Workshop Report to the National Science Foundation

“Data-Driven Cyberlearning for Geoscience and Hydrology Education”

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Executive Summary

[this comes last, after comments and revisions]
1.0 Introduction

Hydrology education involves teaching the description, explanation, and prediction of the occurrence, distribution and movement of water in nature. Hydrology is conventionally taught in a classroom using the fundamental physical laws of mass, momentum and energy. However, students at the undergraduate level have difficulty developing a conceptual intuition about physical scientific processes based solely on mathematical theories or classroom lectures. In addition, hydrology is driven by cause and effect relationships within natural system, and these relationships are difficult to understand because they change with space, time and scale. As a result, there is a need to augment conventional teaching with instructional material that will enable students to explore the natural system and its processes by using field data, simulation models and visualization tools. A recent study found that less than 20% of hydrology educators use community-developed or published materials for the bulk of their classroom activities, indicating that there is a serious dearth of community curriculum development activity in this field (Wagener et al., 2007). Meanwhile, recent advances in instrumentation and information technology has produced myriad of databases and simulation tools for research, but these resources are rarely used in classrooms to the extent to make any significant impact on student learning. In addition, where data and modeling resources are used, no study has been conducted to assess the impact of this pedagogical approach on students’ learning. Based on a pre-workshop survey of the university hydrology education community there is a strong consensus among the community arguing for the use of data, modeling and visualization tools in hydrology classrooms, but the curriculum materials and pedagogical resources to adopt these tools do not exist at the community level. Therefore, there is a need to initiate community efforts to discuss, develop and implement data and modeling driven pedagogy to enhance and complement traditional approaches to hydrology education.

The ultimate goal of this workshop on “Data-Driven Cyberlearning for Geoscience and Hydrology Education” is to create a community of educators organized around a collaborative cyberinfrastructure environment that empowers hydrology instructors to discover, download, publish, interconnect, modify, review, and collaboratively develop curriculum materials for data-driven cyberlearning in the geosciences. The first and foremost step in accomplishing this broader vision involves understanding the needs of the community and hearing their views on how this should be done to create the maximum impact at all levels of geosciences education. Therefore, this workshop brought together a selected group of experts and practitioners from the hydrology, geosciences and earth sciences communities to develop an understanding of whether and how data-driven modeling and visualization approaches can best be used to improve geosciences education. Organized around this broader goal, the specific objectives for this workshop are:

Obj. 1: Identify specific needs for cross-cutting data, modeling, and visualization digital resources that would be valuable for the broader geosciences education community at the upper and lower division undergraduate hydrology education.

Obj. 2: Strategize on how to bridge the gap between data-driven applications in major-focus-area upper division undergraduate education and those in other levels of education (emphasizing lower division undergraduate and community college applications).
Obj. 3: Specify key design criteria for a community cyberinfrastructure by which instructors can discover, download, publish, interconnect, modify, review, and collaboratively develop curriculum materials for data-driven cyberlearning in the geosciences.

Obj. 4: Identify the best ways to train the teaching community on the effective use of data-driven curriculum materials, to achieve broad impact and dissemination of this approach.

2.0 Background

2.1 Challenges and Opportunities in Cybereducation and the Geosciences

Strong voices for change and advancement in STEM education have been coming from the centers of leadership in Engineering and Science. Duderstadt’s (2007) “Millennium” report *Engineering for a Changing World* provides a roadmap to the future of engineering education, including increasingly practice-based and interdisciplinary engineering experiences for university undergraduates. The National Academy of Sciences’ (2007) report *Rising Above the Gathering Storm* highlights the importance of dramatically increased productivity and innovation in STEM fields, and the role of integrated approaches to teaching STEM concepts and toolsets in preparing a generation of U.S. students to be more productive and innovative. The National Academy of Engineering’s (2005) report *Educating the Engineer of 2020* and the National Academy of Science’s (2004) report *The Engineer of 2020* emphasize the centrality of information technology and connectedness between interdisciplinary concepts and tools. All of these voices point to a growing awareness that STEM education needs to be driven by focused, community-based efforts to systematically study and improve STEM education, especially in the university.

The University educational community is beginning to respond to these calls for action. For example, the recent Presidents of the American Society for Engineering Education (ASEE), Melsa, Rajala, and Mohsen (2009) are sponsoring an effort to survey and synthesize the state of the engineering education profession. Community recognition of the need for action is essential, because it is not possible to educate the engineers and scientists of 2020 without better equipping and supporting the science and engineering professor of 2020 (Morell et al., 2010). Equipping the next generation of science and engineering professors will involve a broader understanding and prioritization of Boyer’s (1990) “dimensions of scholarship” within the university and the professorate, so that the necessary time and energy is focused on improving and rigorously assessing pedagogies, teaching, and especially the creation of new “learning systems” (*JEE* Special report, 2010) necessary for community-based collaboration on the development and delivery of better integrated STEM educational strategies. Taken as a whole, the voices of the past 20 years of STEM educators are calling for the creation of communities of practice for innovative STEM education research and practice, and the university community is now responding.

The improvement of Science, Technology, Engineering, and Mathematics (STEM) education in the USA has been the goal and focus of dramatically increasing volumes of funded research since the 1990’s. A series of landmark reports describe the state of knowledge and grand challenges in STEM education; a selection of these reports and findings will be reviewed as they bear relevance to the development of undergraduate hydrology geosciences cybereducation.

A report, *Fostering Learning in the Networked World* (2008), of the National Science Foundation’s (NSF) Task Force on Cyberlearning established a series of recommendations for
the NSF’s strategies to foster learning in a networked, digital world, notably including (a) the creation of “cross-disciplinary communities of cyberlearning researchers and practitioners”, and (b) fostering “shared, interoperable designs of hardware, software, and services” for cyberlearning activities. The 2010 Boulder Hydrology Cybereducation Workshop responds to the Task Force’s recommendations by initiating a hydrology community of practice focused on developing a cybereducation strategy complementing existing hydrology education initiatives by adding a specific emphasis on “data and modeling driven geoscience cybereducation” (DMDGC) approaches and shared platform development suitable for software and data interoperability in hydrology education curricula. The Task Force’s report also poses several research questions that should be explicitly addressed by this emerging hydrology cybereducation community of research and practice, which we quote here for clarity [emphasis added]:

- How can we leverage the best of cyber-learning advances in the universities and industry to attract and prepare a new, diverse generation of [hydrology] leaders?
- How can STEM instruction incorporate authentic and realistic [hydrology] data from research, models, simulations, and other sources to improve lifelong science learning?
- What forms of user interfaces and interoperable resources will allow students to easily experiment with resources such as [hydrology] simulation models and datasets established by and for experts?
- What are the benefits for [hydrology] science learning of new data visualizations, immersive environments, modeling environments, sensor networks, and other technologies?
- What are the general principles that can guide adaptation of [DCDGC] materials to different learning and educational settings?
- What [cyberinfrastructure] tools can be used to facilitate this adaptation?
- How can [DCDGC] scaling opportunities build on the open-platform opportunities?
- How can [hydrology] domain knowledge [in geosciences and engineering contexts] best be restructured for learning and teaching through cyberinfrastructure technology?
- What should the life cycle of a [DCDGC] educational resource be, and what kinds of professionals and organizations are needed to support the different phases of this life cycle?
- What are viable sustainability models for NSF-supported [DCDGC] innovations?
- How can promising [DCDGC] materials be widely disseminated and sustained for an educationally appropriate time frame?
- How do we support changes in the educational system to provide effective [hydrology] materials, meaningful guidance on pedagogical approaches for implementing cyberlearning, assessment, classroom management, and leadership in the cyber-enabled classroom?
- What different needs exist for different age populations and [hydrology] learning domains [particularly undergraduate geoscience and engineering students]?

