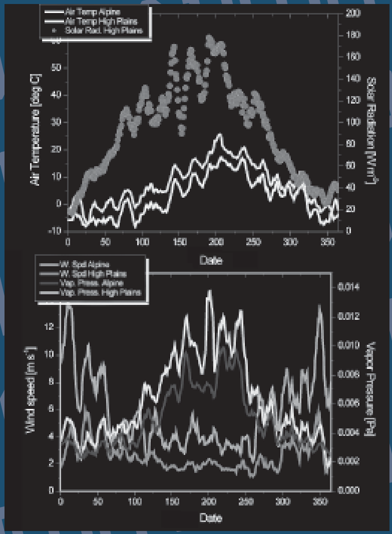
# USING DATA

## in Undergraduate Science Classrooms




FINAL REPORT ON AN INTERDISCIPLINARY WORKSHOP AT CARLETON COLLEGE, APRIL 2002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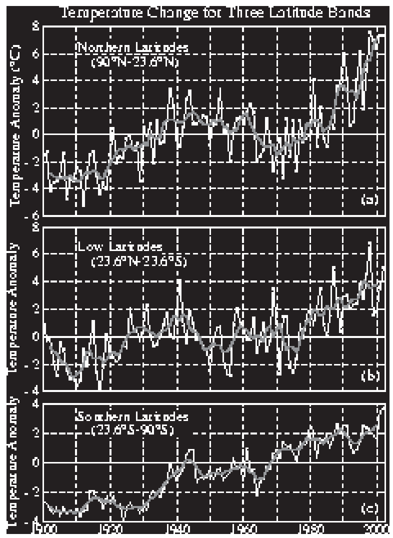
Temperature Change for Three Latitude Bands
Northern Latitudes
(90°N-23.6°N)
Low Latitudes
(23.6°N-23.6°S)
Southern Latitudes
(23.6°S-90°S)
Temperature Anomaly (°C)
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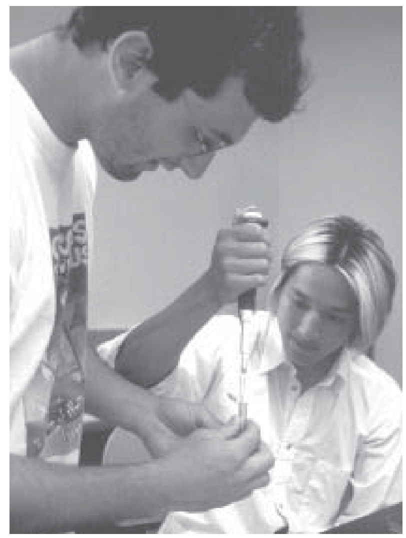

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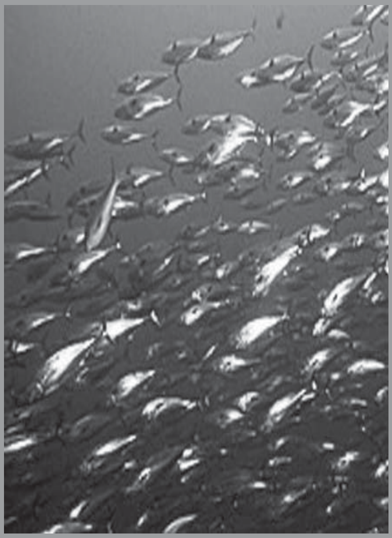

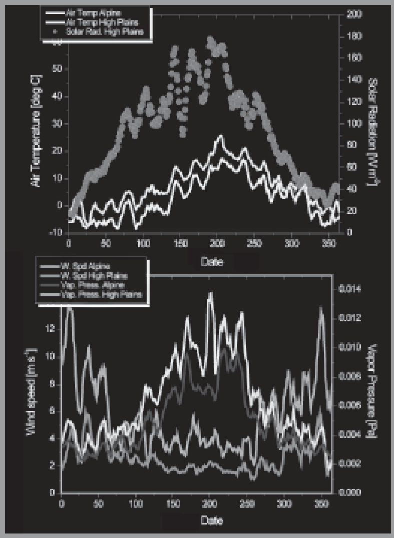


CATHRYN A. MANDUCA
AND DAVID W. MOGK

FINAL REPORT ON AN
INTERDISCIPLINARY WORKSHOP HELD
AT CARLETON COLLEGE, APRIL 2002

Sponsored by the National Science Digital Library with
funding from the National Science Foundation,
Division of Undergraduate Education
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NSDL

NSF

# EXECUTIVE SUMMARY (NSF-0127298)

USING DATA IN OUR CLASSES AND LABS focuses learning on the process of science while capitalizing on new opportunities created by data-sharing and web technology. This report summarizes discussions of 26 faculty from science, technology, engineering, and mathematics (STEM) disciplines and National Science Digital Library (NSDL) project Principal Investigators to better define why, how, and to what effect faculty use data in the classroom. The workshop goals were to advance the effective use of data in the classroom, to support inquiry- and discovery-based learning, to identify common practices in the use of data among the science disciplines as well as their special needs, and to inform the design of online data-delivery tools. Discussion focused on

- What do we mean by data?
- Why is engaging students with data an important part of STEM education for undergraduates?
- What is the range of current practices?
- What do we know about how well these practices work?
- What recommendations for digital libraries, data providers, and online resource developers follow from this discussion?

Data-enhanced learning experiences, including activities in which students collect and interpret their own data and those in which they explore research databases to answer questions, are important tools for student learning. In particular, data-enhanced learning experiences can

- Prepare students to address real-world complex problems;
- Develop students' ability to use scientific methods, including consideration of the values and ethics of working with data;
- Teach students how to critically evaluate the integrity and robustness of data or evidence and of their consequent interpretations or conclusions; and
- Provide training in scientific, technical, quantitative, and communication skills.

For the purposes of this report, we have defined data broadly to include any information that supports student inquiry and participation in the scientific method, including experimental or observational data as well as simulated data derived from models.

Currently, there are excellent examples of how students can be engaged in using data to answer questions from all of the scientific disciplines and engineering. While each discipline has developed its own methods for engaging students with data that are specific to the field, our interdisciplinary conversation pointed out many commonalities among these approaches and opportunities for collaboration.

The observations of master teachers suggest that using data improves learning about science. To strengthen our use of this approach, work should focus in three areas: disseminating examples of effective practice, evaluating the impact of data-enhanced learning, and developing data-access infrastructure and services. The development of a clear articulation of the core learning goals shared among the scientific disciplines will be a fundamental next step for enhancing instruction and evaluation.

For effective instruction, workshop participants recommend that new data-access infrastructure and services focus on the ability of students to perform critical tasks that support learning from data. In particular, instruction will be most effective when students can

- Find and access data relevant to the topic they are investigating;
- Evaluate the quality of this data;
- Use appropriate tools and interfaces to manipulate and render data to answer questions;
- Combine multiple and diverse datasets to solve a central problem, selecting or compressing data subsets to address a specific task;
- Generate visualizations and representations that communicate interpretations and conclusions; and
- Contribute, view, and evaluate their own data in the context of larger datasets.

The workshop participants recommend that NSDL promote the interactions and partnerships needed to develop this type of data access, dissemination of effective instructional practices, and supporting services.

# WORKSHOP PARTICIPANTS

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Cinzia Cervato, Iowa State University
Sam Donovan, Beloit College
Cameron Dorey, University of Central Arkansas
Bruce Douglas, Indiana University
Ahmed Elgamal, University of California, San Diego
Tricia Ferrett, Carleton College
Bruce Grant, Widener University
Susan Jesuroga, University Corporation for Atmospheric Research (UCAR)
Christopher Klaus, Argonne National Laboratory
Kenneth Klemow, Wilkes University
Dean Krafft, Cornell University
Priscilla Laws, Dickinson College
Cathy Manduca, Carleton College
Farzad Mahootian, TERC
David Mogk, Montana State University
Alexandra Moore, Cornell University
Don Murray, University Corporation for Atmospheric Research (UCAR) / Unidata
William Prothero, University of California, Santa Barbara
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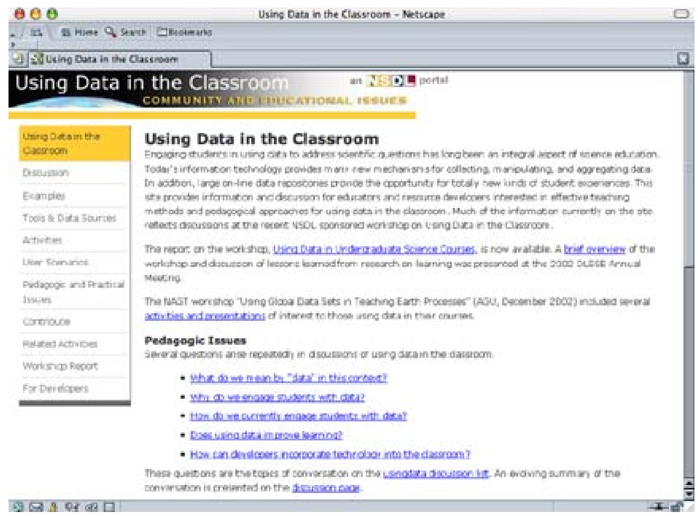
Karen Stocks, San Diego Supercomputer Center and Scripps Institution of Oceanography
Carol Terrizzi, Cornell University
Harry Ungar, Cabrillo Community College
Carl Wenning, Illinois State University

