Vision & Change in the Geosciences:
The Future of Geoscience Education

Geoscience programs will grow & thrive when their graduates
...can demonstrate that their knowledge & skills are grounded in innovative thinking
...are well prepared for their role in a dynamic society.

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6-year NSF-sponsored initiative:

**Vision and Change in the Geosciences**

- Robust academic & employer community vision for Future of Undergraduate Geoscience Education
- Key strategies/recommendations for transformative change
  - Geoscience concepts, skills & competencies
  - Increasing student learning, reforming curriculum & assessment
  - Recruiting, retaining, & promoting success & increasing diversity
  - Impact of the Next Generation Science Standards
  - Skills & competencies needed for Earth, Ocean & Atmospheric Sciences graduate students
  - Preparation for future careers & life long learning
  - Roles of Stakeholders
- Fostering change
  - Case studies from department heads/chairs implementing program changes to meet these needs

Represents input of ~1000 geoscientists

Summits/workshops/surveys
Why? A Call for Action

It is imperative we transform undergraduate geoscience education for the Health of our Profession & Success of our Students

Geoscience “grand challenges” are affecting society – we need to prepare our students to address

- global energy/resource needs in sustainably/environmentally responsible way
- more frequent/intense natural hazards & rising sea levels
- sufficient food/water supplies in a warming climate

Geoscience research & industry has changed – we need to update curriculum/programs to reflect

- interdisciplinary, multi-disciplinary & transdisciplinary teams
- complex earth system problems of societal importance
- new innovative tools, models, datasets & skills, new ways of thinking
Geoscience employment is expanding & rapidly changing – we need to increase enrollments & prepare students for future success

AGI predicts shortage of 35,000 FTEs by 2028

Geoscience Employment Increase 2019-2029

- Geoscientists
- Hydrologists
- Environmental scientists and specialists
- Atmospheric and space scientists
- Soil and plant scientists
- Conservation scientists
- Geological and petroleum technicians
- Environmental science and geoscience technicians
- Geological and hydrologic technicians
- Atmospheric, earth, marine, and space sciences faculty
- Environmental science faculty
- Mining and geological engineers
- Natural sciences managers


Careers of today will not be those of the next decade
Geoscience enrollments are declining & are the least diverse in sciences

We need to recruit, retain & promote success

- Increase first gen & underrepresented students in geosciences
- Increase diversity, equity & inclusion

Education has changed with effective, research-supported teaching strategies

We need to widely adopt active & experiential learning & interactive use of technology

- Motivate & enable improved learning
- Develop knowledge, skills & competencies
Geoscience Graduate Programs

Most Ph.D. & M.S. STEM students will not go to academia

- STEM Ph.D. students: 45% business; 46% academia  [NSF NCSES, 2013]
- Geosciences: 51% Ph.D. & ~4% M.S. go into academia  [Wilson, AGI, 2015]

Graduate programs: too narrowly focused on academic research

- Students need to develop skills valued by both academic & non-academic employers
What is in: Vision & Change?

Articulates broad geoscience concepts, skills & competencies needed by undergraduate geoscience majors

Courses/activities should enable students to develop
  • Working framework for knowledge gained during education & future career
  • Geoscience skills & competencies at progressively higher levels integrated into multiple classes
    • Practice, establish mastery
    • Recognize how these skills are broadly employed

Summarizes skills & competencies needed by graduate students in Earth, Atmospheric & Ocean Sciences for future success

Discusses effective strategies for increasing student learning, reforming curriculum & assessment methods/resources
  • Curriculum & teaching designed around student learning outcomes
  • Assessment focused on competencies
Geoscience Education – what employers expect*

Foundational knowledge – good education in geosciences
• Breadth in geosciences, grounding across all sciences

Understand geoscience concepts & processes
Develop scientific, technical & professional skills

Build Competency – ability to successfully accomplish something
using knowledge & skills
• Diverse and adaptable skill set
• Intellectually flexible
• Ability to learn

Earth as a Complex System
Non linear complex systems
Energy, mass, fluid transport (movement and flow), residency, and cycles
Work/changes that affect the Earth’s systems
Solar system interaction