The NSF Task Force on Cyberlearning (Section 3.3.2) expresses a concern that the “data deluge” [Cyberinfrastructure Vision for 21st Century Discovery, 2007] has not been harnessed and adequately translated into STEM learning outcomes. The chief barrier to use of computational models in education is cited as “scalability”, which translates as the fitness of cybereducation approaches for use by educators who lack the resources to provide expert programming and technical support for those approaches. To solve the scalability challenge, three practical criteria for DMDGC curriculum materials’ best practices are formulated by the Task Force:
1. **Easy Experimentation:** Intuitive interfaces should not require programming or operating system knowledge of students or educators.

2. **High level of interactivity:** Models and visualizations must execute and evolve quickly (20–40 seconds is suggested) to provide effective feedback and hold attention.

3. **Classroom activities:** Models and data must be embedded in typical and traditional classroom learning activities such as lectures, and should feature built-in outcome assessments.

   It is important that we add additional generalized criteria for successful scaling of DMDGC curriculum materials and their supporting cyberinfrastructures, implicit in the research questions posed by the Task Force:

4. **Niche-Specific:** Materials must be tailored to specific learning learning outcomes, populations, professions, demographics, age-ranges, cognitive levels, cultures, and languages; for the purposes of this report, we are focused on English-speaking undergraduate engineering and geosciences hydrology students in the university classroom.

5. **Precision Search and Discovery:** Materials must be easy to find and therefore indexed using multiple organizational schemas and portals that allow users to identify the right materials for their niche needs. This implies advanced “recommendation engines” (Resnik and Varian, 1997), federated/networked “portals” that organize materials for specific niche communities (e.g. SERC, NSDL, and their niche-community partners), and indices that associate curriculum materials with various national, state, and local educational standards (e.g. National Science Teachers Association- NSTA- portal for K-12 science teachers).

6. **Persistence, Sustainability, and Longevity of Access:** Materials must be archived and accessed through persistent and sustainability funded institutions with a mandate for long-term archive and dissemination (e.g. NSDL, DLESE); niche-specific communities are usually not able to sustain these services over the long term. Sustainability of access also implies access that is cost-free to subscribers and users, and is rather funded up-front by the projects that developed the materials and/or by public funding sources.

7. **Modularity, Adaptability, and Flexibility:** Educators must customize and contextualize materials to relevant and local applications, so DMDGC materials should be designed into “bite-sized”, precisely defined modules that can be easily adapted and remixed into new sequences and combinations of topics as needed. This in turn increases the sustainability of materials which can be adapted rather than completely scrapped and rewritten as the learning community’s needs shift over time.

   If these best practices can be adopted, the Task Force is confident that,

   “…incorporating information and communications technologies into science and mathematics can restructure the necessary expertise for reasoning and learning in these domains, in effect opening up greater access to complex subject matter…” (*Fostering Learning in the Networked World*, 2008, pg. 13)

   Efforts have been made by the international educational community of practice to take steps toward implementing the best practices of scalability in the supporting cyberinfrastructure and institutions of the educational community. The principle of free, openly licensed Open
Educational Resources (OER) was established by the UNESCO in 2002 for the purposes of promoting international sharing and democratization of educational resources for the benefit of the developing world. Around the same time, the Massachusetts Institute of Technology implemented its Open Courseware (OCW) initiative that posts the complete content of thousands of courses on the internet, available without charge; hundreds of other universities have since joined this initiative and contributed course content at the undergraduate level. More recently, the National STEM Digital Library (NSDL) has emerged from a crowded community of peer “digital library” hub organizations as the leading hub of a large and growing federation of U.S. niche communities of educational practice, providing long-term archival mirroring and federated resource search services for more focused niche-community portals and “Pathways to the NSDL”, and their learning materials. Within this federation smaller centers such as the Science and Engineering Resource Center (SERC) provide focused editing and publication services for specific projects in their disciplinary domains and provide the “pathways” or portals to the NSDL.

Some recent examples of exemplary cybereducation learning applications include visual representations of links in algebra and calculus (Kaput, Hegedus, and Lesh, 2007), uses of scientific visualization for complexity investigations (McKagan et al., 2008), “Microworlds” for learning computational thinking (DiSessa, 2000), and hundreds of others since the inception of the internet and the microcomputer revolution. Dozens of NSF Directorates and other U.S. Federal programs have likewise funded the development of “cyberlearning” products in almost every educational discipline. However, as explained by the Learning in the Networked World (2008) report, many cybereducation efforts in the first two decades of the world wide web (WWW) have failed to achieve fully scalable and sustainable outcomes because the seven principles of scalability (outlined above) had not yet become self-evident during the life cycle of those initiatives. The most common scalability/sustainability errors are “dead portals” where a niche community’s short-term efforts to develop curriculum materials languish undiscovered, and “monolithic tutorials” which provide comprehensive instruction on a complex sequence of cognitive, theoretical, and modeling tasks that are tightly coupled and therefore difficult to adapt or update when software tools are upgraded or the application context is shifted. Both errors usually lead to a needlessly rapid (less than 5 years) expiration or obsolescence of current DMDGC curriculum materials, which is an unacceptable fate for otherwise exemplary projects that take so many years and so much money to develop.

As we seek to develop cyberinfrastructures and curriculum materials for DMDGC hydrology education, it is essential that we learn from recent experience and spend our efforts on systems and materials that are fully sustainable and scalable. More work still needs to be done to develop scalable cyberinfrastructures capable of fully supporting rich DMDGC hydrology education, and the educational materials that fully exploit the potential of cyberlearning approaches. This workshop has identified two key scalability gaps in current capabilities as (1) robust cyberinfrastructures capable of supporting rich and modularly structured DMDGC content, and (2) assessment-driven pedagogical strategies guiding the optimal use of this DMDGC content as a supplement for traditional educational activities. Future Geoscience Cybereducation community efforts- and especially the hydrology community- should focus on solving these two fundamental research challenges.

2.2 Review of Cybereducation Collaboration and Dissemination Initiatives
The National STEM Digital Library (NSDL) was specifically cited by the NSF Task Force on Cyberlearning (*Fostering Learning in the Networked World, 2008*) as a resource of value for undergraduate educators, and is therefore understood to be a critical dissemination interface for any platform developed or adopted for DMDGC purposes. The NSDL maintains a robust dissemination cyberinfrastructure that mirrors content provided on a federation of pathways (e.g. the K-Gray Engineering Pathway [http://www.engineeringpathway.com/ep/](http://www.engineeringpathway.com/ep/), and the Science Education Resource Center- SERC- [http://serc.carleton.edu](http://serc.carleton.edu)) which are community-specific educational content portals, and allows users to discover content published by any of those portals. The NSDL is continually evolving its content access mechanisms through a network of engaged partners, e.g. the “Instructional Architect” system developed by Utah State University to allow the use of NSDL content on instructional websites. Best practices and technologies, e.g. the SMETE resource discovery API, have been incorporated into the NSDL’s services. The Digital Library for Earth Science Education (DLESE, [www.dlese.org](http://www.dlese.org)) is now a geosciences pathway to the NSDL, and a close partner in the NSDL’s dissemination strategy. This resource has the critical mass and support of the broader educational community, and should be a part of any effective hydrology education curriculum material dissemination strategy.