# INTRODUCTION

NEW GOALS FOR SCIENCE EDUCATION REFORM call for students to develop scientific habits of the mind (AAAS, 1990) and to learn by direct experience with the methods and processes of inquiry (NSF, 1996). One of the great promises of the National Science Digital Library (NSDL) is the ability to make it easy for students in a variety of learning environments to explore data to answer their own questions (NSF, 1998; Zia, 2001; Manduca et al, 2001). The Using Data in the Classroom workshop was convened at Carleton College in April 2002 for faculty and resource developers from across the science, technology, engineering, and mathematics (STEM) disciplines to explore effective methods for engaging students with data in courses and labs. The 26 workshop participants were interested in advancing the effective use of data in the classroom, supporting inquiry- and discovery-based learning, and informing the design of online data-delivery tools. This report summarizes the key ideas emerging from these discussions with a particular focus on

- What do we mean by data?
- Why is engaging students with data an important part of STEM education for undergraduates?
- What is the range of current practices?
- What do we know about how well these practices work?
- What recommendations for digital libraries, data providers, and online resource developers follow from this discussion?




Additional information is available on the NSDL Using Data Portal at http://serc.carleton. edu/ usingdata

# WHAT DO WE MEAN BY DATA?

THE NOTION OF "DATA" MEANS MANY THINGS TO DIFFERENT PEOPLE depending on the context of what they are trying to accomplish. For example,

- In ecology and the geosciences, spatial and temporal referencing of data that describe phenomena in natural systems is essential, whereas this type of information has little or no significance in lab-based sciences.
- A NASA scientist may think of data as a continuous stream of ones and zeros coming from a satellite, but to others, data means processed images or other representations derived from the original information that produced them.
- To an engineer, predicted performance parameters of systems operations derived from modeling routines may be recognized as data.

Data is the foundation upon which we build scientific arguments, thus the term is applied to a wide variety of observations and results in different contexts. Data is recognized or defined by its role in a scientific investigation or experiment (generating hypotheses, testing, describing conditions) and by its use supporting scientific explanations.

> "Using data in the classroom is any learning process that uses observations defined in the most general sense as a fundamental component to the learning enterprise in a way that a) supports student inquiry and participation in the scientific method, b) supports effective evaluation of data uncertainties and applicability, and c) improves students' quantitative and critical thinking skills. The observations involved could be raw or derivative data streams that have been collected by students or professionals or simulated data derived from models."
>
> — **Definition adopted by workshop participants**

Workshop participants developed the above definition of data as one that is appropriate for faculty trying to help students understand the meaning of scientific exploration and analysis. We defined data broadly to include any information that supports student inquiry and participation in the scientific method. Through our discussions, we recognized three areas where use of the term "data" is often controversial:

- To describe processed versus raw measurements;
- To describe model results versus observations; and
- To describe images versus their digital underpinnings.

**We recognized three areas where use of the term “data” is often controversial: to describe processed versus raw measurements; to describe model results versus observations; and to describe images versus their digital underpinnings.**

In all of these discussions, it was clear that the use of the word “data” reflects the experiences of the users, the particular context in which they work, and the questions they are trying to answer. Thus, those who work transforming streams of digital data into data products designed to answer particular questions often refer to the unprocessed data as “data” and the processed data as “product,” while those who work applying the processed products to problems refer to the product as “data.” The discussions demonstrated the richness of our work with data and our need to be careful in defining our meanings, particularly when working across disciplines.

We recognized that not only what we call data, but also the criteria for validity are context specific. Thus, for example, in addressing questions regarding the impact of humans on the Earth system, interviews yielding qualitative historical observations may be important data. In studying questions regarding molecular structure, qualitative observations may have no part and highly precise measurements may be the only valid data. Similarly, in addressing some questions, images alone may provide important data. In other circumstances, it may be impossible to rigorously answer questions without working directly with the digital data that is processed to create images. Scientists have long reported the accuracy of their data, recognizing that data that is sufficiently accurate to answer one question may not be applicable to another.

In an analogous fashion, the kind of data that is valuable in a classroom setting depends directly on the learning goals and content of the course. In some circumstances it is desirable to require students to start with raw data and work through an entire analysis to draw conclusions. In others it may be valuable to start with processed data or to work only with images. The data to be used depends on the educational context. Given the vast amount of data that is currently available, informed decisions must be made by educators regarding the selection of datasets and subsets and the compression or resolution that is sufficient or required to meet specific learning goals.

Included in our definition of data were synthetic data derived from models and simulations, as distinct from information that is derived from measurement or observation. Models and model building play an essential role in understanding data and in inquiry-based probing of data. We defined a model as “an idealization that embodies certain aspects of the ‘real thing’ that are of interest” (from Workshop Physics, Priscilla Laws, personal communication). Although some workshop participants argued that data should be strictly based on observation and derived from measurement, the application of models and their products has significant pedagogic value and is included in this definition to facilitate our broader discussion of data-rich activities.

# WHY DO WE ENGAGE STUDENTS WITH DATA?

There are specific attributes of data that make them useful. In particular, scientists strive to fully characterize their data to enable a better understanding of its limitations. Thus, while data that are collected or preserved without attributes (such as the procedure for collection, conditions during collection, instrumentation, temporal and spatial referencing, error or uncertainty, and an indication of quality assurance procedures) may be valid for some questions, the use of such data is often severely limited. Similarly, data that can be reproduced is more useful in answering questions as its validity extends beyond a particular case or instance. Thorough description and characterization of data remains a significant challenge for data providers who aim to support appropriate and effective primary intended uses and to enable the possibility of repurposing data to unanticipated applications in related fields.

MANY EDUCATORS FEEL PASSIONATELY THAT IT IS IMPORTANT to engage students with data as part of teaching science. It is important to ground any discussion of teaching methods or web-based tool development in an understanding of what educators are hoping to accomplish through data-rich activities. Faculty identify goals for students working with data that include mastery of content and skills, development of higher order thinking skills including a sophisticated understanding of data, and goals for personal growth. In specific, workshop participants identified six reasons for engaging students with data as part of their scientific training:

- To prepare students to address real world complex problems;
- To develop students' ability to use scientific methods;
- To prepare students to critically evaluate the validity of data or evidence and of their consequent interpretations or conclusions;
- To teach quantitative skills, technical methods, and scientific concepts;
- To increase verbal, written, and graphical communication skills; and
- To train students in the values and ethics of working with data.

**Students on their way to becoming informed voters, consumers, citizens, and scientists must develop a strong understanding and facility for using data.**

Dickinson College, Workshop Physics

Working with data provides an opportunity for students to directly participate as scientists. As the role of data in our world grows, it is increasingly important that students be empowered to use data and to overcome any sense of intimidation in the face of data. Students on their way to becoming informed voters, consumers, citizens, and scientists must develop a strong understanding and facility for using data. Scientists speak repeatedly of the need for a broader understanding of the opportunities that applying scientific thinking and knowledge bring to our society, as well as for an increased sophistication in understanding the limits and uncertainties of this approach. Too few students understand that scientists usually inquire about how physical, living, or designed systems function, that there are multiple reasons for undertaking scientific research that span from practical concerns to intellectual pursuits, or that the results of scientific inquiry — new knowledge and methods — emerge from different types of investigations and public communication among scientists. Of particular concern to scientists is the need to foster in the broad population the ability to recognize alternative models and explanations and to analyze them using data, logic, and scientific understanding.

Workshop participants recognized that working with data can help students understand the methods of science and develop skill in applying scientific reasoning. In specific, participants focused on using data to provide opportunities for students to

- Ask questions or state hypotheses;
- Design and conduct scientific investigations;
- Understand the quality of data;
- Draw conclusions that reflect the data, are logical, and integrate prior scientific understanding;
- Understand the certainty of conclusions; and
- Understand the ethics and process of collecting and interpreting data.

