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ABSTRACT

Imaging and visualization tools have assisted Earth scientists in answering age old questions by changing their orientation while reshaping the questions they ask. Imaging and visualization are powerful instructional tools still in the early phases of curricular infusion in the science education setting. This paper calls for a collaboration between imaging and visualization and presents information on involved organizations and technology related to imaging and visualization in science. Educational implications from imaging and visualization at NASA and retrofitting the curriculum to match scientific technology advances are discussed. (Contains 15 references.) (ASK)

Running head: IMAGING AND VISUALIZATION IN SCIENCE EDUCATION

Imaging and Visualization in Science Education

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Imaging and Visualization in Science Education

I. Introduction

For some time we have been using images on bulletin boards and textbooks. But the computer, and its ability to provide high resolution imagery on the screen, provides a new palette for the brush strokes of one's mind. Images come in all shapes and sizes. From deep space we have shuttle photos, satellite images, computer-generated images, maps, and digitized photos. From inside our bodies we have rendered medical photos, computer-generated anatomical models, and digitized 3D images. The platform for viewing these images are photos, books, web sites, and CD-ROMs. The tools provides for color variation, scale interpretations, and cognitive orientation of the image. The cognitive demands on individuals for interpreting images is an intense activity. And when all is done the images must be stored thus creating a burden on the consumers using such data forms. These issues of image types, platform, interpretation, use, and storage form the basis of this paper. Imaging, as a verb, is defined as the acquisition, enhancement, re-representation, and re-distribution of a graphic image for analysis and reporting. Visualization is defined as the representation of data using software tools.

II. Need

Imaging and visualization tools have assisted Earth scientists in answering old questions by changing their orientation and, at the same time, reshaping the questions they ask. Students have been viewing LANDSAT images and possess guides to use them in the classroom (Tindal, 1978). The Technical Education Resource Center (TERC) notes that with those same tools, students "can better understand key concepts in Earth science; develop skills of scientific thinking and problem solving; and conduct their own Earth investigations(Barstow, 1997)." But how do students develop this deep and better understanding? How does this technology infuse itself into the curriculum? In new education initiatives, images and the way we look at or represent things in images are still small, or non-existent, parts of the curriculum.

In point of fact, while the words "picture" and "satellite data" appear in Earth space science and science and technology sections, the National Science Education Standards make no mention of the words "images," "graphics," and "visualization." The word "computer" is referenced twice under the Guide to the Content Standards section dealing with abilities necessary to do scientific inquiry. The vague reference to computing is covered in two paragraphs, taking no longer than 12 lines, as the standards, in grades 5 to 8 under the standards "use appropriate tools and techniques, to gather, analyze, and interpret data" and, in grades 9-12, "uses technology and mathematics to improve investigations and communications" (National Research Council, 1996). Benchmarks of the American Association for the Advancement of Science (1993) provide a more focused set of grade-level expectations in delineating student competencies. And so the picture is bleak if standards are to rush us urgently into using imaging and visualization in the classroom. It has been up to government and industry to provide the technology but it will be up to the educators to infuse this technology into the classroom.

It is documented that the quantity and quality of instruction to acquaint students, as future citizens, with earth system concepts and processes is practically non-existent (Mayer, 1995). While such documentation does not discuss the efficacy of the standards in curriculum reform, it points out the fact that imaging and visualization is a powerful instructional tool still in its early phases of curricular infusion in the science education setting. On the other hand, it is reported that "Visualizations allow the teaching of subject material not ordinarily taught, and allow it to be taught earlier in the curriculum" ("Graphics and visualization," 1995). If one believes that advances in knowledge influence science, then those same advances will find their way into the curriculum, which itself, must advance. Yet imaging and visualization in the sciences does not seem to have occurred in the science curriculum for elementary, middle, and senior high school students. Students will certainly encounter this technology in medical imaging, neuroscience, combustion engineering, fluid mechanics, groundwater pollution, weather mapping, astrophysics and geological sciences. What they do not come to appreciate is the development, analysis, or discussion of such representations in their science curricula.

III. Involved Organizations

State and federal government, international and other organizations currently using weather satellite systems include meteorological organizations, universities and colleges, some secondary schools, environmental management organizations, local and state government bush-fire control centers, marine and harbor organizations, international airports and agricultural spraying contractors. Despite massive processing capabilities of modern-day computers, imaging and visualization research is dependent upon an investigator's ability to visually recognize patterns in the data. Scientific activity goes about creating efficient displays for the meaningful representation of data. The purpose of imaging and visualization is to enhance knowledge of space sciences through the effective application of advanced computer science and technology. NASA's goal is to expand its research agenda toward understanding the Earth as a system and eventually toward comprehending the origin of the universe as well as its path in evolution and future embodiment. There are unprecedented volumes of data being generated as probes venture out into space and such images require rigorous analysis and interpretation that leads to meaningful scientific, policy and values insight. Since this activity is designed to provide a widely distributed research community with access, ability to manipulate, tools to analyze, and visualize, it is the responsibility of educational systems to promote fledgling nascent activity for students in the imaging and visualization field.