However, these dissemination systems do not create their own content- specialized communities of educational practice do this (e.g. for oceanography, the Enduring Resources for Earth Sciences Education- ERESE- [http://earthref.org/ERESE/](http://earthref.org/ERESE/)). The goal of the hydrology DMDGC community’s dissemination efforts should be to create excellent curricular materials, and disseminate those materials using the broader existing cyberinfrastructures. The hydrology DMDGC community has unique needs that cannot be filled by existing dissemination systems. DMDGC curricula go beyond static materials, and begin to enter the territory of Learning Management Systems (LMS, e.g. the Advanced Distributed Learning network or ADLnet, or Edu 2.0, [www.edu20.org](http://www.edu20.org)) and Course Management Systems (CMS, e.g. Moodle- [moodle.org](http://moodle.org)). Systems like the Multimedia Educational Resources for Learning and Online Teaching (Merlot, [www.merlot.org](http://www.merlot.org)) allow educational users to browse many educational materials, contribute their own materials, and create their own personal collections of curriculum materials for use in specific courses. Perhaps the best example of a highly polished and well-integrated LMS and CMS is operated by the K-12 oriented National Science Teachers Association ([www.nsta.org](http://www.nsta.org)), which delivers thousands of science content modules, each with its own outcomes and pre/post assessments, indexed by grade level, topic, and state-by-state educational standards, and all available through a personalized course management system ([learningcenter.nsta.org](http://learningcenter.nsta.org)). The ideal hydrology DMDGC will incorporate elements of these dissemination, learning content management, and course management systems, utilizing as many shared services as possible, while adding focused capabilities to support learning content that integrates visualization, data access, and modeling activities with seamless assessment and formative feedback.

### 2.3 Best Practices in Learning, Pedagogy, and Assessment for Cybereducation

A brief summary of the recent findings of the educational literature is now warranted, to the extent that the literature agrees on best practices relevant to hydrology DMDGC approaches. 

The influential National Academies report *How People Learn* (2000) contains a thorough review of 20th-century approaches to pedagogies utilizing computers, modeling, and data, back to their beginnings as early as 1968 (Atkinson, 1968; Suppes and Morningstar, 1968). This report has a wealth of wisdom gleaned from 20th century research on education and pedagogy. We will
review the findings of this report and related materials as they bear relevance to the problem of DMDGC methods in hydrology education.

It is essential that new technological approaches be methodically combined with “traditional” pedagogical approaches to optimally exploit the relative advantages of each approach. A key advantage of DMDGC approaches over traditional lecture formats is the interactivity of computerized approaches (Greenfield and Cocking, 1996), which can dramatically increase the timeliness and usefulness of the formative feedback which is so essential for knowledge-building (Bereiter and Scardamalia, 1993). Visualization of modeling and data results helps students understand difficult distinctions or equivalencies between concepts, such as the difference between temperature and heat (Linn et al., 1996), the difference between rainfall volume and depth, the relationship between a gradient and a flow along that gradient, or the equivalence between elevation head and pressure. Crucially, it is increasingly possible for students to learn using the same modeling tools and data resources that they will utilize in a future career, which drives motivation for learning and increases the transfer of knowledge to nonschool contexts How People Learn (2000, Chapter 3). However, it is also emphasized that more abstract learning approaches are generally more transferable, so a balance between abstract and contextual pedagogies must be maintained. DMDGC approaches can provide this balance when combined with “traditional” theory-based hydrology education and existing knowledge of effective pedagogical approaches (White and Frederiksen, 1998).

Because geoscience is a fundamentally spatial discipline, DMDGC approaches have fundamentally new capabilities not accessible by traditional lecture-based educational approaches in the geosciences. Simultaneous visualization of multiple spatio-temporal data sources (e.g. with a Geographical Information System, GIS) creates the potential for the analysis of complex and dynamic relationships between three or more variables. It has been demonstrated that expert observers using visualization systems can detect complex patterns and relationships not previously noticed (Brodie et al., 1992; Kaufmann and Smarr, 1993). Computer-based simulation and visualization is one of the most powerful and fundamental advances in science, and is arguably as important as the development of symbolic mathematics or writing (Haken, 1981). The ability to instantly explore many alternative solutions to a problem, or visualize the impact of changes to a system (e.g. STELLA modeling environment, Forrester, 1991), allows the student to access an intuitive and deep learning of the connections between processes. We are no longer constrained to the exploration of simple relationships between pairs of variables, and now have access to complex systems involving networks, nonlinearities, discontinuities, and rich dynamics (Holland, 1995). The human brain is very skilled at visual processing, and visual exploration of data can help students achieve deeper learning (Gordin and Pea, 1996). Visualization has been applied as an approach to enhance Civil Engineering education, among other areas (Grimes et al., 2006).

The How People Learn (2000) report outlines five opportunities for increasing student learning using computerized approaches to pedagogy, which bear repetition here (in Chapter 9):

1. Bringing real-world problems into classrooms through the use of videos, demonstrations, simulations, and Internet connections to concrete data and working scientists.
2. Providing "scaffolding" support to augment what learners can do and reason about on their path to understanding. Scaffolding allows learners to participate in complex cognitive performances, such as scientific visualization and model-based learning, that is more difficult or impossible without technical support.
3. Increasing opportunities for learners to receive feedback from software tutors, teachers, and peers; to engage in reflection on their own learning processes; and to receive guidance toward progressive revisions that improve their learning and reasoning.

4. Building local and global communities of teachers, administrators, students, parents, and other interested learners.

5. Expanding opportunities for teachers' learning.

The *How People Learn* (2000) report highlights three qualities of excellent feedback for optimal student learning, which bear repetition here (Chapter 6):

1. Excellent feedback mirrors good instruction,
2. Excellent feedback happens continuously, not intrusively, as a part of instruction, and
3. Excellent feedback provides information about the learning that students are achieving.

*Formative feedback* differs from *summative feedback* in that summative feedback issues a “grade” or assessment at the end of an activity and provides no chance for students to learn or improve based on the feedback, but formative feedback assessments are issued incrementally at timely points during a learning activity, without an associated “grade”. The educational literature demonstrates that formative feedback is essential for student learning. Formative feedback assessment is time consuming, but research demonstrates that it must be done rapidly (Chen et al., 2010), at the same time as the authentic interactive learning experiences, in order to be effective (Gibbs, 1999), and especially in learning environments where individual face-to-face interaction with an instructor is difficult, such as in large classes or online learning systems (Roselli, 2006). Accordingly, DMDGC hydrology applications should not neglect a focus on implementing formative assessments. These assessments should be explicitly tied to the formal conceptual outcomes of instructional material so that learning outcomes can be directly assessed, and should occur in the natural flow of problem-solving, modeling, and analysis work. Short in-class quizzes on theoretical concept outcomes relevant to recently completed modeling work, and live interactive reviews where students communicate modeling results to their classmates and instructors, are both excellent methods for providing formative feedback that integrates DMDGC approaches with traditional instructional approaches. Assessment, including student self-assessment, is crucial for student learning (*Assessment as Learning*, 1994), but assessment is also crucial to provide data on which to base beneficial improvements to degree programs and academic units in the university (*Assessment at Alverno College*, 2005). Feedback assessments should therefore be integrated into all DMDGC approaches, for the benefit of students, communities of educational practice, and academic units.