**Working with data allows students to experience many of the constraints of science, including the limitations of data.**

Complementing the opportunity that working with data provides for understanding the methodology of science are opportunities to understand the tools that scientists use. Those for which a broad understanding was most commonly discussed included:

- Quantitative analysis and reasoning;
- Visual representations of data (graphs, maps, and visualizations);
- Technology for collecting and manipulating data; and
- Broad discussion and debate to evolve scientific understanding.

Working with data allows students to experience many of the constraints of science, including the limitations of data. Students can gain an appreciation that data are generated by people and that data collection may be driven or biased by specific agendas or needs. They can come to understand the limits to available data, the impacts of data collection on humans and the environment, and the methods that are used to select and interpret data. In this process they may come to question why we have certain kinds of data, how they are acquired, how they are used, and associated ethical questions. Most importantly, students can face uncertainty and learn that data are never precise. This enables an understanding of the importance of determining magnitude of uncertainty and error in any dataset and its implications for the significance of interpretation and the certainty of conclusions.

Data-rich learning experiences present significant opportunities to contribute to the personal growth of students, including the opportunity to develop understanding of real-world complex problems and the ability to act on that understanding. Data-rich activities can be used to engage students with issues of their own choosing in deep, interdisciplinary, inquiry-driven thinking that fosters the development of higher order critical thinking skills and enables integration of scientific reasoning into a student's decision making and life reasoning. This approach can prepare students to utilize interdisciplinary thinking to build and use a world view drawn from the full spectrum of their knowledge. It serves as a foundation for an ongoing study and use of science throughout life by developing the needed confidence and learning skills. Such an approach integrates an understanding of scientific principles with their use and is critical if we are to move science from the realm of the academic or industrial expert into our societal decision-making process.

Workshop participants found that they had the same goals for all students, including those in introductory classrooms and those pursuing a science major. The abilities to find, access, manipulate, and interpret data are essential skills for future scientists and for a scientifically literate and capable public. However, the amount of time committed, the expected skill levels, and the balance between content and process will necessarily be different.

# HOW DO WE CURRENTLY ENGAGE STUDENTS WITH DATA?

EACH OF THE *STEM* DISCIPLINES (AND SUB-DISCIPLINES) has its own unique view of the important data required for answering scientific questions of interest and the best methods for manipulating and interpreting these data. Faculty in every discipline have developed methods for engaging students with the most exciting data and techniques in their field to convey its concepts and methods. Given that all of our disciplines are grounded in a similar understanding of the scientific method, it is not surprising that our interdisciplinary conversation pointed out many commonalities among these approaches.

We found that faculty use data in two fundamental ways: to illustrate concepts or ideas and to enable student investigations. Within each of these realms, a spectrum of instructional methods is employed, depending on the level of instruction, the physical setting, and the particular learning goals. In this report, we concentrated on using data to enable investigation, as these activities tend to focus on skills that span the disciplines.

One of the primary advantages of data-rich investigative activities is the ability to motivate learning either through student interest in a particular problem or in the data themselves. Five common

### EXAMPLES OF THE TYPES OF GENERIC QUESTIONS WE USE DATA TO ILLUMINATE

**Informational**

- Descriptive: What is it? What kind is it? Where is it? When is it? Who is it?
- Operational: How does it work? What does it do?

**Explanatory**

- Causal: Why does it work that way? What is the reason for that?
- Teleological: Why did he do that? What was the purpose for that?

**Procedural**

- Methodological: What is done? What could be done?
- Technical: How is that done? Is it done this way?

**Heuristic**

- Investigative: What could we find out? How could we find out?
- Speculative: What would happen if? What could happen if?

**Valuative**

- Normative: Is it any good? How good is it?
- Significance: What difference does it make? So what?

models emerged for investigative activities that engage students across the disciplines.

- Open-ended activities that encourage students to ask questions of the data in order to discover patterns and relationships as a basis for understanding scientific processes or concepts.
- Activities that address a real, often complex problem to foster an understanding of scientific concepts and their application to the world around us.
- Activities that use analytic mathematical models, computer models or simulations to help students discover functions that describe data and the behavior of complex systems under varying conditions. This allows students to interpret data, test hypotheses, or make predictions.
- Guided interpretation of data, testing of hypotheses, and making predictions.
- Activities that replicate or simulate documented scientific investigations (e.g., classical experiments) to lead students to an understanding of fundamental scientific observations or principles. In many cases, these activities also allow students to compare their work to published results.

In practice, there is a wide variation in how these types of investigative activities are used in various disciplines and settings. One primary distinction involves the origin of the data. Here we recognized three end-member models, though in most cases, data-rich learning activities involve components of all three.

- **Students collect and interpret their own data, often in the context of a larger dataset or model that has been developed by the scientific community over time.** Student-generated data can be collected as part of a laboratory, course, or independent research project. Traditional undergraduate theses are excellent examples of this type of activity. The GLOBE project (www.globe.gov) for K-12 students provides an example of an extensively developed, structured activity of this type that enables data-sharing via the Internet. Working with student-generated data raises important data management and quality issues, particularly when trying to generate datasets for broad use based on multiple student contributions.
- **Students use existing datasets to answer questions, often asking their own new questions.** This may involve looking at a single dataset with new purpose or combining a variety of data sources. While students have been analyzing existing data as the basis for

**A balance must be struck in all cases between supporting and guiding students' learning and providing opportunities to explore.**

learning concepts or techniques in laboratories or problem sets for decades, online data-access and data-manipulation tools have increased our ability to engage students with imported data, particularly large research databases. Working with imported data is currently constrained by a variety of data-access and -manipulation issues.

- **Students collect data, develop a model of the processes at work, and test the relationship between model predictions and observed data.** This technique is best developed in physics, where it lies at the heart of Workshop Physics (http://physics.dickinson.edu/~wp_web/WP_homepage.html)

Much of the variation in activities that engage students with data reflects differences in the learning environment, the goals of the activity, the goals of the course, the expertise of the students, access to tools and resources, and the physical setting. It is important to recognize that independent exploration and interpretation of data in its richest form is a highly sophisticated activity requiring much expertise. Thus, considerable skill is needed on the part of the instructor to match the level of expertise required to successfully complete the activity to the level of student expertise. A balance must be struck in all cases between supporting and guiding students' learning and providing opportunities to explore. Deep exploration of a particular problem that facilitates development of critical thinking skills must be balanced against time constraints and the desire to introduce a breadth of content. Technology and skills must be introduced at a pace and level that allow students to gain mastery, without allowing mastery of technology to get in the way of learning. Given the range of learning situations in which faculty use data-rich activities, it is no surprise that the design of these activities shows a broad range, spanning from highly structured experiences with very targeted skill development to highly student-driven explorations focused on developing high level data-management and inquiry skills.

To illuminate the range of current activities, we have developed a collection of examples. (See pages 16 and 18 for samples or view the full set at our website, http://serc.carleton.edu/usingdata/examples.html.)

Workshop participants recognized the value of combining complementary approaches from different STEM disciplines to addressing problems in educating students. Data-rich experiences have high potential for helping students create conceptual links both within and between courses. The interdisciplinary Global Change Program at the University of Michigan (http://www.globalchange.umich.edu/index.html) provides an example of using the same data in different courses to create linkages. In addition, common scientific principles or ideas that cross disciplinary boundaries offer exceptional opportunities for collaboration between scientific disciplines in fostering connections

# USING DATA TODAY: TEACHING PHYSICS WITH MODELS AND DATA

## An Example from Dickinson College

Priscilla Laws

Dickinson College, Workshop Physics

Workshop Physics is a method of teaching calculus-based introductory physics without formal lectures. Instead students learn collaboratively through activities and observations. Observations are enhanced with computer tools for the collection, graphical display, analysis and modeling of real data. Typical Workshop Physics classes meet for three two-hour-long sessions each week and students use an activity guide published by John Wiley & Sons.

The Workshop Physics project at Dickinson College represents an attempt to redesign the teaching methods in introductory physics courses to take advantage of recent findings in physics education research and introduce students to the use of modern computer tools. In the past 15 years, the program has received major grants from the Fund for the Improvement of Postsecondary Education and the National Science Foundation for curriculum development, equipment acquisition, and the conduct of teacher workshops. A number of observations and assumptions have guided the development of Workshop Physics:

- Reducing content and emphasizing the process of scientific inquiry;
- Emphasis on directly observable phenomena;
- Eliminating formal lectures; and
- Using the computer as a flexible tool for the collection, analysis, graphical display of data, and analytic mathematical modeling.

