

Planning the Future of GeoCyberEducation:

Report from a Workshop,

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Executive Summary

The geoscience community has come together repeatedly in the last fifteen years to examine how the growing world of cyberinfrastructure tools, data archives, and information resources is impacting education and research in the field. The earth, ocean, and atmospheric sciences have been early adopters of cyber-tools to facilitate both educational activities and research (e.g., Manduca and Mogk, 2000; Carbotte, et al 2001; Allison et al 2002; 2003). A range of Internet-accessible data resources and user facilities have been built to provide geoscientists access to Earth data of all types, and cyber-tools developed to visualize and analyze these data have improved markedly in both their power and usability (as examples: PaleoStrat (www.paleostrat.org/); EarthChem (www.earthchem.org/); Marine Geoscience Data System (www.marine-geo.org/); GEON (www.geongrid.org/)). New and ongoing Federally-funded geoscience research efforts are themselves developing new information resources and tools, or are working with (and helping to enhance) existing geoinformation systems (e.g., the MARGINS/GeoPRISMS Data Portal (www.marine-geo.org/portals/geoprisms/); Earthscope (www.earthscope.org/data)). However, the rapid advances in information technologies, along with growing user needs for access to searchable data, and for greater documentation of the datasets being retrieved, lead to continuing challenges in communication across various

geoinformation systems, and obstacles in establishing community standards, both for the documentation of widely varied kinds of geoscience data, and also as regards common platforms for data access that can encourage the broad use and application of these resources.

These obstacles are particularly substantial for the use of these burgeoning geoinformation resources in education. While the geoscience education community was an early advocate for wide digital availability and use of data (see Manduca and Mogk 2000; also www.globe.gov/), the lack of educational mandates at the initiation of many geoinformatics projects, and the lack of involvement of education professionals as partners during their development, meant that many promising systems were constructed without education-related users in mind. Differences among the professional backgrounds and experiences of geoscience educators and those who constitute the new and growing professional community of geoinformatics specialists (most of whom began their professional careers as geoscience or computer science researchers) has resulted in problematic communication and cooperation. These disconnects are compounded by the complexity of the educational landscape in terms of audiences and stakeholders; by the limited presence of geoscience-trained educators in K-12 and two-year college settings; and by state-level variations in educational standards and associated testing protocols. Thus, at a time

when many of the most pressing issues facing our society are inextricably entangled with the geosciences (climate change, sea level rise, energy and mineral resource shortages, natural disasters, pollution of our oceans and air; availability and quality of potable water), educators are taking only limited advantage of the wealth of relevant Internet-available geo-information, and those tasked with stewarding that information have made limited progress in repurposing these resources to educational advantage.

The landscape of geoscience cyberinfrastructure has changed markedly in recent years with the advent of user-friendly commercial and publicly available geospatial information platforms (ArcGIS; Google Earth/Google Maps and related tools). As well, “Web 2.0” social networking and collaboration/communication platforms are changing in fundamental ways how learners and users of all sorts interface with the Internet and with information generally. Given these trends and our discipline’s historical challenges and interest in the effective use of cyber-information, the time is ripe to revisit these issues. This report documents the outcomes of a workshop held to examine the future of cyber-education in the geosciences, consistent with the recommendations of the NSF report on cyberlearning (Borgman et al 2008), and in the context of the rapidly changing ways that the public, and in particular students, are interfacing with Internet-sourced information of all kinds. Key

recommendations that arose from our discussions include:

- The necessity for our community to take better advantage of the growing repertoire of commercial, community-based informatics tools and resources to communicate and manipulate geoscience content for researchers and educators. A critical part of this involves generating closer ties with key commercial informatics providers as a community and an important “customer base”.
- To take best advantage of commercial platforms, new targeted geoinformation/ geoeducation oriented tools, systems and resources need to be developed that build upon these publicly accessible capabilities, entailing both ongoing communication between geoinformation specialists, their funders and relevant corporate entities. This carries over into issues of interoperability among academic and commercial cyberinfrastructure systems, a crucial element to ensuring access and wide use of these tools and resources.
- Recognizing the generational nature of digital facility – that the “digital natives” of today are in elementary and middle school, and not the professionals tasked with guiding their learning in this new frame - it is crucial to expand professional development opportunities for geoscience educators at all levels so

they can gain facility with the use of current and new Internet technologies and identify their effective classroom applications.

- As it is important to document the educational benefits and impacts of these new tools and approaches, The NSF and other educational granting agencies should target support toward educational assessment projects examining non-traditional geo-cyberlearning approaches, as the means to documenting and disseminating effective geoscience cybereducation strategies.
- As the effective development, utilization, and assessment and

evaluation of cyberinfrastructure tools in geoscience education requires successful collaborations among geoscience domain researchers, geoscience educators, and geoinformatics specialists, the NSF and other granting agencies should generate more and more explicit funding opportunities to support collaborations among professionals in these groups. These collaborations should, as appropriate, involve private sector participation, and could even be offered as cooperative public/private funding opportunities.

Introduction:

The geoscience community has come together repeatedly over the last fifteen years to examine the question of how the growing world of cyberinfrastructure tools, data archives, and information resources is impacting the directions of education and research in our field. The earth, ocean, and atmospheric science disciplines have been early adopters of cyber-tools to facilitate both educational activities and research (e.g., Manduca and Mogk, 2000; Carbotte, et al 2001; Allison et al 2002; 2003). A wide range of Web-accessible data archives, information resources and interactive user facilities have been built to provide community access to geoscience data and information of all types. The wide range of cyber-tools that have been developed to visualize and analyze these data are rapidly improving in both their power and usability (as examples: PaleoStrat (www.paleostrat.org/); EarthChem (www.earthchem.org/); Marine Geoscience Data System (www.marine-geo.org/); GEON (www.geongrid.org/)). Both new and ongoing funded geoscience research efforts are either developing new information resources and tools, or are working with (and helping to enhance) existing geoinformation systems (e.g., the MARGINS Data Portal (www.marine-geo.org/portals/margins/); Earthscope (www.earthscope.org/data); others). However, the rapid advances in information technologies, along with growing user needs for access to searchable data, and for greater documentation of the datasets being retrieved, have led to

challenges in communication among the various geoinformation systems, and to obstacles in establishing community standards, both for the documentation of widely varied kinds of geoscience data, and also as regards common platforms for data access that can encourage the broad use and application of these resources.

These obstacles have been especially substantial as regards the use of geoinformation resources in education. Although the geo-education community were early advocates for the digital availability and use of scientific data (see Manduca and Mogk 2000; also www.globe.gov/), the absence of educational mandates at the beginnings of many geoinformatics projects, and the lack of involvement in such projects by engaged educational professionals, meant that many promising systems were constructed without education-oriented users in mind. Differences among the professional backgrounds and experiences of geoscience educators, researchers, and those who constitute the growing community of geoinformatics specialists, (most of whom began their professional careers as geoscience or computer science researchers) result in difficulties in effective communication about resource needs, uses, and functionality. This problem is compounded by the complexity of the educational landscape, with its diverse student and teacher stakeholder audiences; by the limited presence of geoscience-trained educators at the K-12 and

community college levels; and by state-to-state variations in educational standards and associated testing protocols. As well, the limitations in our understanding of human cognition and preconceptions as it relates to learning geoscience content, and the absence of recognized “best resources” and/or best practices for the classroom have hampered efforts aimed at the broader adoption or adaptation of Web-served geo-information across educational levels. Thus, at a time when many of the most pressing issues facing societies globally are inextricably tied to the geosciences (climate change, sea level rise, energy and mineral resource acquisition and shortages, natural disasters, pollution of our oceans and air; availability and quality of potable water), educators are taking only limited advantage of the wealth of Internet-available and relevant geo-information, and those tasked with stewarding that information have made only limited progress in repurposing their resources to educational advantage.

