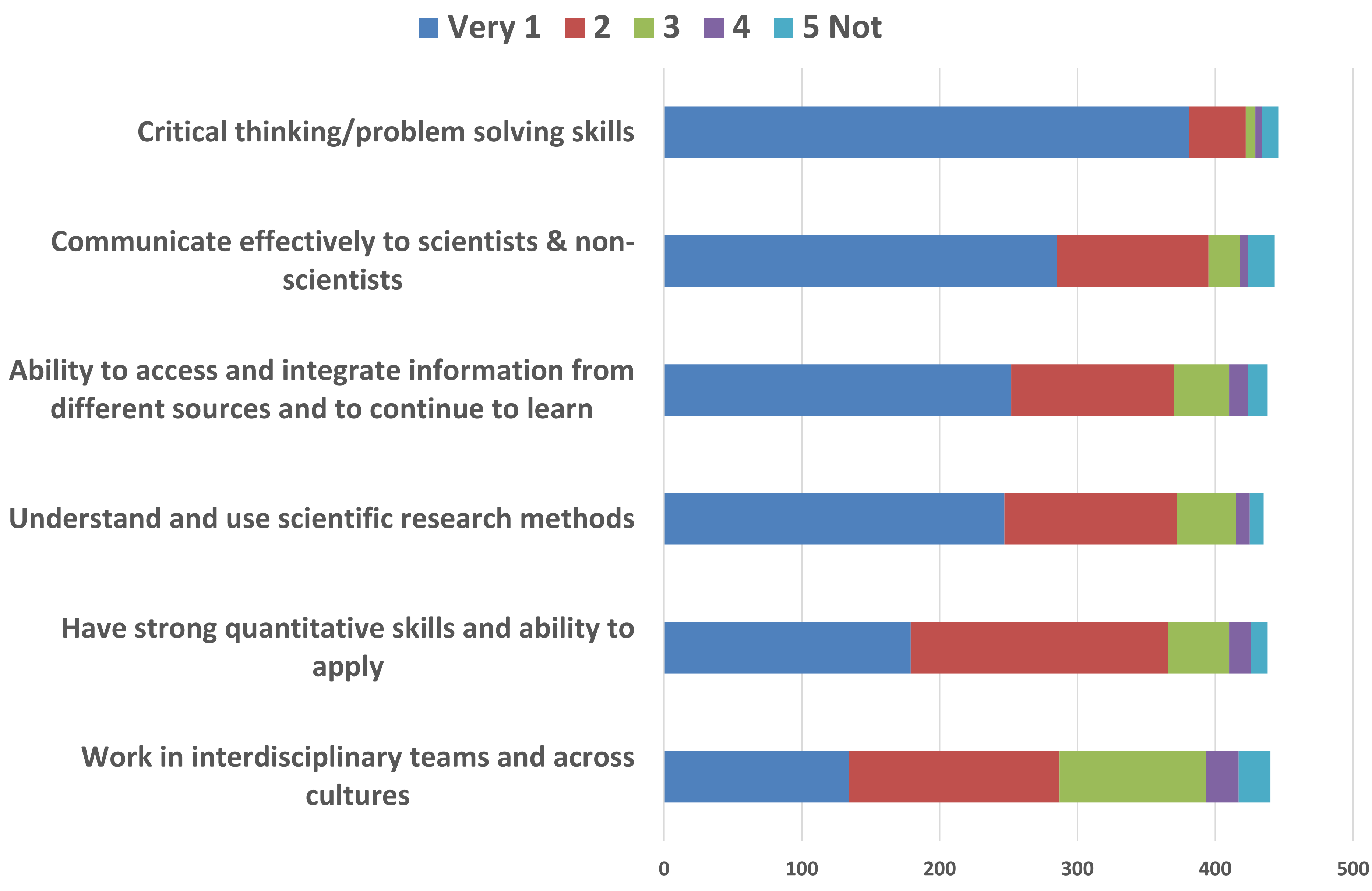
Earth Structure

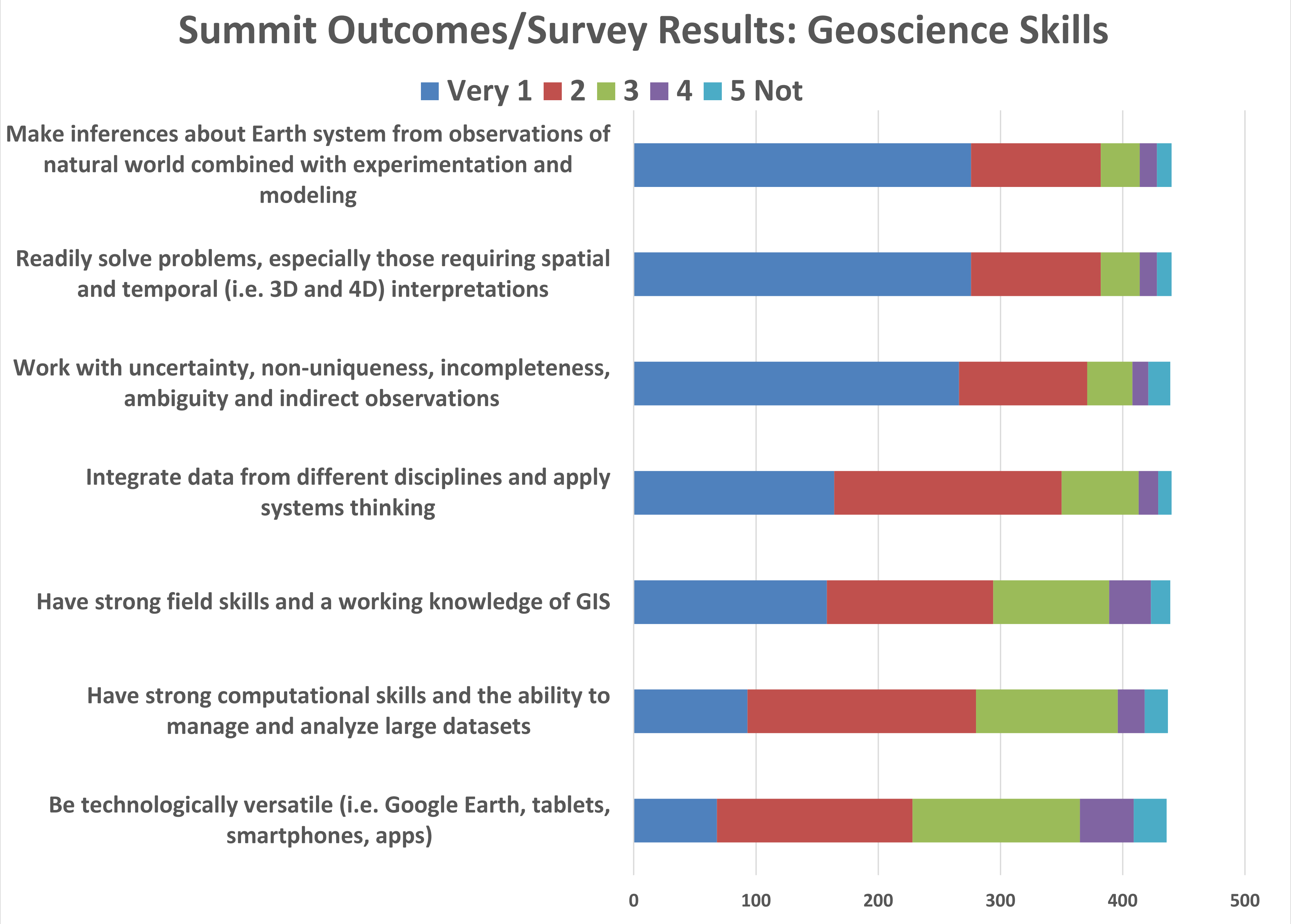
- **Structure of Earth**
  - Mechanical and compositional layers
  - Tools for defining earth structure (seismic waves, analysis of earthquakes, etc.)
- **Deformation**
  - Stress and strain
  - Rock mechanics & deformation processes
  - Fractures, faults, folds, other structural features, etc.
- **Plate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

Summit Outcomes/Survey Results: Science Skills





Summit Outcomes/Survey Results: Geoscience Skills
Very 1
2
3
4
5 Not
Make inferences about Earth system from observations of natural world combined with experimentation and modeling
Readily solve problems, especially those requiring spatial and temporal (i.e. 3D and 4D) interpretations
Work with uncertainty, non-uniqueness, incompleteness, ambiguity and indirect observations
Integrate data from different disciplines and apply systems thinking
Have strong field skills and a working knowledge of GIS
Have strong computational skills and the ability to manage and analyze large datasets
Be technologically versatile (i.e. Google Earth, tablets, smartphones, apps)
0
100
200
300
400
500

Employer Workshop: Geoscience Thinking

- 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

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

Technical Skills

- 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 – integrate into geo courses throughout
  - Differential equations/linear algebra
  - Probability and statistics (so understand risk)
  - Understanding of scale
  - 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

Field and Technology Skills

- Field Camp and Field 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 and software

Non-technical Skills

- **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 codes of conduct
  - Business acumen and risk management
  - Cultural interactions, cultural literacy, emotional literacy, learning styles, awareness of implicit biases
  - Leadership
  - Career awareness/resume/interview preparation
- **Global perspective**
- **Understand 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

- **Outcomes:**

  Links on http://www.jsg.utexas.edu/events/future-of-geoscience-undergraduate-education/

  - **Summit Summary Report**
  - **Survey - ongoing**
  - **Archived Summit webcasts**
  - **AGI/AGU Heads/Chairs Webinar**
  - **PPT slides**

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- **Sustained change in geoscience undergraduate education**
  - Combined, coordinated efforts of departments and programs
  - Administrators, individual faculty innovators
  - Geoscience professional societies & future workforce employers

- **Affect culture change - administration down to student level**