All the introductory physics have been taught in a workshop format at Dickinson College since the 1987-88 academic year. Students meet in three two-hour sessions each week. There are no formal lectures. The course content has been reduced by about 15 percent. Each section has one instructor, two undergraduate teaching assistants and up to 24 students. Each pair of students shares the use of a microcomputer and an extensive collection of scientific apparatus and other gadgets. Among other things, students pitch baseballs, whack bowling balls with rubber hammers, pull objects up inclined planes, attempt pirouettes, build electronic circuits, explore electrical unknowns, ignite paper with compressed gas and devise engine cycles using rubber bands.

The Workshop Physics Activity Guide can be used with a standard calculus-based textbook. Currently we are using a new text entitled *Understanding Physics* by Cummings, Laws, Redish and Cooney. In general the four-part learning sequence described by cognitive psychologist David Kolb is emphasized. Students often begin a week with an examination of their own preconceptions and then make qualitative observations. After some reflection and discussion, the instructor helps with the development of definitions and mathematical theories. The week usually ends with quantitative experimentation focused on the verification of mathematical theories.

**For more information, see: http://physics.dickinson.edu/~wp_web/wp_homepage.html**

**Teaching with data is not easy and helping students to draw strong inferences and conclusions rather than erroneous ones is particularly important and challenging.**

between ideas taught in different courses (e.g., time series data and rates of change, orders of magnitude, and scale).

In sum, we currently engage students with data in diverse ways, providing a rich set of opportunities for students at all levels to meet a wide variety of learning goals. Participants believe that STEM education could be strengthened by providing broader dissemination of existing practices in all of the disciplines. However, teaching with data is not easy and helping students to draw strong inferences and conclusions rather than erroneous ones is particularly important and challenging. There is currently a large spectrum of skill in using data-rich activities to facilitate learning. Most faculty, including those who are highly skilled, will benefit from support in improving their use of this instructional technique. In particular, we believe that the effective use of data in courses could be increased by providing faculty with the following resources:

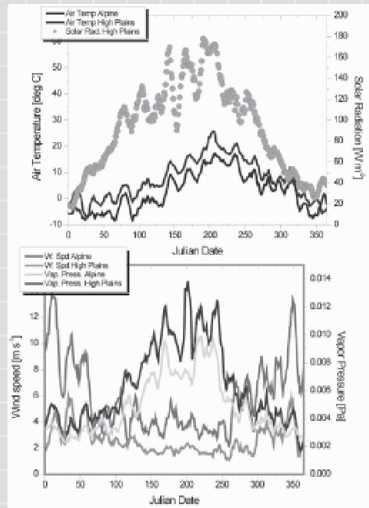
- Information about problem-based learning methods in general;
- Examples of ways in which faculty use data in courses and for cross-curricular integration;
- Examples of effective methods for guiding students in independent data exploration;
- Examples of topics for student investigation that have community and other real-world connection; and
- Problem sets, activities, or other materials with associated tools and data and assessments appropriate for use with data-rich activities, including those that measure learning gains in higher order thinking.

# USING DATA TODAY:
# DATA IN A FIELD CLASSROOM

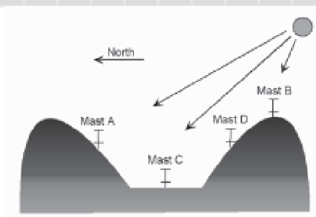

## Indiana University, Department of Geological Sciences Courses G329 and G429e

**Bruce Douglas, Bennet Brabson, James Brophy, Clara Cotten, David Dahlstrom, Erika Elswick, Dick Gibson, Sally Letsinger, Andrew Oliphant, Greg Olyphant, Mark Person, Lee Suttner**

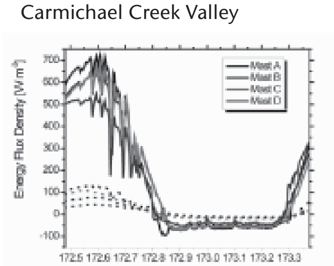

In 1996, the Department of Geological Sciences at Indiana University began to offer a series of courses (G329, G429e) designed specifically to provide students with exposure to data acquisition, manipulation, and integration. The data types range from simple, single-value measurements to multiple value time series with calibration and empirical relationships embedded in the datasets. The students collect data within an instrumented watershed covering 162 square miles adjacent to the Judson Mead Geologic Field Station. The Willow Creek Demonstration Watershed was established in cooperation with the U.S. Forest Service (USFS), the Natural Resources Conservation Service (NRCS), and the Madison Conservation District. The State of Montana, the National Science Foundation, and Indiana University provided funds to instrument the watershed. Objectives for the watershed include: a) hydrologic studies and research on the geologic framework of the area (Douglas et al., 1997; Elliott, 1998a, 1998b; Elliott et al., 2002); b) development of a physically based model for forecasting timing and patterns of snowmelt in the headwaters of the drainage (Letsinger, 2001); and c) development of a state-of-the-art curriculum aimed at interdisciplinary training in environmental science (Douglas et al., 1996).




Annual trends in solar radiation and temperature (top) and wind speed and vapor pressure for alpine and high plains settings within the WCDW for 2000 from the two permanent weather stations.




Schematic of micrometeorological station configuration in the Carmichael Creek Valley




Topographic control on the diurnal cycle of net allowave radiation (solid lines) and ground heat flux (dashed lines) at four locations in Carmichael Valley June 21/22, 2001. See Figure 7 for mast locations. The role of south versus north facing controls on the surface radiation budget and ground heat flux is clearly evident.

## SINGLE-POINT DATA

Data collection and level of data integration build over the length of the courses. The simplest data includes assignment of a rock or geologic formation name and measurement of the pH, specific conductivity, or temperature. Complexity is added through spatial and temporal dimensions.

## TEMPORAL AND SPATIAL DATASETS

Meteorological data are particularly well suited to enhance students' observational and technical skills in basic measurement and quantitative analysis using spreadsheets. Seasonal trends of basic meteorological variables show the role of seasonality and differences attributed to locational characteristics across a relatively short distance. Students construct, deploy, and maintain a basic micrometerological station of their own. These stations are first deployed in an open field to: a) teach basic wiring, logging and serial communication techniques and b) establish a calibration that can be used to adjust field values for comparative analysis. Students then deploy four stations in various locations, including a valley cross section to examine topographical controls on energy flow and meteorological variables.

**For more examples of ways that data is being used in classrooms today, see: http://serc.carleton.edu/usingdata/examples.html.**

# DOES USING DATA IMPROVE LEARNING?

AT PRESENT, THE STRONGEST EVIDENCE THAT USING DATA IMPROVES LEARNING comes from the integrated assessment of skilled faculty observing students in their courses. Faculty who are leaders in education, like those who attended this workshop, are enthusiastic about engaging students with data because they observe students' learning gains. While these types of observations form a strong starting point for recommending further development of data-rich learning, a major recommendation of this workshop is that the STEM community undertake a rigorous, documented evaluation of the impacts of data-rich experiences on student learning.

We need information that will allow

- **Faculty** to determine how engaging students with data should be used to meet course and departmental learning goals;
- **Administrators** to appropriately value faculty time spent developing and implementing these activities;
- **Sponsors** to determine priorities for supporting these types of projects; and
- **Student learning** to be enhanced in light of a research base that informs educators about instructional practices that address students' abilities and needs.

We need to know if teaching with data

- **Increases content and procedural knowledge**

  Do students learn more content or retain it better? Do they have a better understanding of this content that allows them to apply it to their everyday life or to their integrated understanding of science? Are they better prepared to perform a scientific experiment and develop a scientific argument? Do they better understand the limits of their analysis and its underlying uncertainties? Can they apply this understanding to their daily lives? To real world problems?

- **Improves students' life skills**

  Do students improve their ability to think critically, identify and solve problems, communicate, think quantitatively, and use technology?

- **Changes student attitudes toward data and science**

  Are students better motivated to learn scientific concepts and procedures? Life skills? Are they more interested in using scientific thinking and data in their daily lives? Do they better understand how scientific information can be effectively used in public decision making?

Most importantly, we need to understand what aspects of teaching with data support these learning gains. What spectrum of pedagogical approaches and instructional methods increase student learning in particular areas? Under what conditions and for what types of students?

A clear outcome of this workshop is the recognition that faculty in all disciplines share a core set of learning goals focused on the methods of science, scientific reasoning, and associated analysis and communication skills. However, these shared goals are still poorly articulated. Further interdisciplinary discussion for the purpose of converging on a description of these shared goals would be a major contribution to STEM education. By fostering and documenting a clearer understanding of these shared goals, we would provide a stronger framework for students to learn, faculty to develop instruction and assess learning, administrators to guide program development and collaboration within institutions, and for all to communicate the core of what we are trying to accomplish. Such an articulation is a critical first step toward a rigorous evaluation of scientific learning and of the impact of data-rich activities on this learning.