A variety of studies (e.g. Gibbs, 1999) have verified a general pattern relating the extent of learning activity (Biggs, 1999), the degree of interaction with others, and the degree of active learning (Gibbs, 1982 and Ramsden, 1992) to increasing efficiency of learning retention in students. In this pattern, students retain in their long-term memories and skillsets 10% of what they read, 20% of what they hear, 30% of what they see, 50% of what they see and hear, 70% of what they discuss with others, 80% of what they use to solve a problem, and 95% of what they explain and teach to others. The teaching experience of the workshop participants generally bears this pattern out as true for undergraduate hydrology students. Accordingly, this literature and research provides general motivation and support for DMDGC approaches which are inherently visual and problem-oriented, and particularly for those approaches that involve teamwork or the
The use of data and models as a communication tool used by students to explain concepts to their peers.

The best DMDGC approaches also utilize a framework of authentic (meaning practice-like and realistic) problem-based experiences which motivate students by presenting them with something they can “use” in their future careers, and which engages them with the “real world” of applications (Knowlton and Sharp, 2003, Smith et al., 2005). Ericsson, Krampe, and Tesch-Romer (1993) argue that problem-based learning is essential for the acquisition of expert performance, in which experts are distinguished from novices in two ways: (1) Experts notice features and meaningful patterns missed by novices, and (2) Experts’ knowledge cannot be reduced to abstract sets of facts or propositions but rather reflects knowledge conditioned on a specific context of application. Reinforcing this point are two key concepts from a new model proposed for engineering education by Sheppard et al. (2008): (1) “Teach key concepts for use and connection”, and (2) “Integrate identity, knowledge, and skills through approximations to practice”. Cordray et al. (2009) report that assessed learning impacts are moderately but significantly positive when using “challenge-based” computerized learning modules in bioengineering classrooms, as compared with control groups. A small number of academic institutions have successfully redesigned their entire degree programs around Problem Based Learning, and have been able to demonstrate gains in employability and competency in science and technology students (PBL, The Aalbord PBL Model, 2004). It is therefore clear that contextualized, problem-based, challenge-oriented pedagogies have the potential to increase student learning, when properly applied.

However, as discussed in the literature reviewed in this report, it is possible to become an expert in a specific problem application but lack the ability to transfer knowledge to other contexts. Therefore these interactive, active, problem-based, authentic DMDGC activities must always be explicitly linked to abstract concepts and traditional learning outcomes in the hydrology classroom. This type of integrated approach, combined with timely formative feedback, is the best research-supported framework for effective educational outcomes. We observe that implementation examples are beginning to emerge, e.g. the Conceive Design Implement Operate CDIO™ (Crawley et al., 2007) initiative for curriculum development which emphasizes problem based learning, case studies, project based learning, and simulations as the element of “experiential learning”.

It is essential that our pedagogies be assessed using the best available educational research approaches, and that these assessments be integrated directly into DMDGC learning modules. We cannot expect the hydrology education community to accept significant change unless the new curriculum materials and pedagogical methods are supported by rigorous educational research (Watson, 2009, Streveler et al., 2006). A mixture of qualitative and quantitative assessment methods is called for, and has precedents in the educational literature (Borrego et al., 2009). Fortunately, a review of the state of educational methods in engineering education reveals that significant advances have been made in the past decade (Koro-Ljungberg et al., 2008), so we have a number of proven assessment approaches to choose from as we create a research strategy appropriate for the DMDGC hydrology education community. For example, bioengineering challenge-based computerized pedagogies have been quantitatively assessed with some success (Cox et al., 2008). A start has already been made in hydrology education, with early studies on computerized fluid mechanics instruction (Fraser et al., 2007) and with virtual watersheds modeled using the SWAT hydrology model (Horn et al., 2005). Opportunities for assessment are dramatically increased when a large community of educators is utilizing the same online or web-
based curriculum materials, if assessments are built directly and integrally into the materials and assessment data is centrally collected for analysis (e.g. Steif et al., 2009). The DMDGC hydrology education community should take advantage of the best of existing research methodologies to thoroughly assess its pedagogies and materials, in order to create positive educational change that is based on measured results.

### 2.4 Review of Existing Hydrology Education Initiatives and Toolsets

The hydrology geosciences and engineering communities have already begun to assemble some of the elements of the desired educational framework for undergraduate hydrology education, but the work is in an early stage. As reviewed by Manduca et al. (2008), the geoscience community needs to hold a conversation on teaching methods and shared materials; this conversation is beginning at hubs like the Teaching Quantitative Skills in the Geosciences website (http://serc.carleton.edu/quantskills/index.html). The community is just beginning to build shared hubs for the development and dissemination of community-authored educational materials, and although some excellent educational materials already exist in specific topical areas of hydrology engineering and geosciences, these materials have not been integrated together into coordinated curricula with community-standard learning outcomes, or implemented with integral formative feedback and learning assessment mechanisms that will facilitate the formal study and improvement of the curriculum as a whole. Significant barriers remain to a shared hydrology community resource, including immature frameworks for the sharing and integration of intricate DMDGC curriculum materials, lack of a community consensus on defined core educational outcomes at the various K-12 and university levels, cultural differences between the engineering and geoscience application domains of hydrology and their affiliated disciplines (e.g. atmospheric science, geology, biogeochemistry), and a substantial bifurcation between “water quantity” (sometimes called “water resources”) and “water quality” (sometimes called “environmental”) curricula. The following review will highlight selected existing efforts that bear relevance to the development of a community framework for hydrology education at the undergraduate university level in the U.S.A. (and the closely associated pre-collegiate and post-graduate levels). The international hydrology community is already engaged in most of these efforts, and is therefore implicitly included in the discussion.

Many excellent individual contributions have been made to develop specific granular curriculum materials, and it is likely that the summed total of these contributions cover nearly the full spectrum of possible content, style, and pedagogy for hydrology education. However, these individual contributions remain largely isolated and un-integrated with a community framework for curriculum development, and are therefore difficult for the workshop’s participants or the broader community to identify or include in a review. Integrating these valuable individual contributions as published contributions to the broader community curriculum is the ultimate goal for the development of community cyberinfrastructures and collaboratory frameworks, and it is assumed that these contributions will eventually be discovered and integrated into their proper place once the right community-driven systems are in place. However, other than a few examples included for illustrative purposes, this review will not attempt to identify or cite said individual contributions to the body of curriculum.

Three types of toolsets are used in hydrologic modeling and data analysis: (1) a computing environment for processing data (Excel/ArcGIS), (2) a toolbar or extension added to a computing environment, and (3) a numerical model. The first type of tool may be commonly used in several
hydrology courses, but type 2 is not widely used. Type 3 tools (numerical models) are employed by researchers/educators, and require expertise, familiarity with the model and its application in their study watershed context. Existing hydrology DMDGC toolsets can be classified into these three categories.