The landscape of geoscience cyberinfrastructure has changed dramatically in recent years with the advent and popularization of user-friendly commercial and publicly available geospatial information platforms (ArcGIS; Google Earth/Google Maps and related tools). As well, “Web 2.0” social networking and collaboration/communication platforms (i.e., Facebook, Twitter, Google Earth Community, and blog/wiki/social networking applications of all sorts) are changing in fundamental ways how learners and users of all sorts interface with the Internet, with each other, and with

information generally. Given these trends and our discipline’s historical challenges and interest in the effective use of cyber-information, the time is ripe to revisit these issues.

This report summarizes the outcomes of a workshop held to examine the future of cyber-education in the geosciences, consistent with the recommendations of the NSF report on cyberlearning (Borgman et al 2008). Geoscience data and knowledge are exceptionally well-suited to visualization and manipulation using current publicly available cyber-tools and information systems, presenting unprecedented opportunities to impact and benefit learners and users both inside and outside the classroom. Workshop participants were asked to identify exemplars for effective partnerships among geoscience researchers, educators, and informatics professionals, and to outline scenarios for potentially transformative interactions among these groups that address the needs of today’s learners, which are delineated in the report that follows. As well, the participants offered recommendations to the broader geoscience community and to Federal granting agencies as to how best to leverage what has been built to facilitate geoscience education in the future.

Rationale for this Workshop:

Motivations for this workshop come from several directions:

- The need for citizen understanding of key geoscience issues and concepts such as global climate change, environmental degradation and sustainability has never been greater. However, the penetration of the geosciences into K-12 curricula and other traditional educational outlets continues to be limited, with little likelihood for future expansion in a secondary education environment moving more and more strongly toward high-stakes testing as the only metric for success. As well, demographic changes in higher education – the growth of community colleges, where geoscience faculty are uncommon, and geoscience courses are often unavailable, as the gateway to a college degree; and the growing tendency of students to attend multiple colleges during their undergraduate tenures (see NCES 2005-157) – has resulted in and overall reduction in exposure of students to geoscience content and coursework at the freshman and sophomore level, negatively impacting the number of students who pursue geology and related college degrees. This has helped put many geoscience departments at risk, and it has also reduced exposure to the geosciences among both pre-service teachers, as well as for in-service teachers, for whom more and more professional development activity is occurring at community colleges. There is an urgent need for alternate modes of delivery for geoscience knowledge, and new points of entry into the educational “pipeline” that cyber-enabled approaches may be able to provide.
- Rapid advances in computing and networking technology, in particular the development of highly user-friendly geospatial technologies as everyday applications (i.e., Google Earth/Google Maps; Microsoft Maps, etc.) which are exceptionally well suited to the delivery of many kinds of geoscience content, present new opportunities to transform both learning and instructional practice in our discipline. As well, the explosive expansion of social networking and related collaborative “in the cloud” computer technologies (i.e., Facebook/Twitter/LinkedIn; Youtube and other community video server resources; Ning, Box.net, Wikia/Wikipedia; Wikispaces, etc.), and the cultural and societal changes that these technologies are driving, offers unique opportunities to bring critical geoscience learning to national and global audiences as was never possible before.
- The National Science Foundation has invested tens of millions of dollars in

STEM cyberinfrastructure (with particular investments in geoscience-related tools and resources) to support the continuum from research to the classroom (see Mervis, 2009; MacArthur, 2008). The fruits of these past investments have not been well utilized thus far by K-18 students, teachers or others with interests in geoscience learning. Major geoscience research and informatics projects often have extensive funded education/outreach efforts, but these efforts are often not well coordinated with one another, nor do they always leverage existing NSF-funded educational cyberinfrastructure, or effectively engage the geoscience education scholarly community. We as a geoscience community do not fully understand and thus do not take advantage of the skills, tools, resources and assets of our own number as scientific researchers and educators.

Workshop objectives:

The geoscience community was an “early adopter” in trying to leverage information technologies and cyberinfrastructure to support research and education, and a number of past meetings and workshops have focused on issues associated with integrating these activities into our community (see Manduca and Mogk, 2000; Carbotte et al 2002; Allison et al 2003; Marlino 2004). However, advances in

technology and associated societal and cultural changes have often leaped ahead or moved at cross-purposes to these efforts, leaving the geoscience community scrambling to re-purpose funded programs and infrastructure. It has also been historically difficult to initiate or maintain fruitful communication between geoscience education professionals and geoscience researchers, given the divergent professional goals and drivers faced in each community, and the growing “language barrier” (i.e., geoscience researchers are effectively becoming less and less conversant with both the terminology and scholarly construction of educational scholarship and related activities within their discipline, as these activities have appropriately become more sophisticated, incorporating elements of cognitive psychology and main-line educational theory, with the attendant (and unfamiliar) literature and jargon). As well, the advent of a range of Federally supported cyberinfrastructure and informatics efforts in the geosciences has resulted the growth of a new professional community: geoinformaticists, professionals straddling the divides between geoscience and computer science, who are themselves developing their own disciplinary language and morays. Geoinformaticists require deep and sustained communication with both geoscience researchers and geoscience educators in order to develop and maintain relevant online resources and tools, but obstacles to this communication have so far been a significant barrier in meeting these ambitions.

The overarching goal of this workshop was to bring together leaders in the education, research and informatics communities in the geosciences to foster conversation on future directions for geoscience “cyber-education”. Participants examined and reported on the Federally funded cyberinfrastructure resources and tools available today, as well as societally significant tools and resources available independent of the Federal funding sphere. The workshop sought to understand how and why K-18 students, teachers college faculty, and others use geoscience data and information, and what the barriers and opportunities are for utilizing resources from Federally-supported projects/facilities and other publicly available avenues.

Specific workshop objectives included:

- Identifying new means for leveraging the existing geoscience-related cyberinfrastructure resources to support both formal and informal geoscience education that are aligned with the nature of learners today.
- Seeking models for successful collaboration and methods and tools to help the various stakeholders work together sustainably.
- Make recommendations to the NSF and other Federal funding agencies about the kinds of projects, from either the research or the educational end, that have

high potential for transformative outcomes.

Workshop and network structure:

The workshop was held in Arlington, VA from January 6th through 8th. An evening poster session highlighting the range of cyber-education resources and projects across the discipline led into a series of three plenary sessions emphasizing our new understandings of learners/users, the growing body of data and information resources and tools in the geosciences, and effective models for collaboration among the various geoscience communities. Breakout discussions following each plenary focused on identifying changes that our community may need to make based on these new understandings, and on developing possible project and partnership scenarios for moving the community forward. Scribes - graduate students in geoscience education - recorded the detail of each breakout discussion and of panel discussions during the plenary sessions. The workshop planning team mined the scribed records for ideas and project scenarios to be incorporated into the workshop report.