Much of the intellectual framework and many of the tools needed for a rigorous evaluation of the impact of data-rich experiences on student learning have already been developed. For example, the use of portfolios, journals, and lab notebooks, written reports, class presentations, and oral examinations have been piloted for use at both the K-12 and undergraduate levels. Many of these techniques have been implemented on large scales in the K-12 community, providing important information about their strengths and weaknesses for cross-community comparisons. Multiple choice tools for measuring changes in attitude toward science and in critical thinking skills are available and projects are established that enable community-wide analysis (e.g., Field-Tested Learning Assessment Guide, http://www.wcer.wisc.edu/cl1/flag/). Research in specific disciplines has begun to evaluate the impact of different teaching methods (e.g., McDermott. and Redish, 1999, and Redish, 2003).

Workshop participants had several practical suggestions for how as a community we might move forward in collecting the evidence needed to demonstrate to colleagues and administrators that engaging students with data improves students' learning.

First, we need to increase our collective understanding of the work that has and continues to take place within the disciplines, in science education, and in learning science. Workshop participants recommend that we collect and disseminate the results of existing studies to STEM faculty. Our collective support of these activities will elevate their importance and encourage faculty to build on this work to think critically about the relationships between their teaching and student learning. It will also provide a higher level of understanding of the range of assessment tools available and encourage broad assessment of learning beyond content examinations for instructional methods of all types.

**What do we want students to learn? What should they be able to do? How would we describe success? How do we think our instruction leads to these goals?**

Second, as described earlier, we need to engage a broad discussion of learning goals and instructional models related to engaging students with data. In detail, what do we want students to learn? What should they be able to do? How would we describe success? How do we think our instruction leads to these goals? How could we test if our hypotheses about the relationship between instruction and learning are true?

Third, we recognize three opportunities for collecting data across STEM education that will shed light on the impact of data-rich activities on learning.

- Many fundamental thinking and communication skills are taught across the scientific disciplines. Learning gains for these skills could be measured with standard assessment tools administered across the disciplines. This would provide a large sample base for analyzing the impact of instructional methods on learning of these skills in a wide variety of settings.
- A number of fundamental scientific concepts are taught across many disciplines and in a wide variety of contexts. Development of an assessment tool for measuring students' understanding of such a concept and its applicability in a variety of situations would enable a cross-disciplinary study of teaching methods and their impact on conceptual understanding. The assessment tool is envisioned as a small multiple-choice module that could be embedded in tests in a wide variety of courses. Possible topics include
    - Basic ideas of thermodynamics
    - Exponential growth/decay
    - Diffusion
    - Heat flow
- There are many opportunities to gather information about learning on small to medium scales within a discipline or a set of courses that address a particular set of content goals. Digital libraries provide a mechanism for sharing assessment tools among faculty that can encourage the collection of data that can be aggregated and analyzed to address the impact of instructional techniques at this scale. For example, shared exam questions among faculty teaching plate tectonics could address the role of activities where students construct the global distribution of earthquakes from recent earthquake activity on their understanding of plate tectonic theory, the application of this understanding to their knowledge of earthquake hazards, and their motivation to learn more about earthquakes.

In thinking about the development of assessment tools, we recognize three important design criteria.

- Assessments should lead to a rigorous understanding of learning gains around particular goals.
- Assessments should make sense to students and to those hiring and evaluating faculty for promotion and tenure. Results should be expressed in ways that can be understood by students and administrators and that are well aligned with course goals, institutional goals, and reward systems.
- Assessments should be designed to fit naturally in courses and to support the students' learning process. Instructional time is a precious commodity, thus assessment goals must be chosen carefully and assessments designed that maximize the use of this time and student learning. This requires that assessments be considered as part of the design of the course, not added on after the design is complete.

Lastly, we recognize the importance of collecting information that will help faculty and departments be successful. We need to collect and disseminate information to faculty that will allow them to make changes in their courses that improve student learning without making painful mistakes or wasting time. They need information about patterns of student resistance to changes in learning environment and about learning environments that support students in the face of challenging learning. They need to have information that will allow them to evaluate which changes are likely to lead to major gains in learning in order to focus their efforts in a time-limited environment. They need tools to measure their success that will validate their efforts with hiring committees and administrators. Departments need to know what the impact of changes in teaching methods are on their enrollments, on the students and future teachers in their general education courses, and on the success of their majors.

**Assessments should lead to a rigorous understanding of learning gains around particular goals.**

TIPS FOR DESIGNING SUCCESSFUL ACTIVITIES

Based on their experiences, workshop participants identified nine tips for success in engaging students with data:

- Design exercises with student background in mind — an overwhelming or negative early experience with data can be devastating to student confidence.
- Create a safety net to support students through the challenges of research.
- Develop a balance between guidance and inquiry that is appropriate for the student and the learning objectives.
- Create opportunities for students to work with data and tools outside of class or lab.
- Match the time spent in learning tools to the goals of course and student proficiency, being careful not to introduce more tools or techniques than students can master.
- Reflection, discussion, and reporting are important aspects of the research experience that need to be incorporated in the planning of the exercise.
- Design for success by making sure the data exist, they are accessible, the tools work, and that help is available.
- Integrate physical samples and models with digital resources whenever possible.
- Create purposeful projects that are meaningful and relevant in the context of the class, curriculum, the students' experience and interests, and society. For example, projects can demonstrate/simulate the conduct and process of science, be directed towards making a new contribution (or at least replicating an authentic scientific experience), or perhaps provide a service to the community (e.g., watershed monitoring).

# THE ROLE OF TECHNOLOGY: RECOMMENDATIONS FOR DEVELOPERS

DIGITAL LIBRARIES HAVE AN IMPORTANT ROLE TO PLAY in enabling effective teaching and learning with data. This role is recognized in the vision and goals of the NSDL (Zia, 2001; Manduca, McMartin and Mogk, 2001), which include

- Providing mechanisms for incorporating primary scientific research data;
- Enabling student-friendly access to scientific data to support learning by direct experience with the methods and processes of inquiry and discovery;
- Advancing scientific knowledge and understanding; and
- Enabling inter- and multidisciplinary educational opportunities.

To achieve these goals, developers of the NSDL must provide access to data and to the tools required to promote both good science and good education. The excitement of discovery should be a common experience for researchers and students alike.

Workshop participants felt strongly that while new advances in technology are providing exciting opportunities to engage students with data, the complexity of data access and analysis tools is a barrier to use in courses. In specific,

- Raw data streams are often unintelligible to the uninitiated.
- Specific data products are often difficult to find.
- Linking data to software for viewing, processing, and/or interpreting the results is often difficult.
- Data products are often much larger and/or more comprehensive than can be effectively used in a classroom environment.

However, new advances provide promise that these problems may be solved. In specific,

- Data providers now commonly employ education and outreach coordinators who understand the needs of educational users.
- Visualization and interpretation tools are being developed for broader audiences with new tools aimed at providing integrated access to distributed data resources with a variety of interfaces to each tool.
- Developers are beginning to think about how to package data and data products into thematic entities that are of relevance for educational needs.
- Developers are beginning to think about data products that include data streams and processing, visualization, and interpretation packages as being unified entities.

**To achieve these goals, developers of the NSDL must provide access to data and to the tools required to promote both good science and good education.**

A tremendous public investment has been made in the development of data acquisition and distribution systems that support research in all the STEM disciplines. NSDL can add significant value to these data systems and services if they can be repurposed for additional educational applications. To assist developers in creating access and tools that will support use in undergraduate courses, the workshop participants recommend that data-access infrastructure and services focus on the ability of students to perform critical tasks that support the instructional role of engaging with data. In specific, students must be able to

- Find and access data relevant to the topic they are investigating;
- Evaluate the quality of this data;
- Use appropriate tools and interfaces to manipulate and render data to answer questions;
- Combine multiple and diverse datasets to solve a central problem;
- Generate visualizations and representations that communicate interpretations and conclusions;
- Contribute student data to larger datasets; and
- View individual student data in the context of larger datasets.

The workshop participants recommend that NSDL promote the interactions and partnerships needed to develop this type of data access and supporting services. In specific, we anticipate that NSDL efforts will be most successful if data services are built

- **As a collaborative effort between scientists and educators**

  These partnerships must be formed early and sustained to ensure that the NSDL ultimately provides data, tools, and derivative products that will be both used and useful in instructional activities.
- **To anticipate multiple uses of datasets and tools**

  It is expected that many datasets may be repurposed for multiple uses across the STEM disciplines.
- **To meet the needs of the end-users (i.e., students and faculty)**

  These users should be enabled to make informed decisions about how and in what context data will be accessed, processed, and interpreted.