The Massachusetts Institute of Technology (MIT) sponsors the Star:Hydro hydrology modeling curriculum, which is an open, interactive modeling and visualization curriculum emphasizing distributed surface water hydrology and statistics (http://web.mit.edu/star/hydro/index.html). Star:Hydro has been utilized by a number of educators around the USA for the past decade, and has been a valuable resource for the community. The University Center for Atmospheric Research’s (UCAR) COMET program is a widely utilized online training program that provides both free educational materials and paid residential and online courses for hydrology, emphasizing the meteorological aspects of hydrology. (http://www.comet.ucar.edu/). The Community Surface Dynamics Modeling System (CSDMS, http://csdms.colorado.edu) provides free access to online modeling of the Earth’s surface in a high-performance distributed computing environment, with models contributed by the broader community and eventually integrated into the CSDMS. The Teaching Quantitative Skills in the Geosciences website (http://serc.carleton.edu/quantskills/index.html) provides pedagogical advice and specific resources for quantitative geoscience teaching at a variety of levels, including the undergraduate university geosciences classroom.

The U.S. Army Corps of Engineers’ Hydraulic Engineering Center’s (USACE-HEC) modeling tools (http://www.hec.usace.army.mil/), especially HEC-RAS and HEC-HMS and their GIS-enabled versions (Geographical Information Systems, GIS), have motivated the development of a number of hydrology DMDGC curriculum materials, including those of this report’s editors (see GIS and Water Resources Modeling Workshop materials at Merwade’s website, http://web.ics.purdue.edu/~vmerwade/tutorial.html). The HEC’s modeling systems have reached a nearly universal level of exposure in the engineering hydrology community (along with the popular SWAT model), and are therefore a common toolset for DMDGC activities in undergraduate and graduate hydrology courses.

Last but not least, the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI, www.cuahsi.org) leads an Education and Outreach initiative which has organized videos, debates, seminars, Hydrologic Literacy Standards (satisfying the NSF’s Earth Science Literacy Initiative- ESLI- in the hydrology area), and a database of hydrology-related education programs in the USA. CUAHSI also leads a Hydrologic Information System (HIS, http://his.cuahsi.org), which has succeeded in providing standards-based and service-oriented access to a wide variety of hydrologic data sources in the USA. CUAHSI sponsors the MOCHA curriculum initiative (see below), and the HydroHUB online seamless modeling environment for hydrology (www.cuahsi.org/hydrohub/). The ArcHydro data model and toolsets and their derivative versions (e.g. the CUAHSI HIS Observations Data Model), jointly developed with cooperation from CUAHSI HIS leadership and the ESRI GIS company, are also supported by CUAHSI’s HIS project. Any hydrology DMDGC efforts must be executed in correspondence with CUAHSI, owing to CUAHSI’s central role in the USA hydrology community’s data interoperability (HIS), modeling (HydroHUB), and education (MOCHA) initiatives. CUAHSI represents both geoscience and engineering communities in hydrology in the USA.

The Modular Curriculum for Hydrologic Advancement (MOCHA, www.mocha.psu.edu) was established to create a community-driven curriculum based on Powerpoint-formatted modules covering standardized university-level hydrology outcomes in a traditional hydrology course,
including assessments and pedagogically compatible module design. This community aims to establish a *Hydrology Body of Knowledge* (HBOK) over time by leveraging community input via contributed modules. The community now boasts hundreds of members throughout the world, and is publishing its first modules. MOCHA answers three questions for university hydrology instructors (from MOCHA website, 10 March 2011):

1. “How good could a watershed hydrology course be if all aspects of the course would be covered by one or more experts in this particular aspect of hydrology, rather than having the whole course created by a single hydrologist?”
2. “How holistic would the approach to hydrology education be if both scientists and engineers jointly cover both the qualitative and quantitative aspects of watershed hydrology?”
3. “How much improvement would be possible if basic pedagogical guidelines would be followed throughout a course?”

These same questions could be asked regarding DMDGC applications, were the best data-driven and modeling curricula designed by experts and integrated into a pedagogically compatible community curriculum structure. Hydrology DMDGC activities could mirror MOCHA community efforts by providing problem-based, computerized, data-and-modeling driven modules to complement the traditional lecture-based curriculum and reinforce MOCHA module outcomes.

### 3.0 Workshop Plan and Activities

In order to begin building a community of practice around hydrology DMDGC approaches in the undergraduate university classroom, and to obtain the necessary input from a broad spectrum of hydrology practitioners in the engineering and geosciences disciplines, the National Science Foundation sponsored a one-day workshop. The workshop was held on July 22, 2010 from 8:30 AM – 4:00 PM at the UCAR Green Campus in Boulder, CO. The workshop was funded by the National Science Foundation through a grant from the Course, Curriculum and Laboratory Innovation (CCLI) grant within the Division of Undergraduate Education’s geosciences directorate. Organization of the workshop was led by Dr. Venkatesh Merwade, Assistant Professor at Purdue University, and Dr. Ben Ruddell, Assistant Professor at Arizona State University- Polytechnic. In addition to the organizers, 23 faculty members and two graduate students attended the workshop (Appendix 1). The format of the workshop included presentations in the morning session followed by group discussions (Appendix 2). The workshop had the following four objectives:

1. Identifying specific needs for cross-cutting data, modeling, and visualization digital resources that would be valuable for the broader geosciences education community at the upper and lower division undergraduate hydrology education.
2. Strategizing on how to bridge the gap between data-driven applications in major-focus-area upper division undergraduate education and those in other levels of education (emphasizing lower division undergraduate and community college applications).
3. Specifying key design criteria for a community cyberinfrastructure by which instructors can discover, download, publish, interconnect, modify, review, and collaboratively develop curriculum materials for data-driven cyberlearning in the geosciences.
4. Identifying the best ways to train the teaching community on the effective use of data-driven curriculum materials, to achieve broad impact and dissemination of this approach.

Before the workshop, a pre-workshop survey (Appendix 3) was conducted to get participants’ input on objectives, and to develop focus questions for the break-out sessions. The first session in the morning included a presentation on Modular Curriculum for Hydrology Advancement (MOCHA) by Dr. Thomas Meixner, brief presentation of the pre-workshop survey results by Dr. Venkatesh Merwade, and a demonstration of existing online curriculum sharing and dissemination systems by Dr. Ben Ruddell. After presentations, all participants were divided into four groups (Appendix 4) for the first break-out session. The groups were redefined for Activity 2 to allow participants to get a chance to have face-to-face interaction with a wider audience. The groups for each session were designed to include a mix of hydrologists and geologists and/or engineers and scientists including diversity in faculty ranks. The objective of this first break-out session that tentatively lasted for 1.5 hours was to engage each group into Activity A (presented below) that touched the first two objective of the workshop.

3.1 Description of Activity A: Design Learning Modules

The participants were directed to think of hydrology learning outcomes that can be accomplished using specific and currently available public domain data and modeling tools, categorize those learning outcomes by academic level: lower-division undergrad, upper-division undergrad, and graduate, and then design two simple data and modeling modules, one for lower-division hydrology and one for upper-division hydrology, to accomplish at least one of the learning outcomes they described. The participants were assigned focus questions to direct the discussion:

- How will you integrate traditional content with computer-based modules?
- How would you assess student achievement of the learning outcome?
- What hydrology learning outcomes cannot be accomplished using models and data? Why?
- Is there a difference between engineering and geoscience hydrology learning outcomes? Can a single set of modules serve both types of outcomes?
- What unique role do these data and modeling driven hydrology modules serve in addressing the “Hydrology body of knowledge” (HBOK) or set of educational standards (e.g. ABET etc.)?
- What existing pedagogical methods (e.g. mastery-based learning) can be best combined with computer-based approaches to teaching and assessing hydrology learning?