In addition to serving as Pennsylvania's NASA-Educator Resource Center (Pitt/NASA-ERC), we participate in an education collaboratory with the Goddard Space Flight Center and other ERCs in Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. In this collaboratory there is high concern with the use of NASA educational resources in new ways for teaching and learning. This concern with imaging and visualization, especially in Earth and space systems sciences, has developed from projections of interest in the National Aeronautics and Space Administration (NASA) resource materials, the use of images in the classroom, and the increasing use of technology in the schools. With the increase of collaborative missions of large scale space phenomena there is a concomitant increase in the amount of visual data received from earth and space observing satellites. Data, whether in numerical or graphic format must be analyzed and represented to facilitate cognitive understanding and knowledge representation.

IV. Technology and Techniques

a. Polar Orbiters

Environmental satellites routinely broadcast two types of low-resolution images, Automatic Picture Transmission (APT) images from polar-orbiting satellites, and Weather Facsimile

(WEFAX) images from geostationary satellites. There are currently two United States-operated, fully functional, polar orbiting weather satellites. These are NOAA 12 and 14. Russia also operates polar orbiters that transmit WEFAX, Meteor 2-21 and 3-5. In addition, both the US and Russia operate other types of polar orbiting weather satellites. The US has defense-related satellites similar to NOAA who will take over this program around the year 2000 as a federal cost-cutting measure. Russia also operates the OKEAN (pronounced "ocean") satellites that transmit WEFAX but are nearly always turned off, except when over Russian territory. A complete glossary of terms and bibliography related to Mission to Planet Earth, remote sensing and direct readout is provided by NASA (NASA, August 1994).

The NOAA polar satellites orbit the earth about 14.2 times per day with orbits inclined about 98 degrees to the equator which means they are in a retrograde orbit. They orbit in the opposite direction to which the earth turns. The advantage to this particular orbit is that satellites cover the same part of the earth at approximately the same time each day. (It's a little more complicated than this but that's the basic idea.) And they do so day after day for the life of the satellite. This kind of orbit is called a sun synchronous orbit. As the satellite orbits, it continuously scans the earth directly below it with its visual and IR sensors and continually transmits this data. Each orbit's scan coverage slightly overlaps the last.

APT makes real-time reception of satellite images possible whenever an APT-equipped satellite passes within range of an environmental satellite ground station. These satellites are in low earth polar orbit, approximately 1,000 Km above the earth, and travel at a ground speed of approximately 25,000 Km per hour. The transmission consists of an audible tone that is displayed as an image on a computer monitor at the ground station. APT images, transmitted by polar-orbiting TIROS-N/NOAA and Russia's METEOR satellites, orbiting 500-900 miles above the earth, offer both visible (0.4-0.7 micrometers) and infrared (0.7-1000 micrometers) electromagnetic spectrum images. In each 24-hour period, these satellites send several images, in "real time", clearly showing current location conditions and future events heading its way. APT images provide 1) simultaneous thermal IR and visible images, 2) coverage of swaths 3000 Km wide, 3) 4Km picture elements(pixel) resolution, and 4) image enhancement capability.

Because NOAA and METEOR satellites are in relatively low orbits, these images offer high definition of surface features. Each NOAA image(see figure 1) is sent complete, with two side by side images of the same area of the earth's surface. When the satellite is passing over an area illuminated by the Sun, one image is in visible light, the other in infrared (IR). When the satellite is passing over an area not illuminated, the visible light image switches to IR in another part of the spectrum.

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figure 1 goes here

High Resolution Picture Transmission (HRPT) images are also transmitted from polar orbiters and has a maximum resolution of about 1KM directly below the satellite. The HRPT data is transmitted at 665K bits per second. Reception of the transmission, however, requires equipment beyond usual school resources.

b. Geostationary Orbiters

WEFAX transmissions are relayed by NOAA's Geostationary Operational Environmental Satellite (GOES) which follow the spin of the Earth at 22,500 miles in space. Another such satellite system is the Japanese GMS 5, which is 36,000 Km above the earth and is always stationed over the same point on the earth's surface. Due to the distant location of this satellite, detail and definition are reduced relative to the Polar orbiters, however these images can be animated, making it very easy to track cloud formation and movement, (ideal for tracking cyclones). WEFAX then retransmits the modified data as visual reproductions of weather forecast maps, temperature summaries, and cloud analysis by way of radio waves. WEFAX provides for 1) hemispheric coverage, 2) 8 km pixel resolution, 3) images at thermal IR, visible, and water vapor lengths, 4) images rebroadcast from other satellites, and 5) new images approximately every hour, 6) weather maps and diagrams, 7) image animation, and 8) unattended and automatic ground station operation.