Further workshop information and resources were engaged using online networking and collaborative tools (<http://geocybered.ning.com>), where participants uploaded relevant documents and presented data resources and tools from their projects and organizations for group perusal. Writing and editing of this report took place through these online networks,

taking advantage of freely available cloud computing tools (i.e., Google Docs). Participants were encouraged to provide information on examples of effective researcher/educator/geoinformatics partnerships, and on existing tools, or potential linkages among tools, that held high potential for application across research and educational applications. This workshop document was produced collaboratively, with participants providing editorial comments and additional content to a first draft completed by the workshop planning team via Google Docs. Recommendations in particular were discussed at length via virtual means.

Participant demographics:

Workshop participants included four-year and community college educators and K-12 teachers, as well as specialists in K-12 teacher training; leaders from geoscience disciplinary research communities, and from the geoscience education research community; officers and education managers from key geoscience professional organizations and leaders from the geoinformatics and educational cyberinfrastructure communities. The list of workshop attendees and their affiliations may be found in the Appendix.

Background and Recent History:

This 2010 workshop did not develop in a vacuum. The National Science Education Standards (NRC, 1996) set goals for science

achievement across all science disciplines that targeted all of the potential student audiences. The geoscience community answered this call across the next decade, working to generate interdisciplinary science courses and curricula, new materials, better assessment of learning, better communication between K-12 and undergraduate educators, and different curricula for training pre- and in-service teachers (GEWG I, 1997; GEWG II, 2005). The creation of DLESE (Digital Library for Earth System Education) was one such effort. In 2000, the vision for the Digital Library in Earth Systems Science was published (Manduca and Mogk, 2000), the result of several years of planning by the geoscience education and research communities. The concept of digital libraries added a 'dynamic dimension' to the heritage of libraries by potentially offering:

- Instantaneous global distribution of information based on specific user needs;
- Flexible organization of information, allowing for effective access from numerous points of entry;
- Access to real-time and archived data sets and the ability to render these data in ways useful and meaningful to the widest range of users; and
- Creation of new, virtual communities of scholars. (Manduca and Mogk, 2000)

The DLESE 'facility' was intended to be interdisciplinary, and was to afford students and educators the ability to rapidly find resources they need, provide the training

and tools needed to effectively use these materials, and enable students to independently explore Earth data – the ambitions and plans were for a transformative entity that would bring together an entire disciplinary community. Initial efforts of the DLESE facility focused on the development and collection of digital resources, and on creating the metadata necessary to facilitate flexible and powerful searching. However, the DLESE funding program also supported faculty outreach efforts through a series of annual DLESE Meetings, which brought together resource developers, K-12 and college educators, and experts in educational assessment.

In response to what were even then seen as rapid changes in the digital world, the DLESE staff led a workshop in 2004 that brought together 50+ researchers and educators to develop a updated vision for Geoscience Education and Cyberinfrastructure (Marlino, 2004). Six overarching recommendations emerged from this meeting:

- Collaborate and build new social structures
- Support ubiquitous learning environments
- Maximize a computational approach to geoscience
- Create dynamic models of student understanding
- Develop smart tools for student learning
- Expand educator professional development

Many of the goals outlined at this meeting were similar in substance to those on which DLESE had been envisioned. Though considerable progress had been made in the years since the DLESE effort began, change was so rapid in the world of the Internet and cyberinfrastructure that a re-direction and a new set of objectives for the community were necessary.

Today, neither the rationale for these earlier workshops nor their goals and recommendations have lost relevance. The drivers for this 2010 workshop are very similar to the drivers behind DLESE and related efforts:

- Public demands for improved STEM education at all levels;
- The need for instructors and students to have access to high-quality educational materials that are presently difficult to find and utilize;
- The need for instructors and students to learn how to effectively use scientific information, methods, and tools;
- Value added to research enterprise by translating new discoveries, information, data sets, and images about the Earth into effective instructional activities, and
- Public's need for access to reliable information about the Earth to inform personal and societal decisions.

As in 2000 and 2004, rapid changes from outside are pushing the geoscience education community to re-vision and re-

direct. In the last decade some of those changes have come from within the discipline, as advances made in adopting an “earth systems science” approach in research have carried into education. NSF-Geosciences supported research centers (National Center for Earth Surface Dynamics; UNAVCO; IRIS), and research initiatives (MARGINS, RIDGE and Ridge 2000, EarthScope, ODP and IODP), cross traditional subdiscipline boundaries. Education initiatives such as the Consortium for Ocean Science Education Excellence (COSEE) network and the coordinated efforts of research centers in association with new initiatives (i.e., UNAVCO and IRIS partnering with Earthscope on research and education) have attempted to bring this new perspective into classrooms. New courses and textbooks at the undergraduate level, community driven curricula for K-12 education (Investigating Earth Systems: AGI), online resources and internet portals (e.g., Windows to the Universe; SERC; MERLOT; and DLESE) seek to bring this new approach to learners of all ages.

As well, the rapid increase in the volume and complexity of geo-information available by various means through the Internet, driven to a significant degree by the “open access” movement, which seeks to make data collected on Federal support and the interpretations of that data freely available, has given birth to the new professional community of geoinformatics. Geoinformatics specialists straddle the intellectual space between the geosciences, information sciences, and computer sciences,

Pertinent Terms and Definitions:

“Cyberlearning” has been defined as “Learning that is mediated by networked computing and communications technologies” (NSF-08204, p. 10), but it also connotes a change in mindset in how learners at all levels interact with data and information and develop knowledge, and in how educators in all reference frames support knowledge development in learners.

“Cyberinfrastructure” comprises the high-performance computing and telecommunications networks, capabilities to access and use remote data and information resources and services, including in particular visualization, analysis and modeling tools. Cyberinfrastructure is a means to conduct new kinds of research and to foster new frontiers of learning by society in STEM and all disciplines, and it provides the suite of virtual tools and resources that can support cyberlearning.

“Geoinformatics” is used to identify the growing community of data archival and management efforts in the geosciences, including those archives maintained by major community research facilities (such as IRIS and UNAVCO) and Federal organizations (i.e., USGS) and funded data management projects aimed at serving different earth and planetary science subdisciplinary communities (e.g., EarthChem, GeoStrat, the Marine Geoscience Data System, etc.).

and seek to provide easy and distributed access to all stripes of geo-information, as well as to provide the cyber-tools necessary to integrate, synthesize and investigate varied data resources. The goals and activities of geoinformaticists are aligned with trends in the evolution of networked computing and the Internet itself, away from passive archival of information for searchers to sift, into a more collaborative and

interactive relationship among users and information, facilitated by widely available, robust, and highly user-friendly cyber-tools. The phenomenon of social networking technologies and their kindred collaborative workspace tools, and especially the rise of Web-assisted and Web-served geospatial technologies (in particular Google Earth and ArcGIS/IMS) are transforming how Earth scientists of all sorts do their work, and are pushing the geoscience education community to make interacting with data a routine part of the classroom.