Deep Time
Conventional concepts of geologic time
Impact on processes
Events and rates
Temporal reasoning

Earth Materials
What is a rock, mineral? Rock cycle
Rocks: physical and chemical properties
Processes that form rocks and minerals
Resource applications, organic-inorganic materials

Earth Structure
Structure of Earth
Plate Tectonics
Deformation
Structural controls on resource accumulations

Surface Processes
Sediment deposition & erosion
Terrestrial & marine surface interactions
Landscape alteration (geomorphology)
Habitability, sustaining life

Hydrogeology
Water cycle
Groundwater/aquifers
Biogeochemistry & aqueous geochemistry
Subsurface-surface water interactions
Economics & public policy

Natural Resources
Understanding “natural resources”
Solid vs. liquid resources, geographic distribution, uses
Ecosystem services, renewable & non-renewable resources
Resource dependency & limits

Climate Change
What is climate change? Geologic scale vs. present
Driving forces & causal mechanisms
Carbon cycle
Impacts of climate change
Earth Science Habits of Mind

Geoscientific & Systems Thinking
- How systems work & interact
- Earth as a complex, non-linear, coupled system of interacting parts & processes
- Temporal & spatial thinking – 3D & 4D

Understanding processes
- Linkages, feedbacks, driving forces
- Impacts

Geologic reasoning and synthesis

Critical thinking & problem solving
Skills

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

Data Analysis Skills
• Handle multiple large datasets
• Geospatial skills/reasoning (GIS)

Field Camp and Field Experiences
Improves spatial cognition, creative problem solving, teamwork, geoscience synthesis

Cross-disciplinary Teamwork on Interdisciplinary Projects/Project management
• Working in teams with different backgrounds, specialties, experience, personalities
• Goal setting
• Time management
• Conflict resolution

Communication skills
• Written & verbal scientific communication & Listening

Non-technical Skills
• Ethics
• Interpersonal skills - ability to work with different types of people
• Professionalism
• Global perspective
• Understanding societal relevance & implications
Skills & competencies: Earth, Ocean & Atmospheric Sciences
Graduate Students
• builds on & expands those for undergraduates

Skills Needed for Success
• Problem solving & critical thinking
• Written & oral communication/listening skills
• Capacity for learning/adaptable
• Systems thinking & approach
• Expertise/depth in core area, strong technical skills
• Data Management, Data Analytics
• High level quantitative skills
• Computational skills, programming, modeling
• Project management, teamwork, leadership
• Ethics & professionalism
• Social dynamics - interpersonal skills
• Understand societal relevance, global perspective
Critical thinking & problem solving
Preparation for “real world” professional projects and/or future research

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 & apply
- Make predictions with limited data

- Work on problems
  - In an open and dynamic system
  - With no clear answers, high ambiguity
  - By analogy, inference and limits of certainty

- Visualize and solve problems in 3D & 4D
- Understand & manage uncertainties
- Understand importance of scale – space & time
- Critically evaluate literature
Critical thinking & problem solving
Most Important Skill – regardless of discipline

Independent critical thinking, problem development, execution & analysis skills

• Pragmatic critical thinking, logical thinking
• Flexibility, open-mindedness
• Good grasp of uncertainty

Define problem & apply an appropriate solution

• Sufficient solution vs. a precise, complete solution

Translate problem to -- so what?

• Articulate importance of outcomes
• What decisions will be made

Understand broader impacts of your research & how to communicate those impacts

Many graduates struggle with being able to define a problem & identifying how to apply the solution (but could solve the problem)
Effective Ways of Developing Skills/Competencies/Concepts

Experiential learning

Constant engagement/opportunities to practice skills/use concepts
- Problem solving; using & analyzing real data in classes
- Written/oral presentation intensive courses
- Collaborative, integrative, interdisciplinary team projects
- Integration & interactive use of technology

Substantial experiences

Experience with authentic research, collection of new information
- Fieldwork & field experiences
- Capstone, problem/project oriented courses
- Independent research experiences/projects, Senior Theses
- Internships, REUs