After Activity A, one member from each group presented results to all participants. Activity B for the second break-out session was designed to target objectives 3-4 of the workshop, and the format was similar to that for break-out session 1. A description of Activity B is given below.

3.2 Description of Activity B: Design Online Learning and Curriculum Development Environment
The participants were directed to consider a time in the near future when an online resource becomes available for hydrology faculty to collaborate on the development and publication of learning modules based on data analysis and modeling. This environment will also host community training activities for students and instructors. In groups, the participants sketched a design, including specific design requirements, for a system that the participants would find useful for their courses on a regular basis. Bearing in mind that the system must be very simple to be useable and to be affordable to build and maintain, the participants were asked to identify the few top-priority functions and capabilities that the system must have. The participants were assigned focus questions to direct the discussion:

- What kind of learning environment will enhance the exploratory skills of students at undergraduate level using data and modeling tools?
- What are your expectations, challenges/hurdles, and new opportunities as contributor and/or user (users can include students and instructors)?
- How should the peer review system work for module publication and distribution?
- How should curriculum contributors be rewarded?
- What is the best way to train teachers in adopting data and modeling driven curriculum in their classroom instruction?
- How can assessment of student learning and module effectiveness be conducted via the same online learning environment where the modules are hosted?

After Activity B, one member from each group summarized their discussion followed by a brief question and answers session. In the final closing remarks, all participants were briefed about the next steps including somechro proposal ideals, and were asked to evaluate the workshop for feedback (Appendix 5).

The workshop concluded at 4:00 PM as planned.

4.0 Workshop Results

4.1 Results of Pre-Workshop Survey

The pre-workshop survey was designed to get participants input on each objective of the workshop. In addition to sending the survey to all workshop participants, other individuals who expressed interest in this effort, but were unable to participate in the workshop, were also invited to participate in the survey. The survey was completed by 37 participants. A brief summary of the survey results categorized by each workshop objective is provided below.

Hydrology is taught at undergraduate and graduate level in multiple disciplines including civil engineering, geological sciences, earth sciences, atmospheric sciences, and agricultural engineering. Undergraduate hydrology courses are mostly taught as upper-division courses meant for students with a hydrology emphasis. In addition most undergraduate courses are introductory courses with little or no emphasis on data and modeling driven teaching. Data and models including GIS are introduced in some graduate level classes across the nation, but the number of schools that offer such classes is limited. In January 2010, CUAHSI conducted a community survey to: (i) assess the current state of data and modeling driven curriculum in hydrology; (iii) gauge the level of support for an effort to develop data and modeling driven
curriculum material; and (iii) get input on issues that the community currently faces in adopting data and modeling driven curriculum teaching in hydrology. A total of 120 educators (approx. 100 from the U.S.) with background in multiple disciplines including engineering and science participated in this survey. Important outcome from this survey is summarized in Table 1.

**Table 1: Outcome of pre-workshop survey on data and modeling driven curriculum**

<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Background</td>
<td>Science (44); Engineering (26); Both (43)</td>
</tr>
<tr>
<td>(2) Your teaching level</td>
<td>Lower Undergrad. (17); Upper Undergrad. (74); Grad. (98)</td>
</tr>
<tr>
<td>(3) Level at which data and modeling is used</td>
<td>Lower Undergrad. (11); Upper Undergrad. (62); Grad. (86)</td>
</tr>
<tr>
<td>(4) Should data and modeling driven curriculum be primary method of instruction</td>
<td>No (91); Yes (19)</td>
</tr>
<tr>
<td>(5) Software Used</td>
<td>Excel (89), ArcGIS (60), Matlab (33), Modflow (25), HEC-RAS (15), HEC-HMS (15)</td>
</tr>
<tr>
<td>(6) What type of data and modeling would you do in your class if high quality free curriculum material is available</td>
<td>GIS analysis and visualization (79); hydrologic modeling (77); data access and pre-processing (70); Custom Modules (67); tutorials on how-to’s for modeling (62); online lectures and webcasts (51)</td>
</tr>
<tr>
<td>(7) Constraint in using data and modeling</td>
<td>Time commitment (56); steep learning curve (51); lack of access to easily adoptable teaching material (31); difficulty in keeping up with technology (26)</td>
</tr>
</tbody>
</table>

Clearly, a lot of data and modeling driven teaching is used at upper undergraduate level (Q.3), but the most common tool that is used at upper undergraduate level is Microsoft Excel (see response to Q.5) without much use of actual data pre-processing, modeling and visualization. The use of ArcGIS, Matlab and other modeling tools is mostly incorporated at graduate level hydrology courses. The need for curriculum material that involves the use of field or public domain data, modeling and visualization is clear from response to Q.6 in Table 1. In addition to the CUAHSI survey, an independent survey of undergraduate and graduate courses show that very few (less than 15) institutions offer undergraduate and graduate level courses that use actual geospatial and time series data, geo-processing and modeling to teach hydrology. This list is provided in supplemental documents.

Considering the extensive use of modeling and other tools in research and professional world, it has become necessary to train the undergraduate students in data handling, model applications and visualization for a successful career. In addition, few would disagree with the strategy of supplementing a traditional curriculum with the latest tools and technology. However, adopting data and modeling tools in teaching is not easy. As found in the survey (Q. 7), instructors who want to use computing tools in their courses face several practical problems including: (i) negotiating a steep learning curve, and then staying up-to-date with the latest
developments; (ii) creating additional teaching material which is not always available in books, and must be extracted from hundreds of pages of users manual; (iii) collecting or creating datasets to feed the computing tools, and (iv) the lack of an organized user community precludes investment by software companies in tools to service the needs of hydrology geosciences educators. Unavailability of computing tools in the curriculum hinders students’ ability to go beyond text book knowledge to explore the field in depth through self learning. Overall, developing instructional tools for learning is a significant time investment on the instructor’s part, which is often impossible to commit. The most appropriate way to address this issue is to construct a system where a community of educators (not individuals) can contribute tools, teaching materials and data, which can be adopted by any member of the community, thus creating an efficient, consistent and state-of-the-art learning environment for undergraduate students.

4.1.1 Survey Results for Objective 1: Identify Cross-Cutting Community Resource Needs

The broader hydrology community provided significant input into the types of resources that are developed for undergraduate DMDGC education applications. All datasets used, including GIS layers, observations and remotely sensed data, should be freely available public domain datasets. This is workable, because nearly all hydrology datasets are already public domain and are becoming more accessible through efforts such as CUAHSI’s HIS project. Several analysis tools were identified as useful for hydrology instruction. Although some of them are public domain (e.g., QGIS, S, R, uDig, PostGIS, etc.), the most commonly used tools such as ArcGIS, Matlab and Excel are proprietary but widely available in universities. Most modeling tools that are commonly used for surface water hydrology are in the public domain except for the Watershed Modeling System (WMS) from Aquaveo. The list of modeling tools used for Hydrogeology is shorter, and half of them are proprietary. Availability of public domain data and tools was identified as one of the desired attributes of instructional resources. The community generally believes that freely available toolsets are preferable to proprietary toolsets. Other positive aspects of public domain data and tools (e.g. Matlab) include the transferability of data analysis and modeling skills to other scientific domains.