Major Themes of the Workshop:

Data & tools:

A key aspect of the transformative impact of modern communication technologies is fast and seamless access to an ever-increasing volume of globally distributed digital information. This applies particularly to scientific work and discovery. Modern information technology capabilities have led to new paradigms in how research is conducted and communicated, offering innovative ways to access, organize, analyze, visualize, and integrate diverse data resources generated through field observations, experiments, quantitative modeling, and data analysis.

Digital data resources in the geosciences have grown substantially over the past 10-15 years, reflecting the growth of global real-time monitoring of the earth system, advances in data acquisition technologies, and the recognition by the scientific

community and funding agencies that the preservation of data acquired using public funds in digital data collections democratizes access to research resources, facilitates re-use and testing of hypotheses, and provides new research opportunities. Digital data collections have become essential components of the research infrastructure, but have thus far been underutilized for educational purposes.

Data resources in the geosciences are diverse in nature, ranging from disciplinary data centers such as those maintained by national research support facilities such as IRIS or UNAVCO; community-based disciplinary archives like EarthChem and PaleoStrat; data catalogs of federal or state agencies (e.g. USGS, NASA); thematic data systems assembled for science programs such as the International Ocean Drilling Program and MARGINS; to smaller databases compiled by individual or groups of investigators to support specific research efforts. The structure, content, and functionality of these data collections are driven by the needs of their scientific users for the efficient, informed, and flexible application of these data in research. Issues that have driven the evolution of these resources are documentation of data quality to allow proper assessment, comparison and synthesis of the data; standards for data acquisition and archival that enable integration of diverse data types across space and time for multi-disciplinary studies; and unique identification of data to permit its tracking through the cycle from publications to underlying source data. It is

essential that users can easily extract, visualize, analyze data sets, and integrate them with other relevant information. More and more geoscience data collections provide ready interfaces with popular visualization and analysis tools such as GoogleEarth and ArcGIS, as well as more basic analysis packages such as Microsoft EXCEL®. Other projects have developed visualization and analysis tools designed for the specific needs of geoscience research: examples include GeoMapApp, a free Java-based GIS viewer designed to work with a range of ocean science datasets; JMARS, a Java-based imaging tool used to integrate a range of primary and secondary Mars global datasets; the CUAHSI-HIS information systems for hydrologic datasets; the UNIDATA systems for manipulating and visualizing atmospheric and near-Earth datasets; and the GEON Integrated Data Viewer.

The diversity of data and users, inconsistent standards and practices for archival and cataloging of scientific data, and (until recently) limited incentives for scientists to contribute data and to participate in community data systems are some of the technical and cultural challenges facing the sustainable growth of comprehensive data collection systems that were pointed out by workshop presenters. Another important obstacle is the fact that the existing research data resources were in fact funded and built to serve researchers, so important background and explanatory information (such as: the reasons for collecting the data, the scientific questions

that were being addressed, and the importance of the data beyond the specific scientific problems that prompted its collection) are generally not provided, or at least not in a way that is easily accessible to an educator. To move many of the current data systems toward serving the needs of educators will require support for some “pre-packaging” of data, and/or tools which can provide easy aggregation and visualization capabilities for the non-specialist, capabilities which currently aren’t available either in Federally-funded data systems or via freely available information systems into which data can easily be ported.

Learners and Users:

Students have to a large degree transitioned away from the historical preconception learners as passive absorbers of knowledge who must be guided to understanding by a trained educator and through a carefully organized curricular structure. The Project Tomorrow 2003-2008 Speak Up surveys of surveys of K-12 students, teachers, parents, administrators and pre-service teachers describe the upcoming generation of students as “pace cars” for adopting and adapting different kinds of information technologies for use in their learning, generally leaving their teachers and school administrators to catch up (Project Tomorrow 2006; 2008; Rainie and Anderson 2008). The “digital disconnect”, defined as the gap between how today’s students interface with information technologies in the classroom versus how they use technology in their everyday lives, is

substantial. Students express significant dissatisfaction with their ability to use technology in the classroom - they "power down" to go to school. Students are using, and desire to use, technology more extensively in and out of the classroom for communication, collaboration, creativity, and professional productivity. Both the Project Tomorrow surveys, and surveys conducted by the Pew Internet and American Life Project, identify a new entity – a "Free Agent" or "Networked" learner – who pursues his/her learning in a largely self-directed fashion, un-tethered to the traditional structures and formats of education. This new generation of learners is facile with technology and expert in the aggregation of data, albeit not in its interpretation and synthesis – some have suggested that they may be even more challenged than past generations of students in this regard (e.g., Greenfield, 2009). They take advantage of the power of connections and virtual networks, and are not bound in their educational activities to the physical networks of home and school. They are avid developers of content - content generation and re-purposing is the distinctive feature of this generation of learners - and seek to learn through experience and co-creation, learning more through the process of creation than from the finished product. Social networking tools like Facebook are the "dashboards" to the Internet for these learners, as they include all their favored tools for communication and connection (text messaging, email, image/video/audio uploading, and status updates). Children

become "networked" learners at remarkably early ages through their immersion in information technologies at home and at play, though generally not through their experiences at school.

The natural inclination of today's students is to blur the lines between education-in-school and informal learning, and between open-ended social interaction and the educational process. Their facility with information technologies present unique opportunities for interaction with geoscience content, much of which is highly amenable to the networking and geospatial tools with which these learners are both familiar and facile (i.e., photos and video in Facebook or Youtube; georeferenced content in Google Earth KML formats or ArcGIS Shape files). New-to-market technological advances, such as automated GPS locators in cellphones, make possible the collection of large bodies of georeferenced information, including scientific observations. The blurring of the boundaries between formal and informal education offers the real possibility of reaching K-12 level learners, as well as others, with high-quality geoscience content through content-rich virtual social networking and content-sharing environments, that they can carry back into the classroom, State-mandated educational guidelines irrespective.

Challenges that modern networked students present to educators are how best to support and guide them in their learning endeavors. Educators at all levels are being

forced to change their role in the classroom from that of a provider of knowledge to that of a facilitator for learner discovery. Extensive and targeted professional development activities for in-service teachers and college faculty has been, and continues to be necessary to facilitate this transition, along with changes in the pre-service education of teachers. Educators and their administrators will have to find ways to embrace commercial social networking tools and community-developed information resources that have been heretofore seen as problematic in the classroom, and seek to support and learn from students as they make use of these resources in their classrooms. Educators and administrators will themselves have to be willing to become more facile in the use of popular cyber-tools, both to better engage with their students, as well as to determine which tools and approaches are the most effective. Interesting examples of Web-organized environmental activities already exist: Geocaching, a global “treasure hunt” game in which players both place GPS-located “geocaches” and others seek to find them using handheld GPS technologies. (see www.geocaching.com/).

Systems & networks:

The potential of cyberinfrastructure to transform science and education is based in its unique capability to link and network resources that are spatially, thematically, and structurally diverse and distributed, from hardware, software, and content resources to its human users. Networks of

computers, databases, analytical tools, and scientists support taking on new multi-disciplinary approaches to scientific questions through seamless cross-disciplinary data discovery, access, and integration; and web-based communication and collaboration. Such networking allows the scientific endeavor to be more diverse and inclusive, and it encourages examining problems from a systems perspective, which is of particular value in the geosciences. Similarly, cyberinfrastructure can transform education, if new ways for interaction between stakeholders – scientists, educators, students, decision-makers, and the general public -- are explored and implemented.