The NSDL can further promote the use of data in the classroom by supporting efforts to build and sustain networks of educators across the STEM disciplines, develop and implement assessment

**Common data formats or seamless data conversions that enable use with a broad range of tools are a priority.**

methods on learning in data-rich environments, and actively disseminate examples and recommendations of effective practices in using data in the classroom.

Tool developers frequently ask faculty specific questions about user interfaces, data discovery, and analysis tools. The participants offered these suggestions based on their own experiences.

- It is important to be able to browse data by thematic subject and location.
- Excellent metadata documenting the data collection, reduction, and requirements for use are critical (e.g., identification of the source of information; context — in space, time, laboratory, or virtual; methods of collection; instrumental parameters; standardization used; uncertainties; formats for presentation, etc.).
- User annotation could greatly enhance both data discovery and data reliability.
- Faculty need flexibility in developing data subsets and in controlling the data resolution before downloading as needs vary substantially from one educational use to another.
- Common data formats or seamless data conversions that enable use with a broad range of tools are a priority.
- A common data interface including tools for data analysis and visualization would facilitate use at the undergraduate level, where there is limited time for developing expertise with multiple data tools.
- Fast and reliable access to real-time data is an important constraint to its use in undergraduate classrooms.

# ENVISIONING THE FUTURE: USING DATA WITH TOMORROW'S TOOLS

## TUNA TRACKING SCENARIO

**Karen Stocks, San Diego Supercomputer Center & Scripps Institution of Oceanography; Carl Wenning, Illinois State University**

In this scenario, general problem-based learning strategies are employed throughout. Small cooperative learning groups are also employed. Students begin the effort by going through a cycle of "what we know," "what we need to know," and "how are we going to find out?" Given a basic understanding of this problem, students will begin to formulate alternative hypotheses which might account for increased or decreased yields of tuna taken by commercial fishermen. Students will identify data needed to test the various hypotheses.

> *You are a commercial fisherman from Gloucester, Massachusetts, in search of albacore tuna. Recently the catch has been quite poor, and the cost of taking available fish has exceeded the price for which they can be sold upon landing. In short, you are losing money and, unless things turn around, you could lose your operation as well. You need to find a way to increase the likelihood that you will return to port with a significantly improved catch. Your goal is to use available oceanographic, landings, and survey data (National Marine Fisheries Service) to determine a) which one of two dates would be preferable for you to go out to fish and b) where you should go to fish in order to catch tuna.*

### LEARNING GOALS

This activity is geared to non-majors at the university level and high school biology students. Students will accurately identify and characterize physical and biological feedback systems within the ocean and how they affect fish migration and general availability to fishermen on the basis of available data. Data include feeding habits and reproduction data, breeding grounds, bathymetry, water temperature, water salinity, chlorophyll concentration, and current flow. First, on the basis of available data and, second, given landing statistics and environmental data for multiple years, students will characterize conditions which lead to "good" versus "bad" fishing years.

### DATA AND TOOLS NEEDED

Ten years' worth of landings data for tuna (from the National Marine Fisheries Service); monthly datasets on water temperature, salinity, chlorophyll content, precipitation (from satellite data in the National Oceangraphic Data Center); bathymetry maps (NODC), one year of individual tuna tracks from multiple tuna (GPS) and weekly environmental datasets for that year (from NODC or Goddard Distributed Active Archive Center).

Data tools: The ability to overlay tuna tracks with environmental data; method for finding correlations between environmental data and tuna locations.

### ADDITIONAL RESOURCES

FishBanks by Dennis Meadows and William Prothero (see University of California, Santa Barbara).

### ASSESSMENT

Determine most reasonable answer to the question, "What factors affect the migration of tuna fish?" Then students must justify from the data their choice of the better day and better location to fish for tuna. Format might include research paper, class presentation, etc.

< SCENARIOS CONTINUED, FROM PAGE 27

## GEOSCIENCES WITH GLOBAL AND LOCAL SETTINGS SCENARIO

**Tom Boyd, Colorado School of Mines; David Mogk, Montana State University;**
**Bill Prothero, University of California, Santa Barbara; Bruce Caron, The New Media Studio**

In this scenario, students will ask questions of the data about climate change impacts that create correlations for their own lifestyles (eg., impact of snowfall levels and sesasons on downhill skiing). This will connect local observations to global impacts.

The "local-global" link will have students using urban population and geography information in combination with the climate change datasets to explore how historical housing patterns (social geography) might lead to differential effects among different social groups (eg., groups having housing in low-lying areas in the watershed contrasted to groups with housing on higher ground).

### LEARNING GOALS

Entry-level geoscience.

- Bring the Integrated Pollution Prevention and Control (IPPC) impact assessment information down to an urban scale (within each sub-national region in the United States)
- Make the impacts of global change more immediate to citizens who live in urban areas
- Use population and energy usage information and derive greenhouse gas emission levels and climate change to be able to quantify how local energy conservation can contribute to lower global greenhouse gas emissions
- By globalizing the values of local change, show how international agreements can have major impact

### DATA AND TOOLS NEEDED

Socioeconomic data for the locale; locally salient climate change impact assessment data; data and information on the Intergovernmental Panel on Climate Change scenarios; emissions models that these serve as input to; access to coupled ocean-atmosphere models to run emissions inputs.

Global climate change models provide forecasts for the impacts of climate change on a global scale. These forecasts have also been refigured at global-regional, national, and, in the United States, sub-national scale.

### ASSESSMENT

Students working as a group would create a report on the anticipated impacts of climate change for a local area and the potential impact that changes in behavior might have for global climate.

The NSDL could support this by providing access to the IPCC data and additional GIS collections for socioeconomic data that covers the United States.

## LAND USE SCENARIO

**Dave Mogk, Montana State University**

In this scenario, the objective is to complete a comprehensive class project on historical land use patterns in a particular county. It is part of a service-learning exercise: students will access and render land use data to make a public report to county land-use planners, developers and commissioners.

Data should be downloaded into a common GIS-based database and it should be able to be presented on common spatial scales. Students should be able to do a series of overlays to see the relations between physical and cultural features over time.

Students need to use analytical tools to measure changes in land use patterns such as net loss or gain of forest lands, wetlands, agricultural lands; changes in surface water patterns (e.g., channelization, new irrigation ditches); changes in habitat for select species (endangered, large mammals, etc.)

### LEARNING GOALS

This project is designed for entry-level geoscience and geography students.

- A service-learning project
- Collection of useful data for a particular area

### DATA AND TOOLS NEEDED

USGS digital elevation; geologic, soil and hydrologic maps; historical and recent air photo coverage; other historical photographic records of development in the area; multi-spectral Landsat; SPOT and AVIRIS satellite imagery; county zoning maps; habitat maps (e.g., winter and calving ranges for elk); US Census data from the past century — all downloaded into a GIS-based database.

### ASSESSMENT

Analysis of these patterns will result in a report to make recommendations for the areas where: development or preservation may be the best policy; protection of surface and aquifer water supplies is needed; alerts about natural hazards including flooding, slope instability, wildfire, and the like are made available to the public.

# CONCLUSIONS

WORKING WITH DATA IS ONE OF THE MOST EXCITING ASPECTS OF UNDERGRADUATE SCIENCE EDUCATION for students and faculty alike. There is broad consensus that using data in the classroom is an important component of education in all the STEM disciplines for philosophical, pedagogical, and practical reasons. Data-rich environments support inquiry- and discovery-based learning, which in turn allows students to participate in, and better understand, the conduct and products of science. The benefits of using data in the classroom accrue to

- **Students** — in acquiring scientific habits of the mind, their ability to critically evaluate evidence and to solve problems, and in the development of quantitative, communication, and higher order thinking skills;
- **Faculty** — in defining new and stimulating roles as mentors, co-investigators, and colleagues in learning;
- **Courses and curricula** — in the presentation of engaging, authentic, and relevant learning activities; and
- **Science** — in the training of the next generation of scientists and of a scientifically capable public, and in many cases, through new advances in understanding as student-researchers contribute to the scientific enterprise.

Data, broadly defined, is as important to education in all the STEM disciplines as it is to scientific research.

This report recommends that we build on a strong existing base to further the opportunities for faculty to teach and for students to learn from data. The most important conclusion from the workshop is that by sharing across the disciplines we can greatly strengthen our capabilities. Priorities include broad dissemination of information about current practice, articulation of our common goals and objectives, and a new focus on evaluation of teaching methods and student learning from data-rich activities.