There are both land- and marine-based APT and WEFAX satellite systems, which automatically receive, process, display, and archive live weather satellite images to assist in decision making for weather-dependent activities. Marine-based satellite images are ideal for marine and mobile activities such as sea fishing, commercial shipping , ferried and cruise liners, sailing, gas and oil rig operations, Coast Guard services, yacht racing, diving operations, and leisure activities.

c. Synthetic Aperture Radar (SAR)

Acquiring images from space can also be accomplished using space shuttle SIR-C/X-SAR technology. SAR provides its own illumination thus producing reliable repeat data independent of weather conditions or the availability of sunlight, through all seasons, and at any latitude. SIR-C, for example, is a Synthetic Aperture Radar. This refers to a technique used to synthesize a very long antenna by combining signals (echoes) received by the radar as it moves along a track. A long antenna is desirable since, the longer the antenna, the finer the detail the radar can resolve, and the smaller the objects the radar can 'see'. Aperture refers to the opening used to collect the reflected waves which are used to form an image. In the case of a camera, this would be the shutter opening; for radar it means the antenna. A synthetic aperture can be constructed by moving a real aperture or antenna to different positions. At each position a pulse is transmitted, then the return echoes pass through the receiver and are recorded in an 'echo store'.

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figure 2 goes here

Using the flashlight analogy, the bigger the reflecting bowl of the flashlight, the narrower the beam of light generated. For a flashlight the aperture is the reflecting bowl. Similarly, larger radar antennas will have finer beams. The beam width for an antenna (or aperture) of size D is approximately $^{\lambda}/D$ in radians, where λ is the wavelength at which the antenna operates. For a 'real' antenna of length D, and a radar of wavelength , imaging an object at range R, the smallest resolvable object is of size ~ R/D. For a 10m antenna, operating at 800 km range at wavelength 25 cm, this gives a minimum object size of 20 km. With a synthetic aperture of length 20km, a minimum object size of 5m can be resolved, since the resolution of a synthetic aperture is half the size of the actual antenna used, i.e. D/2. Synthetic aperture radar is a technique used to generate radar images in which fine detail can be resolved (NASA/JPL, 1997). Using SAR, geometric and hydrologic image states of the Earth's surface are captured and such data is used to understand oceanographic, ecological, hydrological, and geophysical phenomena.

d. APT and WEFAX Uses

Weather Avoidance Routing identifies various weather features, plans best routes, and avoids undesirable weather. For example, fog banks can be differentiated from cloud by viewing the infra-red and visible light versions of an image side-by-side. Cloud is visible on both versions of the image. However, since fog is of a similar temperature to the sea surface, it does not show up on the infra-red version. On the visible light version of the same image fog banks are clearly visible, allowing a route which avoids the fog banks to be planned.

Temperature Boundary Highlighting between warmer and cooler areas in an image can be shown clearly by coloring the parts whose temperatures lie within a specified range. The latitude, longitude and temperature of points along these boundaries can then be identified. For example, sea surface temperature boundaries are often an indicator of the types and quantities of fish surfacing to feed. Boundaries can be highlighted using temperature coloring so possible areas of good fishing can be determined easily.

Distance and Bearing Measurement lines between a point (such as your station position) and points of interest can be plotted, giving the distance and bearing to the point and the temperature profile along the line. For example, the distance and bearing to a weather front can be determined and monitored over a period of time on successive images.

Weather conditions are continually changing, and a forecast for two days hence may not necessarily come to fruition. The weather at the end of the forecast period can be quite different when it arrives at your location. Rain that was forecast fails to materialize, or rain can develop and fall where it was not forecast to happen. Winds are influenced in the same manner. With Meteorological Data Gathering equipment it is possible for the user to either confirm a forecast or to see events that are likely to alter the incoming weather from that forecast. This makes it possible to make more accurate weather predictions for a location (Available WWW: http://www.ozemail.com.au/~orbis/weather.html).

V. System Issues

Avoiding misapplication of the technology requires a realistic and detailed match between the extent of required hardware, the complexity of learning and using the software, and essential client needs. Minimizing misapplication demands consideration of certain questions. Such questions are where is imaging and visualization needed; can the computer truly facilitate the analysis; how complex is the organization of the software; is data capture and analysis easily accomplished; and are 3D and 2D images, as knowledge products, easily inventoried for future use? Visualization requires that scientists free themselves from rigid notions on the display and presentation of data. It is in visualization that non-traditional approaches to data representation find a home.

a. Color

Visualization uses color, transparency, texture, along with rotation, pan, zoom, and animation. For example, students are introduced to the use of digital numbers (DNs) and X,Y coordinates as seen in the Values table. The DNs indicate gray scale values from 0 to 256, and range in shade from white to black. They will looks at various shades of gray and then turn their gray scale images into false color images, also ranging from 0 to 256. As far as digital images are concerned, an analog image converted to numerical form can be stored in a computer. The image is divided into a matrix of small pixels which represents a specific amount of area, i.e. 4.1 km in APT or 8 km in WEFAX. Each pixel has a data number value quantifying the radiance of that spot on the image between white and gray. False color is applied by assigning a graduated color palate to represent the shades of gray. The color is "false" because it represents an assigned, rather than actual, color. Visualization unfolds unique morphological features such as concentration and rarefaction. Color can identify "hotspots" and focus on the phenomenon and not a single data point in the set.