What are the components of networks required to support and empower geoscience education? A geo-cybereducation network will need to integrate a wide range of expertise, resources, tools, and services that can readily be discovered, accessed, and adapted to new demands.

- Powerful and simple discovery tools to locate new resources
- Social networking and collaborative tools that allow participants to exchange experiences, learn from each other, find information, and help one another.
- Real-time communication spaces: chat- and web-conferencing spaces, Web-supported venues for live communication (i.e., Skype teleconferencing; webcasting) and spaces for sharing digital objects

- Multiple ports for access, through a variety of devices (i.e., PC's, cellphones, PDA's, etc.)
- Virtual structures and services that encourage and reward participation. Users will see the benefits of their usage, which will both foster curiosity as well as longer-term engagement in projects
- Services that support cross-disciplinary collaboration, so as to facilitate participation by education researchers, communication experts, and all the relevant stakeholders. Various kinds of incentives may be needed.
- Support for the operation and maintenance of the network, be this via extramural funds or institutional sponsorship.
- Robustness and reliability of network-based tools and resources, which need to work every time or risk losing users.

The challenges that need to be addressed and overcome to make these networks useful, functional, and sustainable and become ubiquitous infrastructure will be similar to those encountered in building the initial geoinformatics systems:

- Standards for interfacing of data and resources, and the interoperability of existing and new systems
- Developing community trust in the quality of the resource and the tools provided
- Openness and inclusiveness in the development of new resources and

tools – in particular, the involvement of educators and education-related professionals in the development, modification and/or implementation of new informatics systems.

- Clear attributions of origins and authorship, with appropriate credit given to researchers who collect and interpret the data initially.
- Content and context beyond the data - both the storylines on the gathering of the information and the content itself, to permit for quality control and to provide context on its use for non-specialist users.

Communication and Collaboration:

No one person has all the necessary skills to succeed in the complex systems that will support geoscience cyberlearning. High-quality communication and collaboration are essential and must be supported. Communication necessarily needs to occur across a range of different stakeholders:

- *Communication between students:* The Speak Up and Pew surveys indicate that embedded text messaging is their most popular form of virtual communication among students. Using email as a stand-alone technology is continuing to decline (Rainie and Anderson 2009). Use of email, instant messaging, and texting combined showed only a 27% increase in use from 2007 to 2008, while the use of social networking as a

communication/collaboration technology (which include email, text messaging, and Twitter-like short content feeds) showed a 150% increase. Students are texting in the classroom, as well as at all other times, for a wide range of purposes, some (though certainly not all) of which are education-related.

- *Between students and educators:* Both the Speak Up and Pew surveys indicate that students have moved strongly toward using their personal social networking sites as their “dashboard” for accessing the Internet. Students have become accustomed to having access to information online on a 24/7 basis. Many K-12 teachers and college educators still operate in the mode of being the (presumptive) primary information resource in their classrooms, but they are largely not recognized as such by their students today. As well, the predilections of students to gathering their knowledge via Internet-based sources conflicts severely with traditional classroom information outlets of lectures and paper textbooks, and presents new challenges to instructors in helping students ascertain the quality of information they have gathered.
- *Between geoinformatics professionals and students:* Data resources need to be made readily accessible to

multiple audiences. Interfaces should be designed so that instructors and students can navigate them to obtain the information they are looking for. The Speak Up and Pew surveys consistently indicate that K-12 students, like some teachers, want access to real data that they can manipulate and analyze to create their own learning content, which can only be provided through intuitively accessible data portals

- *Between geoinformatics professionals and educators:* Many K-12 teachers want "packaged" data that is not only in a usable format, but **also includes the context of the data and its application**. College-level educators generally need less in the way of interpretive packaging, but still require information on context, relevance, and use. Ideally, teachers and college faculty need more frequent opportunities to partner with and communicate with data providers toward developing data resources that are linked to lesson plans and curricular needs, and can tie into relevant national and state educational standards at the K-12 level, and into the structure of geology degree programs at the college level.
- *Between scientists and geoinformatics professionals:* These communities need to expand their dialogue about formatting standards

for different classes of data, as well as about metadata relevant both to research and educational applications, so that new datasets can be seamlessly and quickly brought into digital archives, making it available for use to researchers, material developers, and (potentially) teachers and students.

- *Between scientists and teachers:* These communities need to communicate about what kinds of datasets are most useful and appropriate to use in the classroom, particularly in the context of growing demands for national and state standards.

Based simply on the skills and resources required, it is clear that effective collaborations will need to involve more than just a scientist and educator, or even a scientist, educator, and geoinformatics professional. A challenge all of these groups face is how to find collaborators of different stripes - how can scientists usefully connect and interface with education professionals (be they teachers, resource developers, or assessment experts)? How can geoinformatics professionals connect and interface effectively with scientists and educators? It may well be that other kinds of expertise (social scientists, cognitive scientists, experts in organizational communication) will be necessary to generate effective models for geoscience cybereducation - and if so, how does one interface usefully with these other classes of

experts? Collaboration is 'an endothermic process' to quote one workshop presentation (Manduca, 2010); it takes more time and more energy than one may anticipate, especially when one works across disciplinary divides. However, this investment can pay off with new ideas and opportunities, which cross content areas and traditional boundaries.

The social networking and collaborative technologies that are the hallmark of "Web 2.0" have the potential to facilitate and maintain a range of collaborative activities among individuals with common interests. However, these technologies are less effective as a venue for initiating collaborative interactions, especially among individuals who have no natural professional connections, and who are not "digital natives" accustomed to the social mores of virtual interaction. The initiation of true cross-disciplinary collaborations requires the clear enunciation of participant objectives and the development of trust, so live interaction and communication are necessary. Once trust and shared objectives are established, virtual communication has greater value as a tool for sustaining collaborative activities.

One potential use of Web 2.0 social networking tools early in the collaboration process is in providing venues for initial contacts among communities of professionals. Some existing public social networking systems (e.g., LinkedIn, Epernicus) already seek to do this explicitly.

Example Collaborative Models:



DLESE (the Digital Library of Earth System Education)

DLESE was built on a shared community vision. Its beginnings were in a broad-based collaborative effort responding to community needs. With its users as its contributors, this digital library is filled with a range of resources that seek to transform learning about the Earth. At its outset, metrics aiming to assess its impact on student learning were integrated into the project design.

The DLESE team spent considerable time in the project's early stages discussing an essential prerequisite to cyberlearning: that community-based collection building was key to establishing the project. It was up to the community to drive the functionality of the library and its content, while the DLESE facility needed to offer significant technical support to community collection builders for this open resource. A critical component of developing the infrastructure for effective learning was to engage educators in co-development efforts with domain, information, and learning scientists. The DLESE cyberinfrastructure was established as an open platform with interoperable components for preservation, discovery, and access. Web services were put in place to enable diverse users and facilities to incorporate DLESE.

Lessons learned from the DLESE effort include:

the need to engage with the educational research community from the beginning, and continuously to maintain the relationship;

educational reform (changes in teacher practice and resulting educational impact) does not happen in the span of a funded grant;

cyberlearning requires robust infrastructure that is not built and sustained with short-term projects; needs to be deployed at a scale to begin to achieve impact.