At the present time, the Internet and digital libraries are creating new capabilities for data access, manipulation, and sharing that will change the way we work as scientists, educators, and citizens. The NSDL has an important role to play in this arena in supporting the development and use of resources that facilitate teaching and learning with data. Critical to success will be leadership in the NSDL that brings together scientists, faculty, teachers, and developers in a true partnership that will allow the interdisciplinary collaboration needed to first create and then support the educational use of new tools. In the process, we will learn that the lines between

**The resources that help students learn a scientific discipline will play an important role for scientists whose research leads them into new fields, as well as citizens developing an understanding of the application of science to their lives.**


Rob Morrow

learning and research are blurred. The resources that help students learn a scientific discipline will play an important role for scientists whose research leads them into new fields, as well as citizens developing an understanding of the application of science to their lives. Research on how students learn from data will have important application to how scientists and citizens learn from data. We stand poised to make major strides in using data throughout our lives by first learning from one another and then moving forward together.

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# REFERENCES


American Association for the Advancement of Science (1990). *Science for all Americans*. New York: Oxford University Press.

Douglas, B., J. Olyphant, G.A., Suttner, L.J., Boone, W., and Carlson, C. (1996). Integrating skills and techniques of environmental geoscience into an existing field geology program. *Geological Society of America Abstracts with Programs*, 1996 Annual Meeting, 28, (7), A-267.

Douglas, B., S. Saul, and C. Stern (1986). Rheology of the upper mantle beneath southern Chile inferred from mantle xenoliths. *Journal of Geology*, 95, 241-253.

Elliott, W.S., Jr. (1998a). Tectono-stratigraphic control of Quaternary and Tertiary sediments and structures along the northeast flank of the Tobacco Root Mountains, Madison County, Montana. M.S. thesis, Indiana University Department of Geological Sciences, Bloomington, IN.

Elliott, W.S., Jr. (1998b). Geologic map of the Harrison 7.5' quadrangle, Madison Country, Montana (Part 1). Montana Bureau of Mines and Geology, Open File Report MBMG 375.

Elliott, W., Douglas, B.J., and Suttner, L.J. (2003). Structural control on Quaternary and Tertiary sedimentation in the Harrison Basin, Madison County, Montana. *The Mountain Geologist*, 40, (1), 1-18.

Kolb, D. (1984). *Experiential Learning: Experience as the Source of Learning and Development.* Englewood Cliffs, N.J.: Prentice-Hall.

Laws, Priscilla (1993). Workshop Physics: reflections on six years of laboratory-based introductory physics teaching. *Proceedings of the American Association of Physics Teachers Conference, Lab Focus.*

Letsinger, S.L. (2001). Simulating the evolution of seasonal snowcover and snowmelt runoff using a distributed energy balance model: Application to an alpine watershed in the Tobacco Root Mountains, Montana: Ph.D. dissertation, Indiana University Department of Geological Sciences, Bloomington, IN.

Manduca, C.A., McMartin, F., Mogk, D.W, eds. (2001). *The National SMETE Digital Library: pathways to progress*, http://doclib.comm.nsdlib.org/PathwaysToProgress.pdf

McDermott, L.C. and Redish, E.F. (1999). Resource letter on physics education research. *American Journal of Physics*, 67:9, 755.

National Science Foundation (1996). Shaping the future: few expectations for undergraduate education in science, mathematics, engineering, and technology. NSF 96-139. Arlington, VA: National Science Foundation.

National Science Foundation (1998). Report of the NSF Science, Mathematics, Engineering, and Technology Education Library Workshop. NSF 99-112. Arlington, VA: National Science Foundation.

Redish, E.F. (2003). *Teaching Physics with the Physics Suite.* New York: John Wiley & Sons.

Zia, Lee (2001). Growing a National Learning Environments and Resources Network for science, mathematics, engineering, and technology education: current issues and opportunities for the NSDL Program. *D-lib Magazine*, 7:33. [www.dlib.org]

# ADDITIONAL RESOURCES

## TOOLS

### Computers in Chemistry at Cabrillo College (C4)

http://c4.cabrillo.cc.ca.us/index.html
Molecular visualizations and animations that are combined with text, narration, and interactive controls to create software tutorials.

### Discover Our Earth

http://atlas.geo.cornell.edu/education/index.html
Cornell University's Discover Our Earth educational web pages provide interactive data analysis and mapping tools accompanied by datasets, images, graphs, maps, and movies.

### Enviromapper Storefront

http://www.epa.gov/enviro/html/em/index.html
This is a mapping tool for viewing and querying environmental information. Users can click on or type in a location to generate maps that contain environmental information stored in EPA's Envirofacts Warehouse.

### Global Ocean Data Viewer

http://oceanography.geol.ucsb.edu/AWP/oceanviewer/ODView.html
This is a viewer for global ocean temperature, salinity, wind, precipitation, evaporation, and other data. Data are displayed in 3D views with map and depth sections.

### Interactive Mapping and Data Analysis

http://atlas.geo.cornell.edu/ima.html
This site provides direct access to digital datasets using a web-based application tool. Datasets include geography, geology, geophysics, and images.

### IRI/LDEO Climate Data Library

http://ingrid.ldgo.columbia.edu
The Data Library is a powerful tool that allows users to access, manipulate, and view a wide array of earth science data.

### MELTS

http://gneiss.geology.washington.edu/~ghiorso/MeltsCALC/index.html
MELTS is a software package for modeling crystallization of magmatic systems. The software can be used to calculate phase equilibria or to compute thermodynamic properties of mineral solid solutions.

### My World: A Geographic Information System for Learners

http://www.worldwatcher.northwestern.edu/myworld/index.html

This GIS tool is designed for middle school through college classrooms. My World contains features such as geographic projections, table and map views of data, distance-measurement tools, query operations, and customizable map display.

### The WorldWatcher Project

http://www.worldwatcher.northwestern.edu/index.html

This software allows students to explore, interpret, and analyze geospatial data. WorldWatcher contains data libraries for earth energy balance, climate, physical geography, and human geography.

## EXAMPLES AND ACTIVITIES

### A River Runs Through It

http://www-ed.fnal.gov/help/Meehan_Nolan/sum_page_dupage.shtml

Students use monitoring equipment to conduct water tests, fish observations, and insect identifications and to collect data related to physical properties of a stream or river.

### Athena: Earth and Space Science for K-12

http://vathena.arc.nasa.gov/index.html

Athena uses remotely sensed data to construct knowledge about the world. Datasets and instructional pieces are related to oceans, the atmosphere, Earth resources, and space/astronomy.

### Atmospheric Visualization Collection

http://avc.comm.nsdlib.org/cgi-bin/wiki.pl?Getting_Started_With_The_Lesson_Plan_Sandbox

Several atmospheric science lesson plans and visualizations are available from this site. Examples of some of the topics are a snowflake model, weather balloons, a radiation budget model, and drawing contour plots.

### Bioinformatics

http://www.angelfire.com/ga2/nestsite2/bioinform.html

This example provides seven educational modules that allow college students to explore the National Center for Biotechnology Information database.

**Bridge: Ocean Sciences Education Teacher Resource Center**

http://www.vims.edu/bridge/index.html

This is a growing collection of online marine education resources, including datasets, lesson plans, pedagogical tips, and discussions.

**Center for Educational Resources (CERES) Project**

http://btc.montana.edu/ceres/default.htm

This series of web-based interactive astronomy lessons for K-12 students is closely aligned with the National Science and Mathematics Education Standards and makes maximum use of online NASA resources, images, and data.

**Center for Improved Engineering and Science Education (CIESE)**

http://www.k12science.org

This program features educational projects that focus on utilization of real time or primary data available from the Internet and collaborative projects that utilize the Internet's potential to reach peers and experts around the world.

**Discovering Plate Boundaries**

http://terra.rice.edu/plateboundary/index.html

This exercise is based on five world maps containing earthquake, volcano, topography, satellite gravity, and seafloor age data. The exercise is based on the "jigsaw" concept, mixing the students to work in different groups during the exercise.

**Earth Exploration Toolbook**

http://serc.carleton.edu/eet

Step-by-step instructions and a sample activity for five earth science datasets and software tools.

**Event-Based Science: Remote Sensing Activities**

http://www.mcps.k12.md.us/departments/eventscience/rs.index.html

This program uses newsworthy events to establish the relevance of science topics. Data is gathered from interviews, photographs, web pages, and inquiry-based science activities.

**Flooding Exercises**

http://www.tulane.edu/~sanelson/geol204/hmwk5_00.htm

This exercise uses USGS data to determine the probability that a flood of a given discharge will occur in any given year.

**Forest Watch**

http://www.forestwatch.sr.unh.edu/index.html

This is a student-scientist partnership to study white pine health in New England. Primary and secondary students collect and process data on air pollution damage to forests near their schools.