Image processing also includes stretching, recoloring, sharpening, softening, blurring, edge detection, all of which can be accomplished using off-the-shelf software such as Adobe Photoshop. Any software used should have the capability to import and export images in TIF, GIF, TGA, BMP, DIB, and PCX formats for use elsewhere.

b. Data Reduction and Comparisons

The products of NASA are knowledge and understanding. The ultimate test of that understanding is the closure between theory and conclusions of studies by representing and predicting physical processes. The process of visualization promotes data reduction and model-measurement comparisons. The primary bottleneck to visualization and data handling is the lack of adequate software allowing scientists to interactively visualize and analyze data within complex computing environments. The tools must be (1) flexible and simple, (2) simple and easy to input data, (3) link visualization with analysis, and (4) meet scientific expectations with respect to rigor and substance. All of this hinges on the substantive knowledge of the specialist/analyst and not the machine knowledge of the computer specialist.

The factors that effect computational intensity and complexity involve refining grid sizes to account for fine-scale effects (resolution); realistic descriptions replacing algorithms with better parameters (sophistication); conducting simulations as opposed to anecdotal studies; and interact with the results from internal and external perspectives and conveying the results for colleagues and laymen to grasp this knowledge and understanding (comprehension).

Visualizations are not pretty pictures but keys to discovery leading to understanding and to convey that insight to others. The notion of virtual reality is exciting because the interactive exploration embeds the viewer within the visualization as an actual participant. It is in the realm of virtual reality that 3-dimensional imaging displays a unique advantage over 2-dimensional images.

Communication is important. NASA's Science Internet connects assets consisting of computing resources, data centers, analysis tools, and science users into a worldwide network of collaborators, resources and services. In imaging, data forms a physical image where physical space is represented on the 2-D image plane. In contrast, the direct measurement arena, the space is described by quantities which represent physical characteristics of the 3-D medium. Direct measurement space-science data resides in a digital abstract space and not on a plane characterized by physical dimensions on an object.

c. Computer facilitation of visualization

Image processing software must deal with snapshots, collection of data over time, animation, differences in images, and model-to-data comparisons (Foster, Roble, and Ridley, 1995). Snapshot codes display results at a single point in universal time(UT). Time-dependent code-display model results from multiple UTs, typically one-to-ten days with hourly resolution. Time is usually displayed on the X-axis and such plots help visualize the model response time varying quantities such as those found during geomagnetic storm events. Comparison of such images are made with model results of ground-based instruments. The variables of longitude, latitude, altitude, and time are usually used to represent the models. Time dependent analysis of a model is assisted by animation of time-interpolated results. A model field may be interpolated between hourly histories or extrapolated over time to predict events and recorded to VCR for classroom use.

The tools for imaging and visualization fall under a number of categories:

- Image Display tools (for two- and three-dimensional displays);
- data feedback tools (for line plots, histograms, and pixel and bounding box tracking);
- Tools for comparing data sets (for 2- and 3-dimensional scatter plots, and compare and combine tools);
- Frame- and time-based controllers (for animation); and
- Control Widgets (sliders, rotators, pan-zoom, color table editor, and data subsetting tools.

VI. Data Issues

The utilization of imaging and visualization in the classroom is not unlike that used in space physics investigations. The scientist who receives the data must maximize scientific understanding within a limited budget and time frame. In general there are available, but limited, financial resources which restrict the analysis in the available time. Original data and data products derived from original data descriptions (called metadata), must be archived permanently and securely. Most data are unique and will not be superseded in the near future. In fact it is no longer possible to repeat space missions simply because the instrumentation has improved. But archived data must be retrieved easily and at any time(Russell, 1995). Interactive graphics can serve as that easy retrieval vehicle. All data and metadata must be catalogued. Catalogue lists must be solidly linked to these files. Easy access to the catalogue is as important as access to the data. The mediation of these tasks can be facilitated with software but the danger is that software becomes outdated as does systems on which software runs. Groups managing and archiving sole, proprietary, or primary data sets should establish an archive with an easily searched catalogue. The Internet provides the best vehicle for storage and access and obviates the need for vast storehouses and sites.

a. Inventories of images and knowledge products

Students, with APT , WEFAX, and SIR-C access can:

- capture, record and display the images
- change image scale and contrast and add color
- identify and label image features
- overlay maps and grids, locate points, and measure distances
- calibrate and map environmental temperatures
- calculate cloud percentages
- enhance water, land, or cloud patterns
- create and printout enhanced graphic displays

But what is the "vehicle" by which students are transported to the "working platform" for developing knowledge products? This paper proposes that there be an open-access vehicle for such work.