Sustainability is also important, as planning for sustainability must begin at the outset and influence technical and social components. Making the switch from a "research project" to an "operational resource" is one of the most difficult but important challenges.



The National Science Digital Library (NSDL)

NSDL began in 2000 as a NSF R&D project, but is now a part of NSF's educational cyberinfrastructure. NSDL covers education at all levels in the STEM fields, and has distributed holdings and services provided and maintained by many organizations. NSDL is structured as a digital learning library, community, and laboratory. NSDL comprises seventeen distinct Pathways: projects focused on the stewarding of educational contents focused on particular grade levels, disciplines, or stakeholder group of NSDL users. The Pathways are built and managed by leading organizations who are trusted by their target audiences. A number of Pathways engage disciplinary professional societies, while others are managed by trusted organizations, educational institutions, or foundations. The Pathways are tasked with providing resources, tools, services, and professional development for their user communities. Resources of note include science literacy maps on the NSDL website and an NSDL channel in iTunes U. NSDL also facilitates partnerships with large educational systems and professional organizations to provide tools and services such as workshops, web seminars, and other professional development opportunities.

The NSDL is currently moving on a path toward self-sufficiency, and each of its Pathway partners are tasked with devising a viable business model and sustainability plan. Those Pathways affiliated with disciplinary professional organizations have had the most success in this regard.

The evolving partnership among researchers, geoinformatics professionals and educators in the NSF-MARGINS and GeoPrisms Programs:



The NSF-MARGINS Program was a decadal community-based research initiative supported by the Ocean Sciences and Earth Sciences Divisions at NSF. The research foci of the MARGINS program are the varied processes that occur at continental margins, and the funding program sought to support multi-disciplinary research projects within four MARGINS Initiative areas, each of which targeted one to two geographical Focus Sites for integrative study. All MARGINS research and teaching activity has been proposal-driven, but community efforts are coordinated by a Steering Committee comprising MARGINS-interested researchers, and a Chair of the Steering Committee who manages the MARGINS Office, which provides logistical coordination for community conversations. MARGINS-funded Workshops and Theoretical/Experimental Institutes aim to engage a broad swath of the geoscience community in thinking about MARGINS science. The MARGINS program requires researchers to provide all MARGINS-funded data to the Marine Geoscience Data System (MGDS) at Lamont-Doherty Earth Observatory or appropriate national repository to make it available to the broader research community. In response to the five-year program review, the MARGINS Office and Steering Committee sought to expand the education and outreach efforts of the program, explicitly targeting undergraduate-level education as their primary audience, and seeking new ways to bring the "fruits" of MARGINS-supported science (in particular, new ideas about subduction and continental rifting processes, and the supporting data) into the classroom.

The MARGINS Data in the Classroom Project (funded through the Course, Curriculum, and Laboratory Improvement Program in the Education and Human Resources Directorate at NSF; see <http://serc.carleton.edu/margins/index.html>), initiated in 2007, seeks to engage the MARGINS scientific community in the re-purposing of MARGINS scientific results for use in introductory and upper-level undergraduate geoscience courses. The initial collaboration involved several MARGINS scientists, the MARGINS Office, and SERC, and subsequently expanded to include MGDS staff responsible for the management of the MARGINS Data Portal. Many of the 30+ MARGINS "Mini-Lessons" produced thus far take advantage of GeoMapApp™, a free Java-based geospatial visualization and data analysis tool developed initially to support researchers' efforts to make use of MGDS resources. The project directly supported two multi-day faculty workshops and one evening mini-workshop at a professional meeting, at which geoscience educators and researchers developed and evaluated "mini-lessons". In addition to education activities at other MARGINS workshops, the project has assisted the MGDS and EarthChem geoinformatics efforts in their education and outreach efforts, including a jointly-sponsored webinar focused on classroom use of MARGINS data and GeoMapApp.

The partnership between MARGINS scientists and the marine geoinformatics community has now expanded beyond the funded CCLI effort to include the development of educational applications of MARGINS data as part of funded synthesis efforts for the Subduction Factory initiative (Jordan, et al 2009). As an example of how MARGINS research can be employed as a cybereducation tool, this project is mining Earthchem datasets for high-quality, comprehensive geochemical and isotopic data for lavas from the two Subduction Factory focus sites (Izu-Bonin-Mariana and Central America) and models these quantitatively to allow undergraduate and graduate students to explore how subducted materials and mantle interact to produce arc magmas. Planning for a second decade of a MARGINS-successor program included a planning meeting explicitly aimed at education and further growth of education-related partnerships with the geoinformatics community was a central theme of the vision statement that arose from this event.

The CCLI project and MARGINS education efforts overall enjoy high visibility in the MARGINS community, with regular reports and requests for participation sent out via listserv announcements and MARGINS newsletters. Now approved for a second decadal program, the new effort (NSF program entitled GeoPRISMS) will include expanded educational staffing in the Program Office and the continuation of the Education Advisory Committee established during MARGINS. The primary challenge that these efforts face is getting university and community college educators other than resource developers to use these materials and report back on their effectiveness, an issue faced by other like projects.



AMS Programs to Enhance Diversity

AMS programs enhance diversity in the geosciences through the DataStreme Advancing Minority Participation in Science (AMPS) program which focuses on under-represented K-12 students and teachers, as well as the AMS Weather Studies and AMS Ocean Studies Diversity Projects. Geer et. al (2004) describe in detail the imperative for AMS Diversity Projects, most notably that African American, Hispanic/Latino, American Indian/Alaska Native, or Native Hawaiian/Other Pacific Islander groups comprise 27% of the U.S. population (U.S. Bureau of the Census 2000), but make up only about 7% of the total science and engineering workforce (National Science Foundation 2000a). Within the geosciences, minorities earn only 4.6% of all bachelor's degrees, 3.3% of master's degrees, and 5% of Ph.D. degrees (National Science Foundation 2000b). In order to maintain a robust and competitive scientific workforce, it is essential to increase minority participation in the sciences (Congressional Commission on the Advancement of Women and Minorities in Science, Engineering and Technology Development 2000 and Drummond 2004). The challenge in attracting minority students to our disciplines is that many colleges and universities with high minority student populations focus on traditional sciences and do not offer introductory geoscience courses.

From 2002-2007, the AMS/NSF Weather Studies Diversity Project trained faculty members from 145 minority-serving institutions (including 29 Historically Black Colleges and Universities, 52 Hispanic Serving Institutions, and 10 Tribal Colleges and Universities) at annual workshops at NOAA's NWS Training Center in Kansas City, MO, and a follow-up workshop and poster presentation session at the AMS Annual Meeting. The AMS/NSF Ocean Studies Diversity Project (2006-2008) prepared faculty members from 75 institutions to locally implement the Ocean course through annual training workshops at NOAA and University of Washington facilities in Seattle, WA. Over 13,000 minority serving institution students have already taken these courses. While the AMS does not track individual students, professors have reported cases of students entering atmospheric science degree programs following course completion.