Some weaknesses were also identified for currently available data and tools. These include the cost of some proprietary resources, incompatibility of models between different operating systems, steep learning curve associated with some models, and students’ perception of modeling tools as “black boxes”. Weaknesses associated with data mainly included a lack of datasets for students to work within their local watersheds, incompatibility in formats/coverage/resolution of different datasets, and a severe computational burden of pre-processing before using for analysis or modeling. Modeling exercises for students should utilize non-proprietary data and tools as much as possible. Modeling exercises should be based on case studies or scenario analyses that develop curiosity, exploratory and knowledge discovery skills within students. The benefit of having a standard community modeling tool to meet the educational needs of hydrology students was also identified in the survey.

The importance of 2D and 3D visualization for computational discovery and understanding of physical hydrology was emphasized in the survey results. A tool that will go beyond 2D/3D visualization to enable scaling of data in space and time will be useful for hydrology instruction.
4.1.2 Survey Results for Objective 2: Bridging the Gap to Upper Level Hydrology Education

There was a general consensus among respondents, with few exceptions, that most hydrology concepts can be taught using data and modeling tools, with appropriate level of learning objectives and computing skill expectations at different teaching levels (lower or higher undergraduate or graduate level). Topics that can be taught using computerized techniques include water balances, water movement across multiple environmental gradients, and graphical visualization of different hydrological concepts or theories (equations). Besides hydrology concepts, computerized instruction can also expose students to issues associated with modeling such as scale, parameterization, feedback mechanisms between hydrologic components, and uncertainty in input data and model results. Computerized methods should be used with caution to avoid the use modeling tools as black boxes that can only take input and provide output. It is important for students to think about hydrology without computers, and how computers can be used to simulate the system. To develop students’ curiosity for hydrology, field trips in conjunction with traditional and modern computerized instruction is important. Visiting sites where instrumentation generates scenario data is particularly desirable. Engaging students in projects based on real-world issues with outcomes that can be compared and contrasted will create questions in students’ minds that can be answered through computerized methods.

Currently there is no authoritative body of knowledge that codifies the specific skills and hydrology concepts at various educational levels. However, we observe that the CUAHSI education and outreach community, and the NSF funded MOCHA project, are trying to establish a standard for hydrology instruction at university levels. Similarly, the outcome “k” in ABET specifically lists skills associated with modern engineering tools and techniques, which include computerized methods for hydrologic design and analysis. The geoscience community and engineering education community have made some progress in this direction (recall section 2), and survey respondents agreed that the existing literature has a lot to offer a new hydrology cybereducation effort.

4.1.3 Survey Results for Objective 3: Establish Cyberinfrastructure Design Criteria

If a cyberinfrastructure is developed to create a community of instructors, uploading and downloading of curriculum material is the most important utility that the community would like to see implemented. This priority is followed by online assessment, visualization and analysis tools, uploading of data and modeling tools, and social interaction systems. Peer review and rating systems for the curriculum received the least votes (Fig. 1). Many workshop attendees were surprised by this last-place result for curriculum material publication and ratings, because the development of such a system provides a key incentive for faculty to receive review and acknowledgement of their community contributions in the “teaching” dimensions of scholarship. Without this recognition provided by the hydrology education community, it is less likely that significant progress will be made on the development of curriculum materials.
The survey respondents agreed that hydrology instruction should be integrated with CUAHSI HIS and other cyberinfrastructure (CI) activities within hydrology to take the advantage of progress made by different groups. A major constraint in creating a CI is to get a critical mass devoted to this effort to contribute high quality material for student learning. Similarly, there needs to be standard mechanism or framework for contributing to this community effort to avoid repetition or incompatible module submissions. In addition to getting high quality input to the system, sustainable implementation and maintenance of the CI beyond the initial development and testing period should be given consideration in creating this community resource. The ease of use, openness, simplicity and benefit of the CI to individual faculty members must exceed the cost of their investment to make this effort sustainable. If the CI has several modules then there needs to be a mechanism to link them so a student can complete a sequence of hydrology concepts. To enable this workflow of modules, the CI should have a standardized metadata framework for all the contributions including data and modeling tools. The workflow modules can be loosely coupled through inputs and outputs, or can be coupled through a central coupler system that can transfer data and model output from one step to another.

4.1.4 Survey Results for Objective 4: Prioritize Community and Instructor Training Approaches

Figure 1: Percentages of hydrology community survey respondents rating specific learning community cyberinfrastructure capabilities and design criteria as important for their personal applications.
Several mechanisms (Fig. 2) can be used to train instructors on using the cyberinfrastructure for curriculum development, publishing, and sharing. Besides the mechanisms listed in Fig. 2, other avenues such as short hands-on workshops, for example the “On the Cutting Edge” workshop hosted by SERC (http://serc.carleton.edu/NAGTWorkshops/about.html) would add value. Similarly, ways to incentivize faculty for contributing to this effort need to be explored. Increased awareness of the avenues available for publishing educational related work including funding sources will increase faculty interest in a reward oriented system. There is also a need to demonstrate how these efforts integrate with existing teaching tools such as textbooks, or produce new textbooks that are aligned with using internet resources for data analysis and modeling.

![Figure 2: Percentages of hydrology community survey respondents rating specific learning community cyberinfrastructure training and equipping resources as important for their personal applications.](image)

### 4.2 Results of Break-out Sessions

In the second half of the workshop, attendees were asked to break into working groups to complete two activities. One activity, “A”, is an exercise to develop an example hydrology DMDGC module, and the second activity, “B”, is an exercise to create a straw-man sketch of an ideal online curriculum development and online learning environment for undergraduate university hydrology community applications. Exemplary results from the breakout sessions are presented in sections 4.2.1 and 4.2.2 below.

#### 4.2.1 Results of Activity A: Design Learning Modules

- **Title**: Watershed Balance
Learning objectives: learn about basic hydrologic components including storage, fluxes and residence time, recognize hydrologic data uncertainty, and understand spatial and temporal variability.

Tasks: downloading of time series data (e.g., precipitation and streamflow), delineating of watersheds, computing area, conversion of data to comparable units, hypothesis testing and/or answering research questions (e.g., what causes rainfall-runoff correlation to vary from one watershed to other? How do water balance components change in a dry year versus wet year?),

Approach: case studies (compare and contrast watersheds), outcome based (effect of climate and land use)

Undergraduate level skills and/or outcomes: basic understanding of hydrologic cycle, input/out data issues, dimensions, units and conversions, basic understanding of hydrologic simulation using computing tools.

Graduate level skills and/or outcomes: uncertainty analysis, sophisticated modeling using geospatial and temporal data.

4.2.2 Results of Activity B: Design Online Learning and Curriculum Development Environment

- Attributes of a cyber learning environment: it should provide both point observations (e.g., through HIS web services) and geospatial data, should have basic functionality for accessing, downloading and visualizing data, user interests should be generated through short-time activities, tutorials and interactive programs interests, initial system should be simple but users can add complexity.

- Reward system for contributors: ideas include recognition through CUAHSI (e.g., writing recommendation letters for community service), citation of online modules, monetary reward through revenues generated from subscription, rating, usage statistics

- Peer review: this is important to have high quality material for the community, and for contributors to get credit; may discourage some instructors to contribute, the user (instructor) who will use the material can act as a reviewer; users can review, and mix/match modules based on the quality of individual contribution,

- Assessment: the designer of the module should also design the assessment of each module, online surveys, feedback forms, etc.