**Global Learning and Observations to Benefit the Environment (GLOBE)**

http://www.globe.gov/fsl/welcome.html

This program connects students, teachers, and the scientific research community to learn more about our environment through student data collection and observation.

**NOAA Research**

http://www.oar.noaa.gov/k12/index.html

This site provides 12 complete modules for classroom research and investigation experiences. The lessons use Internet data to explore topics such as climate, storms, atmosphere, fisheries, oceans, and the Great Lakes.

**Oceanography Data Access Tutorials — Mini Studies**

http://oceanography.geol.ucsb.edu/Ocean_Materials/Mini_Studies/Index.html

These oceanography and climatology activities are intended as tutorials in the use of data to study particular phenomena. Each assignment contains instructions for students, questions and activities, and data sources.

**Our Dynamic Planet**

http://oceanography.geol.ucsb.edu/ODP_Advert/odp_onepage.htm

This CD-ROM consists of tools for investigations of the theory of plate tectonics. Modules include virtual plate tectonics lecture, geography game, profile game, MAP data display, and graphics workshop.

**Project NOPP Drifters**

http://drifters.doe.gov/

This site allows teachers to use data from ocean drifting buoys to integrate ocean science into their classroom science and math instruction. There are educational activities and curriculum materials developed and tested by teachers.

**Project Skymath: Making Mathematical Connections**

http://www.unidata.ucar.edu/staff/blynds/skymath.html

This middle school mathematics module contains 16 activities that cover topics such as data analysis, graphing, statistics, and measurement.

**Subduction Zones**

http://rainbow.ldgo.columbia.edu/ees/lithosphere/lab7.html

This lab exercise for undergraduates examines the Tonga-Kermadec subduction zone, which is just north of New Zealand in the Pacific Ocean, to determine the relationship between bathymetry, volcanoes, and earthquakes.

**Webshaker**

http://webshaker.ucsd.edu/index.html

The UC San Diego Webshaker is a live earthquake experiment conducted over the Internet. The user can create an earthquake on a test structure, watch the results, and receive data from the experiment.

**The Worldwatcher Project Curriculum**

http://www.worldwatcher.northwestern.edu/curriculum.htm

WorldWatcher provides middle school and high school curriculum materials that integrate scientific visualization into an inquiry-based program of hands-on labs, group work, and class discussions.

## DATA SOURCES

**Climate Change Atlas for 80 Forest Tree Species of the Eastern United States**
http://www.fs.fed.us/ne/delaware/atlas/index.html
This tree species distribution atlas contains a database of climate change scenarios, life-history, disturbance attributes, ecological attributes, and forest type maps for 80 tree species in the Eastern US.

**Data Links for the Earth and Space Sciences**
http://www.windows.ucar.edu/data/data.html
A clearinghouse of data about weather, earth science, space science, planetary science, and astrophysics. Datasets are grouped by audience and subject.

**Earth Observatory Data and Images**
http://www.earthobservatory.nasa.gov/Observatory/
Customizable maps of atmospheric, oceanic, climatic, land use, and biologic data plotted on world maps and animations.

**Elevations and Distances in the United States**
http://mac.usgs.gov/mac/isb/pubs/booklets/elvadist/elvadist.html
USGS database containing elevations of the 50 largest cities, highest and lowest points in each state, summits over 14,000 feet, geographic centers of each state, and more.

**Energy Information Administration**
http://www.eia.doe.gov/index.html
Contains many databases on the production, consumption, and trade of a variety of energy sources. Users may also create custom data tables with selected data and dates.

**GEOROC: Geochemistry of Rocks of the Oceans and Continents**
http://georoc.mpch-mainz.gwdg.de/Start.asp
Searchable database of igneous rocks, including tectonic setting, location, rock types, sampling method, mineralogy, isotopes, and geochemistry.

**Lamont-Doherty Earth Observatory Data Repository**
http://www.ldeo.columbia.edu/datarep/index.html
Datasets sorted by general topic, including life sciences, the oceans, climate and environment, and solid earth.

**NASA GMDC Learning Center**
http://gcmd.gsfc.nasa.gov/Resources/Learning/data.html
Downloadable datasets, models and materials for various aspects of global change and the earth system. Data is grouped by category, including atmospheric, oceanic, geologic, and biologic data.

**National Earthquake Information Center World Data Center for Seismology**

http://neic.usgs.gov/index.html

The site provides access to near real time earthquake data from around the world, as well as data for recent earthquakes. The data can also be searched for information on specific earthquakes.

**National Plants Database**

http://plants.usda.gov/home_page.html

The database includes names, checklists, automated tools, identification information, species abstracts, distributional data, crop information, plant symbols, and plant growth data.

**National Snow and Ice Data Center**

http://nsidc.org/index.html

Many datasets available, including snow cover, avalanches, glaciers, ice sheets, freshwater ice, sea ice, ground ice, permafrost, atmospheric ice, paleoglaciology, and ice cores.

**National Water-Quality Assessment Program**

http://water.usgs.gov/nawqa/index.html

National database from over 50 river basins and aquifer systems with data and maps of stream discharge, water quality, groundwater, surface water, bed sediment, and animal tissue data.

**Online Trends — A Compendium of Data on Global Change**

http://cdiac.esd.ornl.gov/trends/trends.htm

Digital data and graphs of $CO_2$, methane, greenhouse emissions, temperature, and clouds from a range of monitoring stations and time periods.

**Population Reference Bureau**

http://www.prb.org/template.cfm

Easy-to-use, customizable database of population, health, and human geography data. Datasets include education, employment, fertility, poverty, race, youth, and more. Lesson plans are also included.

**Quantitative Environmental Learning Project**

http://www.seattlecentral.org/qelp/index.html

This site provides all of the ingredients for an instructor to create a classroom exercise. Topics include ecology, energy, air pollution, or water resources. With each dataset there is background information about the topic, raw data, and a plot of the data.

**World Glacier Inventory**

http://nsidc.org/data/g01130.html

Contains information for over 67,000 glaciers through out the world. Parameters within the inventory include geographic location, area, length, orientation, elevation, and classification of morphological type and moraines.

**World Stress Map Project**

http://www-wsm.physik.uni-karlsruhe.de/index.html

This database contains information on the contemporary tectonic stress state in the Earth's crust. Stress data can be downloaded, viewed on maps, or used to generate custom maps.

## CREDITS

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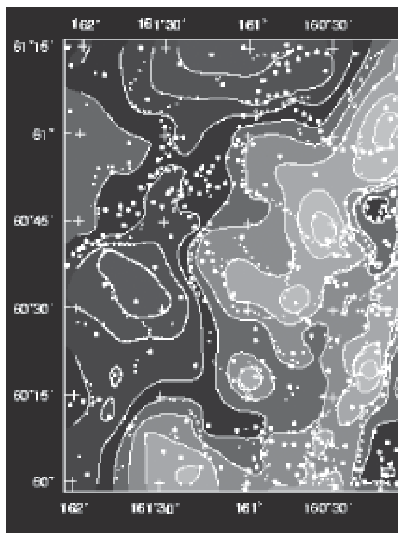
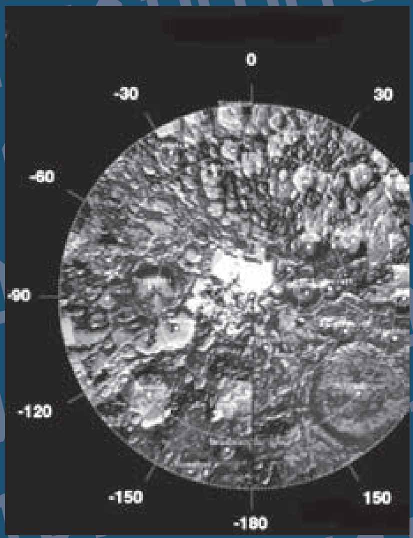
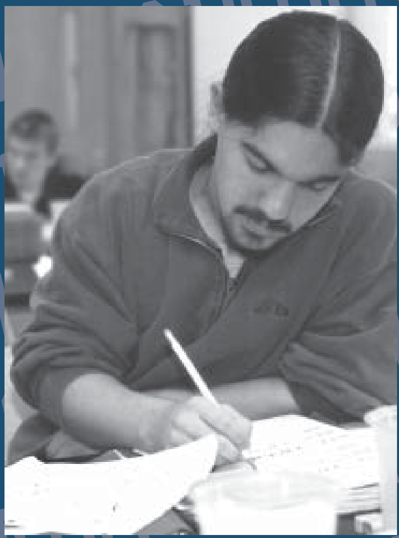


# USING DATA IN UNDERGRADUATE SCIENCE CLASSROOMS

http://serc.carleton.edu/usingdata



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