Taking a lead from research (King, Walker, & Joy, 1995) a major problem is the confrontation with data in a variety of formats from a variety of projects. Older missions may have yielded data no longer serviceable by current computing environments. A solution is to develop a universal format for the data or impose a fixed computing environment. Since imposition is not well received it appears that a solution to the storage of data for imaging and visualization hinges on the development of a universal format. I propose, as a start, the construction of an Internet web site supporting an open Digital Object Observatory and Repository, (thus the name Open DOOR project) at the University of Pittsburgh, NASA-Educator Resource Center.

I take a cue from Distributed Inventory Tracking and Data Ordering Specification (DITDOS), which details the metadata types required to managing data.

When an inventory request is made by a client, data bases and data sets are generated. A (1)data base description describes collections of (2)data sets. A data set describes collections of (3)data holdings and includes information about access privileges and curator information. Each data holding is referred to as a member of a data set. Membership in a data set is maintained through reference to physical data holdings which can be a member of multiple data sets without reproducing the data. This savings is reflected in storage but the issue becomes one of access.

The inventory information is of a fixed format and structure found in a data base. Possibly relational, but not necessary. All that is needed is (4)an inventory relational "table" connecting the "data set" table (defines which data sets are in the data base) with the "member" table (defines which data files are members of a specific data set, and the "curator" table (information on who contributed to the data set. If security is an issue in educational settings, the "privileges" table (delimiting access to the data sets) may be included.

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figure 3 goes here

A "data set" table shows the reference name for the set (**rfname**), the name of the curator i.e. institution or person (**curator**), text description of the contents of the data set (**descds**), and privileges offered(**priv**).

The "member" table shows the external reference name of the data set of which this file is a member(**rfname**), the system name, or pathway, to the data holding to which this entry refers (**sysname**), the data content type of a member is listed as data, document, image, animation, etc.(**type**), the online or off-line status of the member file (**status**), a text description of the class of the storage format, i.e. GIFF, JPEG, etc. (**format**), and description of the contents of the member (**descm**).

The "curator" table shows the reference name of the curator (**curator**), the full name of the curator (**cname**), the institution or affiliation name (**inst**), the full mailing address as street, city, state, zip, and country (**address**), phone number for contacting the curator (**phone**), full E-mail address for contacting the curator (**email**), and Internet address (**internet**).

The "privileges" table shows the external reference name for the data set (**rfname**), the name of a user permitted access (**okuser**), the host through which access is provided (**host**), and privilege level, i.e. Insert, delete, update, etc. (**okpriv**).

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figure 4 goes here

With the exception of the "sysname" field in the member table, all information is an abstraction...something to help organize and manage the original data.

VII. Educational Implications from Imaging and Visualization at NASA

NASA initiatives exist for the promotion of imaging and visualization (see Appendix for World Wide Web locations): Ocean Planet, El Nino, Ozone 1991, Clouds, Changes in Alaska's Glacier Bay, Biosphere, Lunar Topography-Clementine Mission, Musculoskeletal Modeling, Shoemaker-Levy 9 simulations, Convective Penetration in Stellar Interiors, Solar Winds, Evolution of Distorted Black Holes, and Hubble Space Telescope observations (Cohen, 1996).

A number of goals have emerged from space studies. One is to meet the challenge of being able to predict the Earth's environment in the context of its position in the solar system and in the context of global change. To meet this challenge we need the systems and software to efficiently gather and process data sets, develop and compare existing models of representation, and integrate these results into a predictive capability. Appropriately designed visualization tools are necessary to accomplish this. What now exists from NASA is a large-scale cross-disciplinary system for "in situ" and remote sensing data. The system uses Space Telescope, planetary orbiters such as Galileo and Cassini, EOS, and multi-spacecraft International Solar Terrestrial Physics (ISTP) which is projected to accumulate almost a gigabit of data per second. Spacecraft, ground-based observatories, and theory investigation teams will provide an estimated 2.2 gigabytes of data per day. For such data analyses it is necessary to have interactive graphics tools based on advanced visualization techniques. These techniques "compress" complex data into a visually organized optimal form. Mathematical and imaging processing tools are also needed. Facilitating this are tools to access data from remote archives and numerical models to correlate with the data and analysis. All of these tools must be integrated into a single user-friendly system. The goal is to rapidly generate visualizations enhancing the mining of data.

What prompts us to see visualization as the path to enhanced scientific productivity? First, the magnitude of the problems addressed, instrument sensitivity, the volume of databases, and the hardware, software, and computational tools to interpret and assimilate the results. Second, we need tools which, after asking the complex physics, engineering, or science questions, show us the answer as it visually evolves before our eyes. Thus the power of simulation is seen. Through the excitement of watching a process happen, as scientists do, students can assimilate a complex seriation of events and extrapolate or interpolate to the untested or unobserved.