Geospatial Technologies Education at Community Colleges: the GeoTechCenter:



Empowering Colleges:
EXPANDING THE GEOSPATIAL WORKFORCE

Community colleges serve an important and growing role in the undergraduate education of today's learners. Geospatial technologies education and training programs began to be initiated in community colleges over a decade ago, though not in large numbers initially. Community colleges have been slow to adopt or develop GIS programs because of limited access to computer hardware and software, the absence of professional development for instructor and little by way of available curricular materials. Various NSF Advanced Technological Education (ATE)-funded projects, such as Indiana State University's GIS for the 21st Century boot camp, have allowed community college faculty to receive the training they need to bring geospatial education to their institutions; and a growing number of community colleges received ATE Program support to initiate and to expand geospatial education programs on their campuses. Many of these projects involved direct collaboration with ESRI, while in others participating faculty took advantage of ESRI's community provided materials and took part in the annual ESRI Meetings on GST. In response to the need for coordination among the now abundant GST education programs established at community colleges nationwide, the ATE program funded the National Geospatial Technology Center of Excellence, or GeoTech Center.

The GeoTech Center is a collaborative effort among thirteen colleges and universities, ESRI, and industry to expand the geospatial workforce. The Center and its partners work together to provide professional development for GST faculty, teaching and curriculum resources, career pathways and model core competencies for geospatial technicians. Established in 2008, the GeoTech Center provides the promise of sharing curriculum, competencies, and knowledge, establishing a community of practice among community college educators, and coordinating efforts among institutions, toward developing and supporting geospatial education programs at more community colleges, and incorporating GST instruction appropriately into other degree programs.

Teaching and Social Collaborations to Support Cyberlearning: Lessons from SERC:



SERC the Science Education
Resource Center
at Carleton College

SERC (the Science Education Resource Center) at Carleton College works to improve geoscience education, primarily at the college level, through projects that support educators in STEM fields and related disciplines. Collaborations with faculty are a fundamental part of SERC's practices. Collaborations require much energy to initiate and collaborations are only sustained if they are in the best interest of every partner.

The model for innovation that has been most effective for SERC has been the conduct of and participation in abundant collaborative pilot projects, in which participants develop and contribute educational resources (e.g., Fox et al 2005). Collaboration in resource creation and review yields a competitive advantage for these projects, and the successful pilots can be scaled up. Targeted solicitations from NSF (and other agencies) provide topical guidance for proposers submitting new pilots. The process for innovation here is a feedback loop in which successful pilots produce resources and community interest, and thus grow into larger, more effective and potentially transformative projects.

The feedback system creates broad-based voluntary collaboration. For example, SERC's Teach the Earth provides access to resources and added value as a place where people look for like things, so the time spent by users in resource discovery become viable investments. The SERC resource activity sheet, which has a standard common format, provides a template for sharing materials, as well as for their aggregation, re-aggregation and reuse. If a resource collection has demonstrated utility, the community can request further submissions and propose an expanded project to develop new resources and/or review existing resources, creating a viable and sustainable portfolio. Pilots are a critical first step in this development.

SERC's On the Cutting Edge is an example of rapid and robust flows of information through the system. On the Cutting Edge comprises small to medium sized topical gatherings of faculty that foster networking, information sharing, and collaborative work. Small group collaborations within the meetings allow for a collective whole to develop versus just individual pieces, along with the opportunity for exchange around more than just the task at hand. A webpage is established for each On the Cutting Edge workshop, which houses materials developed pre- and post-meeting. A listserv maintains minimal communication among participants for sending alerts on events of shared interest. Subsequent resource contributions are welcome, though generally uncommon. The feedback between workshop and website is essential to create materials and establish a culture of use – both workshop design and technical infrastructure enable this.

The recommendations from experiences as SERC include supporting pilot projects that explore the full range of possibilities in a content area, evaluate the educational impact of its products, which are generated from grass roots. A phased program, such as those where NSF supports pilots and can scale them up in second- or third-stage funding facilitates this kind of innovation. Support should continue for efforts to improve communication among faculty, via workshops and affiliated web resources that document and discuss the ongoing work of the community, including evaluation.

Cyberinfrastructure for data-driven Cyberlearning in the Geoscience (ASU and Purdue)

Data-driven cyberlearning in the geosciences involves the teaching of software tools and data systems, and therefore requires the development of an online curriculum material dissemination infrastructure with additional capabilities beyond those of existing curriculum material dissemination systems. Software and data systems require additional metadata to describe their content and interfaces; for example, an exercise involving the hydrology modeling software tool "HEC-HMS" might require inputs of hourly rainfall data and hourly streamflow data, as well as a description of the geometry of a river network. The content and format of this data needs to be described and enforced along with conceptual and pedagogical data, in order for this learning module to be fully useful. The MOdular Curriculum for Hydrological Advancement (MOCHA) project is developing a set of hydrology curriculum modules for undergraduate engineering and science education. A parallel effort is underway to develop complementary data-driven curricular modules which teach the same MOCHA concepts using an exploratory data analysis and modeling, and to implement an improved cyberinfrastructure for hosting and disseminating the computerized modules. This ongoing project represents a pilot study and model for the deployment of data-driven curricular modules throughout the geosciences.

Challenges for Geo-Cybereducation

Balancing the Real and the Virtual

Because virtual environments are exceptionally well suited to presenting certain kinds of geoscience content – in particular image and video content – a concern with facilitating geoscience cyberlearning is that it might be used to remove or replace real-world student experiences in the field. Rich virtual experiences may seem enticing replacements for the real thing for resource-strapped geology departments, or (especially) to school or college administrators concerned about costs and liability – virtual laboratory activities have been substituted for real experiments in introductory chemistry programs at some institutions for these very reasons. While at the moment the available virtual field geology activities are relatively rudimentary, the visualization technology for developing very data-intensive, interactive virtual field exercises is already available (see www.lions.odu.edu/~ddepaor/ccli/labs/Welcome.html for examples of interactive, Google Earth-based field activities in a number of locales). These kinds of information-rich activities can create excitement and curiosity in students, and can be a jumping-off point for both more intensive virtual investigations and as guidance in investigating a real field area to best educational benefit. It will be important, however, for geoscientists and geoscience educators to continue to make the case for authentic field experiences as part of the undergraduate experience and as a means of

exposing high school and community college students to the discipline.

Depth of Learning

Another concern raised by workshop participants is how “deep” learning – the kind of learning that entails reflection, synthesis, and critical analysis – is impacted by technology access and cyber-environments. Participating educators noted their experiences with “mile wide, inch deep” students who could identify and locate any sort of content, but seemed to have no ability to build a substantive whole from these many found parts. Greenfield (2009) notes that the everyday experiences of young people with television, video games, and the constant “pinging” connectivity of cellular technologies and social networking systems affords them a very different skillset as students: substantially greater visual-spatial intelligence than their predecessors, but lacking skills in reflection, inductive analysis, and imagination. Carr (2010) goes further, describing the Internet as an “interruption system” that parses the attention of users, in effect training the brain to pay attention to less relevant information under the guise of “multitasking”. The cyber-learning environment of the everyday for students may well actually be training them not to concentrate, leaving the job of teaching the skills associated with focus and concentration to educators.