Active collaboration between academia & employers
Provides advice on helping students prepare for future careers & life long learning

• Career & employment resources
• Frameworks for mapping future educational plans (e-portfolios, IDPs)
• External certifications, continuing education programs
• Changing workforce
• Empowers students to own their educational pathway
Best practices for recruiting, retaining, & promoting success of undergraduate students with emphasis on students underrepresented in the geosciences

Address public perception of the geosciences
  • Emphasize societal relevance & career prospects (high tech, high salaries)

Effective strategies for building community, diversity & student success
  • Use effective pedagogy
  • Mentoring – peer mentoring; faculty to student, mixed cohorts; intrusive mentoring
  • Social & community building activities, spaces
  • Support networks, safety nets, tutors
  • Build & nurture positive departmental/institutional culture & sense of community
  • Develop robust diversity, equity & inclusion plans

Recruitment strategies underrepresented groups
  • Emulate & develop successful recruiting programs
  • Formative early experiences – research, internships, bridge programs
  • Build partnerships between 2YC and 4YC
Effective strategies for fostering change in the academic community: Case Studies

- Results of department heads/chairs efforts to implement change
- 91 action plans – 62% reporting of results
- After 16 months to 3 years

- Engaging faculty in curricular & pedagogy changes
  - Successful strategies
  - Roadblocks/solutions
- Overcoming barriers to instructional reforms
- Advice
- Successful change management strategies

Affect culture change – all levels administration/faculty/students
Engagement of Non-Academic Stakeholders

Actively seek, develop & maintain interactive professional relationships

• Alumni & other employers, retirees, professional society members
  ➢ Advisory boards, career advising panels
  ➢ Professional society chapters (AIPG, etc.), short courses
  ➢ Faculty/employer sabbatical swaps

Active participation

➢ Provide datasets, samples, case studies
➢ Participate or lead fieldtrips
➢ Help with or teach classes or problem-oriented short courses.
➢ Joint class-based research projects, internships
➢ Student research symposia or poster sessions – have be judges

Career advice

➢ Invite to give talks, seminars or in-class presentations
  • Discuss ‘real-world’ perspectives, applications, their jobs, and career opportunities
➢ Short mock interviews, give advice on resumes and interviewing skills
➢ Externships
Stakeholders: Engagement of Professional Societies

Promote dissemination & adoption of Vision/Change recommendations

Connect employers with students
  ➢ Provide career related information, poster sessions with companies/employers, networking opportunities at national/regional meeting
  ➢ Provide venues for employers to interact with students one-on-one
  ➢ Promote externship and internship opportunities – act as a clearinghouse

Connect students to mentors
  ➢ Develop or expand mentoring programs
  ➢ Provide opportunities for young professionals to be mentors

Promote extra-curricular opportunities
  ➢ Develop competency, certification/accreditation, badging programs for desired skills
  ➢ Offer short courses/workshops to develop professional/technical skills
  ➢ Offer summer courses/field experiences for students
  ➢ Strengthen the role of student chapters

Expand opportunities for students to learn to effectively communicate to different audiences
  ➢ Hold sessions for students to present their research with verbal and/or written feedback
    • General public, professionals, employers

Create opportunities for industries/employers to engage with academia

Fund students travel to professional meetings

Increase student focus & encourage continuing membership
Importance of educating the next generation to meet future challenges

Sustained change in geoscience undergraduate education requires combined/coordinated efforts

- Heads/chairs, college deans, central administration
- Faculty – universities, colleges, community colleges
- Geoscience Professional Societies
- Geoscience Employers
- K-12 community
- Museums/informal educational settings
- Alumni/donors

Vision & Change document provides:

Opportunity & challenge to demonstrate that geoscience departments are essential & central parts of each institution
The community vision for the future of undergraduate geoscience education articulated in this report is a roadmap for making critical, positive changes to undergraduate programs over next decade.

Our learning environments and curricula must evolve to confront future geoscience challenges and prepare students to enjoy a vibrant and successful career.

We urgently need to reconsider our role in educating the next generation of geoscientists for the health of our profession and success of our students.
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