VIII. Retrofitting the Curriculum to Match Scientific Technology Advances

The concept of telescience captures the notion that investigators participate in experimental operations from a distance to the instrumentation which is supported by an electronic infrastructure. The concept was developed for the experimental operations of a space station or data gathering instrument but always with the idea that the experimenter might not be at the site but was able to bring her or his knowledge and insight to the success of the experiment. The virtual presence of the experimenter, along with the crew is a logical requirement and has implications for student behavior as NASA unfolds space experiments or provides rich data for use by students in schools.

Computer software and documentation must provide a clear path for manipulating such graphic images, interaction with the software, speed, user-friendliness, and extensibility. We need to port these systems and software to the desks of students to enhance their analytical skills.

A collaboratory for imaging and visualization in the Earth and space sciences would involve sharing of data in real time over a wide area network, control of instruments over the network, and collaboration tools that allow students to work together over the network. There could be shared annotations on the data. Annotations over the Internet could include text, drawings, or voice. For imaging to work in the classroom, it is necessary for teachers to see the curricular implications. That means ideas, lesson plans, and activities must be available and public as part of the repository. There is no shortage of ideas for using imaging and visualization in the classroom. The Environmental Research Institute of Michigan (ERIM, 1994), for example, in its education program presents many ideas for lesson plans and projects. A comprehensive list for planning across the curriculum can be built from these suggestions:

for Engineering, Drafting, and Design

- assemble and test a direct readout station
- study types of satellites and their orbits for land, water, and atmosphere applications
- reproduce scale drawings of satellites and satellite components
- prepare electronic schematics for ground station components
- build scale models of various environmental satellites from, plastic or metal
- print out raw direct readout data, an unprocessed image, and a processed image to illustrate the differences between data, information, and knowledge
- illustrate the many different ways that a single image can be processed and displayed.

for Mathematics

- calculate satellite polar and geosynchronous orbits
- calculate orbital parameters of geostationary satellites for other planets and the moon

for Physics

- study Newton's Laws using earth satellite orbits
- calculate "look angles" and "fields of view" for satellite imaging sensors
- measure Doppler effects of satellite images

for Chemistry

study methods of spectral analysis used by satellites
observe changes in winter Great Lakes ice cover or other large bodies of water and compute the energy involved

for Weather and Climate

- develop weather forecasts for different locations using direct readout images
- track storms and fronts and correlate them with rainfall and wind records
- identify continental air circulation and the movement of the jet stream
- measure snow and ice covered areas and their changes during a winter
- develop seasonal cloud cover indexes for various states or regions of the earth
- determine the energy of a hurricane
- calculate cloud cover percentages
- enhance water, land, or cloud patterns
- create and print out enhanced graphic displays

for Geography and Geology

- draw maps of terrain patterns, drainage, and land/water boundaries
- locate rivers, cities, state, and country boundaries
- draw lines of Latitude and Longitude, locate the Equator, Tropics of Cancer and Capricorn
- identify areas of high population and urban growth, look for their "heat island" effects
- determine geographic effects on weather and climate, e.g. the Great Lakes "lake effect"
- identify landforms: desert, costal zones, islands, mountains, lakes, glaciers
- determine the area of major watersheds and map drainage patterns
- locate active volcanoes

for Ocean and Marine Sciences

- -observe and map coastal and oceanic currents

- correlate the locations of warm and cold currents with cloud cover

for Biology and Life Science

- use ocean thermal images to predict the locations of various species of fish
- identify areas of crop production
- correlate cloud cover, rainfall, and vegetation vigor
- study effects of acid rain on vegetation
- monitor crop diseases, droughts, and effects of flood on vegetation
- assess biological productivity
- relate use of satellite animal tracking techniques to habitat and range information

for English and Composition

- start a Direct Readout reference library or web pages of books, magazines, and images
- research and write an article about environmental satellites
- write and present TV-style weather forecasts and programs
- present reports on satellite subjects
- exchange letters on environmental satellites with students locally and internationally
- create daily weather forecasts and broadcast them throughout the school
- design a school bulletin board to show how satellite images and data are used
- graphically depict principles of remote sensing displays of satellite images
- discuss the accuracy of the data as preserved or distorted by image processing and display
- color or contrast stretch images to communicate different kinds of information.

for History and government

- study the history of artificial earth-absorbing satellites
- use satellite images to study the geography of historical events
- write a comprehensive history of major outcome events of satellite deployment
- use satellite images to plot previous, present, and future transportation routes

for Economics and Business

- prepare a business plan for operating a DR Earth station at your school
- list advantages and disadvantages of providing satellite data as a "free Good"
- describe the contribution of weather satellite data to farming, fishing, travel, and resort industries

for Psychology and Sociology

- -list relative advantages and disadvantages of conveying information with images