However, as noted by Greenfield (2009), it is important for educators to take advantage of the skillsets which cyber-environments afford students. In the geosciences, rich virtual content can create excitement and interest and be used as a lure to investigation and discovery. In introductory courses, developing that excitement and interest is crucial, given that with most students the objective of such

courses is to create a scientifically (and particularly a geoscientifically) literate population, who will be able to make informed choices both personally and in the civic arena on issues where an understanding and appreciation of the geosciences is crucial.

Assessment, Evaluation, and Research

Over the last twenty years, the general knowledge and appreciation by educators at all levels of the importance and use of educational assessment has increased, and information and tools are now available to help educators do a serviceable job in measuring student learning gains in geoscience-related content areas especially at the introductory level (Libarkin and Anderson 2008; 2010; McConnell et al 2006). Whether learning occurs in the formal setting of the classroom, or in blended or online formats, defining clear and practiceable learning objectives are critical to designing assessment protocols that can accurately measure student achievement. In the the K-12 environment, state grade-level educational standards provide a framework within which to define learning objectives, though for the geosciences these standards show considerable inconsistency state-to-state, if there is mention of the field at all. For higher education a like set of standards does not exist, and there is considerable resistance to a standardized geoscience curriculum (see Bralower, et al 2008), though professional performance requirements (i.e., contact-hour and content requirements, and test performances, for licensure as a Professional Geologist; ASBOG 2009) have begun to establish some guidelines. However, the geoscience community has come to a consensus on core literacies in the earth sciences and on critical Earth issues (ESLI, 2009; Climate Literacy

Network, 2009, as examples) which are intended be used as foundations for learning.

The recognized challenges of making effective measurements of student learning gains are complicated further in a cyberlearning reference frame, where geoscience-relevant content may be accessed by students informally as well as in formal classroom settings. The "baseline" conditions from which the impact of classroom-specific interventions can be measured will need to take into account both the exposure of students to rich (but less-structured) geoscience content outside the classroom, and their responses to this external content as related to their classroom experiences. Even with a growing consensus on New studies addressing the potential impact and educational benefits of informally accessible geo-information of various categories will be required to understand how immersion in this growing sea of information impacts student preconceptions and interests.

As we move more comprehensively into a cyber-education perspective, particular challenges related to assessment and evaluation include:

- Investigators may not have direct contact with the learner. This may be the case in part, when learners are interfacing with content informally outside of class; or entirely, for studies in which the objectives are to understand the impact of informal geo-information sources. Exercises as preliminary as getting institutional review board approval or exemption certifications may be complicated by the necessarily vague relationship between subjects (learners) and investigators.

- Learners may use data in ways that investigators did not imagine when experiments were designed, and/or cannot control for in an effective way, requiring in some cases substantive formative adjustment of project design and objectives.
- The context for learning can be highly variable, and can change markedly on short timescales. The potential for disconnection between learning "in the everyday" and classroom experiences is large, and based on the Pew and Project Tomorrow surveys, is an issue already evident in students today. Communicating the 'big picture' of geosciences as a relevant discipline, something which the NSF and other organizations interested in geoscience education have expended substantial resources on (see ESLI, 2009), may need to be re-examined.
- Especially relevant going forward will be further efforts to understand how students learn through the process of collecting, manipulating, visualizing, and interpreting natural datasets, as we still have no recognized best practices for these kinds of learning activities. This issue has been a topic for discussion in the field for some time (see Manduca and Mogk, 2002, for a description of early thinking on this issue, before ready access to data was the norm; and Ledley, 2008, related to making geoscience data usable in the educational reference frame). A range of funded projects have sought to examine this issue (see Goodwillie et al 2009; Ryan and Beck, 2009, etc.).

Recommendations:

The Speak Up and Pew Internet and American Life project surveys of students and educators both indicate that the K-12 educational environment lags the farthest behind their students in terms of both the use of technology, and expectations for its use as an educational resource. In particular, K-12 educators feel that they are inadequately prepared to make effective use of available technological tools, and that they do not have the time and support professional to develop the necessary expertise with these resources to use them effectively. However, the sense of being "behind the students" in terms of understanding the myriad technological tools and resources that are available, and how best to use them educationally, is endemic.

- **Expand professional development opportunities in which educators can gain facility with the use of Internet technologies and identify effective classroom uses for them.**

Existing Federally supported geoinformation systems, both those designed for research applications and those designed for education, risk quickly becoming antiquated relative to user expectations and needs.

While commercial informatics tools and resources are typically nimble in responding to customer needs, our community has not always been effective in identifying itself as a significant "customer".

- **The geoscience community needs to take better advantage of the growing repertoire of commercial, community-based informatics tools and resources to communicate and manipulate geoscience content for**

researchers and educators. As well, our community needs to generate closer ties with key commercial informatics providers.

- An example in this direction is the developing relationships between Federally-supported geoinformatics resources and Google Earth: the Smithsonian Global Volcanism Program's catalog of active volcanoes is a clickable layer within the Gallery section of Google Earth, and the Marine Geoscience Data System (MGDS, now part of IEDA: Integrated Earth Data Applications) is currently in negotiations to provide access to its high-resolution bathymetric and geophysical data of the oceans. As well, the GSA Penrose Conference "Google Earth: Visualizing the Future of Geoscience Research and Education", held at Google headquarters, brought together over ninety geoscience researchers and educators to share expertise with one another, and their perspectives with the Google Earth staff.

Commercial cyber-platforms such as ArcGIS or Google Earth are developed with capabilities specific to the majority of likely users, but also with limitations relative to the needs of geoscience educators and researchers.

- **To take best advantage of commercial platforms, new targeted geoinformation/geoeducation oriented tools, systems and resources need to**

be developed that build upon these capabilities.

- **Interoperability among both Federally-supported and commercial cyberinfrastructure systems is critical to ensuring access and wide use of these tools.**

To make the best educational use of geoscience-related cyber-resources and other technological learning tools, documentation of learning effectiveness using these tools is necessary. Significant challenges in this regard include the fact that educational assessment in the geosciences is slow work in a field does not, as a rule, attract large numbers of students; and the non-traditional instructional strategies and divers reference frames made possible via cyberinformation systems can make rigorous assessment projects significantly more difficult.

- **The NSF should target support for assessment projects examining non-traditional geo-cyberlearning approaches (i.e., linked formal/informal strategies, efforts focused on teacher professional development, etc.) to begin to document and disseminate effective cybereducation strategies.**

Extant difficulties in effective cooperation among geoscience “domain” researchers and geoscience educators have been

compounded by the development of a new professional community, that of geoinformatics. Each of these communities share educational backgrounds, perspectives and “cognitive metadata” different from one another, complicating efforts at mutual understanding of each other’s jobs, needs, and perspectives. All three of these communities undervalue the time, energy, and resources required to collaborate successfully. Existing institutional reward structures encourage separations among these communities, as they do among geoscience subdisciplines.

- **Effective development and utilization of cyberinfrastructure tools in geoscience education and research requires successful collaboration among domain researchers, geoscience educators, and geoinformatics specialists.**
 - The NSF and other granting agencies should create more and more explicit funding opportunities for collaborations among geoinformaticists, geoscience educators, and geoscience domain researchers. These collaborations should, where possible, involve private sector participation (i.e., linkages to Google Earth, ESRI, or other cyberplatform enterprises).

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