- Challenges: measuring effectiveness of this approach on students learning, interfacing/handling sequence of modules and learning outcomes, long term sustainability of the system beyond initial development years

5.0 Summary of Workshop Findings and Next Steps

The attendees of the 2010 workshop reached a general consensus on particular challenges and priorities for data and modeling driven cybereducation approaches in hydrology, which will be summarized here.

- A community-based curriculum material development effort will be a worthwhile use of the community’s time and energy, if it is implemented such that incentives and cost/benefit balances motivate individual faculty members to actively participate (we need critical mass).
• Bridging the gap from lower-division undergraduate hydrology (usually qualitative hydrology) to upper-division undergraduate hydrology (which needs to be quantitative) is a key challenge.
• Any new cyberinfrastructures must connect with geosciences, engineering, and hydrology education infrastructures and communities that already exist, because some excellent work is already being done. Don’t reinvent the wheel on concepts or dissemination.
• A focus on teaching hydrology concepts and modeling skills must be maintained, and a tendency to create “black box” methods avoided.
• Data visualization features are particularly desirable.
• Public domain data and toolsets are strongly preferred.
• Curriculum material cyberinfrastructures must be carefully implemented to maintain rigorous contribution quality and interoperability standards; this will be particularly essential if modules from different authors are to be combined in sequences to teach hydrology concepts.
• Module publication and search functionality is essential, but a more streamlined and accessible method of accessing context-specific and local hydrology data is also important, as is built-in assessment and feedback functionality for modules.
• Workshops and tutorials are the preferred methods of training for the new system.
• Integration with CUAHSI-HIS, HubZero, MOCHA, SERC, and NSDL systems is strongly supported as a best practice.

Taken as a whole, the results of the pre-workshop survey and the attendees’ input provides support for a community-driven effort to develop data and modeling driven cybereducation module content that can be integrated with traditional lecture materials in the hydrology classroom. Significant implementation challenges must be overcome, especially technical challenges associated with sharing modules rich in modeling and data content and also cultural barriers to participation, but these barriers can be partially overcome by utilizing the best existing infrastructures and hydrology education communities and building on their success.

We have an ambitious vision for a network where a user community of educators and researchers can access people, data, modeling tools, and educational curricula – and where they can publish their own curricula for the community to use. The key to this collaborative curriculum development environment is the adoption of a set of metadata standards which allow curriculum to be published as an interchangeable sequence of modules of curriculum content, arranged into sequences organized around structured inputs and output datasets, and the creation of a user community organized around the creation, utilization, review, and dissemination of the curriculum. The next step in this process is the creation of a formal community- likely as a supplemental focus group within MOCHA- to drive the development of this new curriculum resource. The second step, also essential, is to develop a proof of concept for a feasible but more capable cyberinfrastructure that is able to integrate structured DMDGC hydrology modules contributed by the community. A draft concept for this cyberinfrastructure was shared with the attendees of the workshop, who agreed in principle that the concept is a good starting point for development (Fig. 3 and Fig. 4).
Figure 3: Schematic of the proposed cyberinfrastructure and its user community.

The core of our curriculum content management scheme is a “module”, which is conceptually similar to a lesson plan, a tutorial, or a chapter in a textbook. It is a coherent lesson in the area of hydrology and geoscience, which may be published and distributed using the proposed CI. A module has up to four types of objects, two of which are mandatory (one Document per module), and three of which are optional (any number of Tools, Datasets, or Presentations per module) (See Fig. 4):

1. **Module Document.** This is a PDF-format document which contains a complete lesson, including all necessary information for a student (or teacher) to successfully complete the module. This document cites all necessary tools, datasets, presentations, and other material needed to complete the task at hand.

2. **Software Tools.** Any tool (simulation or computational model) that a contributor creates or adapts may be published along with module and data teaching its use. Only original, public/freeware tools may be contributed- if the tool is not the creation of a contributor, and is available elsewhere, then it must be cited in the module document, rather than duplicated.

3. **Datasets (Input / Output).** Similarly, datasets that are the creation of a contributor (preprocessed and compiled by the contributor, derived from other published data sources) may be published in a module. If the data is being published through another source (e.g., public domain data), then it will not be distributed by our system- it should be cited in the module document including explanation on obtaining the necessary data from the original source.

4. **Multimedia resource.** If animations, video, audio, images or slide-based lectures (video based lectures, podcasts) are included to enhance the instructional value of the module, then this is linked as an object.
The sequence of modules is determined by pedagogical approaches conducive to how students learn and can be tailored to specific learning objectives by the instructor. Based on principles of pedagogy and instructional design, the module architecture can be used to systematically share instructional resources while maintaining the pedagogical integrity that has been designed and tested by a contributor to the CI. That is, an instructor can choose to adopt a modular sequence that has been tested and disseminated by others. Alternatively, the instructor can adapt the modules by tailoring them to the needs of the students or the availability of new tools.

The beauty of this module management strategy- which lies at the core of the proposed CI solution- is that it allows for a sequence of modules to be flexibly adaptive (Schwartz et al., 1999), with their interface controlled solely on control of the format of their input and output datasets (file type, variable name, and units of the dataset). There is no need for a contributor to adhere to a stringent and complex set of standards, in order for different modules to be used in sequence. Modules may be strung together to teach a sequence of lessons to accommodate the needs of the learners and not be limited by, (a) the geographical location, such as a watershed or country, for which the data applies, and (b) the specific set of tools and methodologies employed during the module. For example, an instructor in Arizona can use the exact same sequence of hydrology data processing and modeling modules that were developed using a case study in Indiana- but simply by substituting Arizona-specific input data of a correct format, the instructor can use the same curriculum. Alternatively, an instructor may decide that one of the middle modules uses an undesirable toolset or methodology, and develop a new module to replace it. As long as the new module has the same inputs and outputs as the old one, a new tool or method may replace an old one, or a new module may replace a sequence of older modules.

This strategy solves several of the practical problems currently faced by the community (Q.7 in Table 1), because it facilitates incremental, continuous improvement- when a new data processing or modeling tool becomes available, one contributor can develop a module for its use, and then the whole community can adopt that module to replace one piece of their existing curriculum. No longer will each individual need to “reinvent the wheel” by redeveloping a whole curriculum, each time a piece of the technology changes.

With the broader support of the hydrology education community, we are happy to report a successful workshop that has created a starting point for a new community of practice focused on
DMDGC applications in the undergraduate hydrology classroom. We are excited to move forward with the next steps by continuing to build community support for this initiative, and by proceeding with a proof of concept for a new type of simple but powerful cyberinfrastructure capable of supporting the community’s unique needs. We believe that this proof-of-concept effort will provide value to the broader engineering and geosciences education communities, and is worth the effort necessary to take the next step.

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### 7.0 Appendices

**Appendix 1: List of Workshop Attendees**

<table>
<thead>
<tr>
<th>Name</th>
<th>Department</th>
<th>Institution</th>
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<td>UMass - Amherst</td>
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Appendix 2: Workshop Group Activity Summaries

Appendix 3: Pre-workshop Survey

Appendix 4: Breakout Groups

Appendix 5: Workshop Evaluation Questionnaire and Evaluation Results