Summary

Satellite data is available daily, at no charge, no license required, no fee assessed, and no permission to acquire is required. School students have an array of data resources, hardware, and software tools available to them for imaging and visualization studies ("Buyer's Guide," 1995). New patterns and research styles are anticipated for analyzing data and producing scientific findings. The value of the data assets acquired from space extends well beyond the life of the probe or interplanetary mission. In science data is used in studies not originally envisioned and dynamically defined as the heuristic process evolves. Collaboration is now international in scope. Scientific questions are multidisciplinary and involve widely dispersed experimental teams acquiring data from multiple sources. Data needs to be archived and distributed. It will transcend project and science discipline boundaries. A collaboratory for imaging and visualization is needed. It would involve sharing of data in real time, control of instruments, and tools allowing students to work together over a wide area network. As a start, an Internet web site supporting an open Digital Object Observatory and Repository, (the Open DOOR project), is being proposed for the University of Pittsburgh, NASA-Educator Resource Center. There would be shared annotations on the data over the Internet to include text, drawings, or voice.

Curriculum building is a temporal process tied to perceptions and practices. Technology advances impact what should be an active, dynamic, and evolving curriculum building process. Problems addressed by science change and so, too, should the curriculum. While stability is an essential ingredient of planning, the process of curriculum development should not be so rigid as to exclude rapidly-emerging advances in imaging and visualization from the curriculum. A curriculum that is vibrant and promotes development of both teacher and student is the best remedy for reform. First, standardization with flexibility promotes growth. Second, direction for reform evolves from the structure and reproducibility of quality experiences. Third, accountability, evaluation, and assessment are encouraged. And finally, teacher professional development is encouraged and demanded by the level and high degree of knowledge that is to be taught. Imaging and visualization blends the inherent interest we hold with the new technologies in a configuration that promotes new ways of thinking about the worlds at which we look.

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Appendix

World Wide Web URLs for Imaging and Visualization*

Center for Image Processing in Education
http://www.cipe.com

Earth and Space Data Computing Division:
http://sdcd.gsfc.nasa.gov/SDCD.html

Earth and Space Sciences Project:
http://sdcd.gsfc.nasa.gov/ESS/

NASA Center for Computational Sciences:
http://sdcd.gsfc.nasa.gov/ASAVB/SVS/

NASA/Goddard Space Flight Center:
http://www.gsfc.nasa.gov/GSFC_homepage.html

NASA High Performance Computing and Communications Program:
http://cedis.gsfc.nasa.gov/hpccm/hpcc.nasa.html

NASA Jet Propulsion Laboratory:
http://www.jpl.NASA.gov:80/mars/

*Current as of this printing date but always subject to change

Figure Caption

Figure 1. NOAA 14 satellite transmission showing side by side placement of visible and infrared images.

Figure 2. Synthetic Aperture Radar (SAR) imaging schematic (NASA, 1997).

Figure 3. Inventory contents specification schematic for Open-DOOR.

Figure 4. Data set, member, curator, and privileges table relationships.

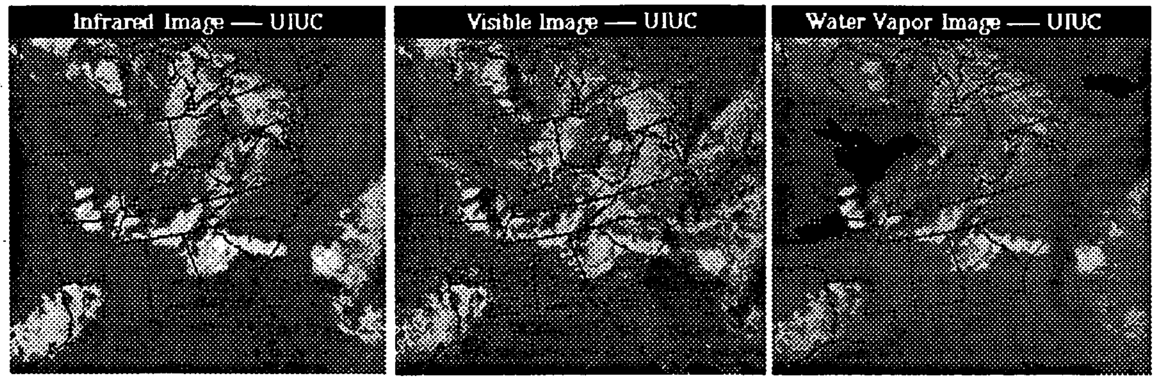

Figure 1. NOAA 14 satellite transmission showing side by side placement of visible and infrared images.

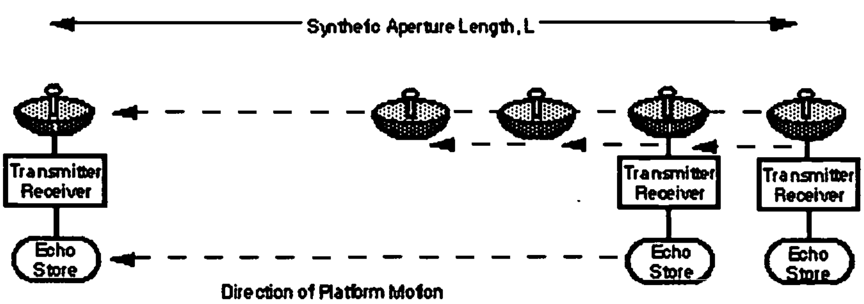

Figure 2. Synthetic Aperture Radar imaging schematic (NASA, 1997).

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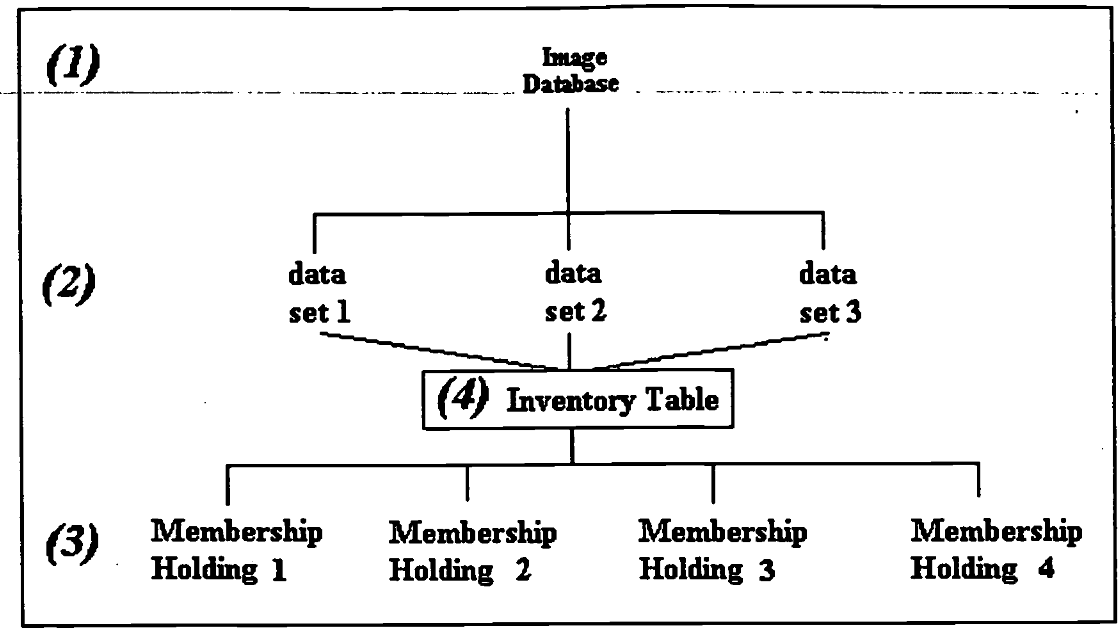

Figure 3. Inventory contents specification schematic for Open-DOOR

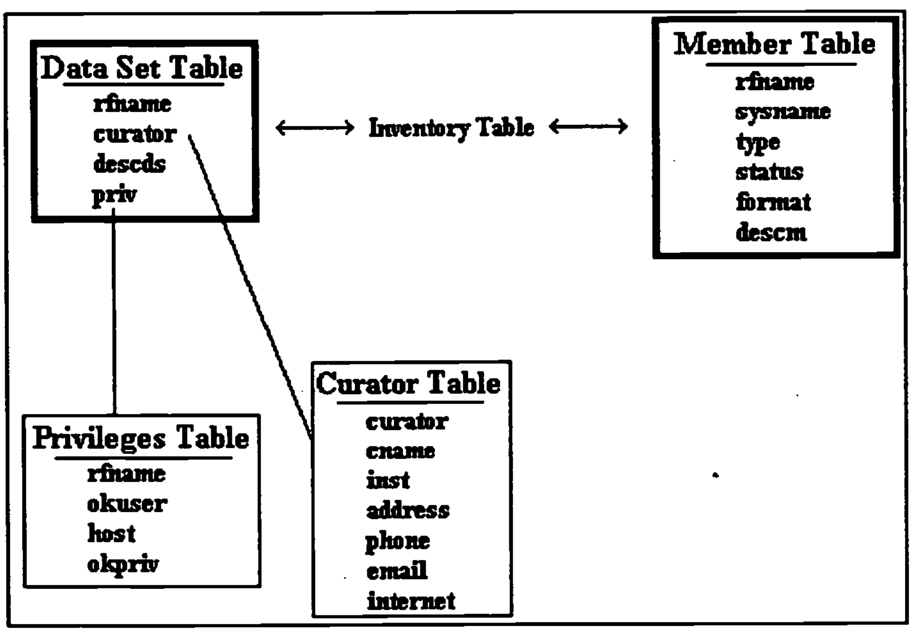

Figure 4. Data set, member, curator, and privileges table relationships.

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