DOCUMENT RESUME

ED 388 245 IR 017 394

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TITLE Which Way Will the Wind Blow? Networked Computer Tools for Studying the Weather.
PUB DATE 94
NOTE 9p.; In: Educational Multimedia and Hypermedia, 1994. Proceedings of ED-MEDIA 94--World Conference on Educational Multimedia and Hypermedia (Vancouver, British Columbia, Canada, June 25-30, 1994); see IR 017 359.
PUB TYPE Reports - Descriptive (141) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Access to Information; *Computer Networks; Computer Uses in Education; Courseware; *Earth Science; Hands on Science; High Schools; *Science Education; *Teaching Methods; Telecommunications; *Weather

ABSTRACT

A suite of networked computer tools within a pedagogical framework was designed to enhance earth science education at the high school level. These tools give students access to live satellite images, weather maps, and other scientific data dealing with the weather, and make it easy for students to make their own weather forecasts by creating high-quality weather maps. These tools are part of the Learning Through Collaborative Visualization (CoVis) project, an advanced technology research and development effort to explore the effects of giving high school students access to many of the same visualization and electronic communication tools used by scientists. The CoVis project is currently working with two high schools in the Chicago (Illinois) area, providing them with technology and curriculum support. To facilitate student work, the CoVis team designed front-end software that assists students in making connections between the visualizations and the phenomena they represent. Three specialized communication tools are provided to allow students located in different classrooms to work collaboratively on projects: Cruiser, a desktop video telephone system, a commercial screen sharing tool called Timbuktu, and a specialized "Collaboratory Notebook" for recording projects and the storing and retrieving of jointly created artifacts. The CoVis classroom uses the learning by doing teaching method, exemplified by the project method of doing science, and the teacher becomes a source of support and guidance, not a source of information. The linking of the CoVis weather tools and the pedagogical approach of the CoVis classroom links the learning of science with the practice of science. Four figures illustrate project computer screens. (Contains 13 references.) (Author/MAS)

Which Way Will The Wind Blow? Networked Computer Tools For Studying The Weather

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Abstract: A suite of networked computer tools within a pedagogical framework was designed to enhance earth science education at the high school level. These tools give students access to live satellite images, weather maps, and other scientific data dealing with the weather, and make it easy for students to make their own weather forecasts by creating high-quality weather maps. These tools are part of the Learning Through Collaborative Visualization (CoVis) project, an advanced technology research and development effort to explore the effects of giving high school students access to many of the same visualization and electronic communication tools used by scientists.

Science education in most contemporary high schools is far removed from the actual practice of science. Students are not given the opportunity to understand what comprises the real work of scientists and as a result are not attracted to science professions. School presents science as a series of known quantities. Student projects, when they exist, recreate answers to historical problems. By contrast, scientists spend most of their time researching questions for which there currently are no answers. In addition, scientists spend a significant amount of time communicating and collaborating with their peers. In this paper, we will describe an approach to studying meteorology that gives high school students access to the same tools and data used by professional and academic meteorologists to forecast and study the weather. This enterprise takes a holistic view of the classroom and its relation to the world outside. To this end, we link computer-based network tools for accessing and manipulating weather data with significant changes in pedagogy for teachers and students.

The Learning Through Collaborative Visualization (CoVis) project at Northwestern University is designed to reconceptualize and re-configure high school science education. A primary goal of CoVis is to enable project-based approaches to science by using computer networks to put students in direct contact with practicing scientists and their scientific tools (Pea, 1993; Pea and Gomez, 1992). A major criticism of current science education (and education in general) is that it isolates students from the world of practice, teaching them decontextualized skills that they are unable to apply in appropriate settings (e.g. Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). Traditionally, K-12 science education has consisted of teaching well-established facts. It bears little or no resemblance to the question-centered, collaborative practice of real scientists. CoVis is an attempt to transform science learning to better resemble the authentic practice of science. The CoVis tools for studying the weather are crafted to make this possible.

The CoVis Learning Environment

Weather As Subject Matter

Most people have some intuitions about weather. They talk about it in casual conversations with strangers. They stand out on their porch in their bathrobe for five minutes while deciding whether or not to wear a sweater or carry an umbrella. Although they listen to the television weather man, they know that even with all his maps and charts, he is often wrong.

Furthermore, there has been an increasing interest in weather at all levels of society, perhaps prompted by the dramatic weather events of the past two years. On the Internet, resources related to weather have long been popular. Two heavily used resources for on-line weather data are the "Weather Underground" at the University of

Michigan and the "Weather Machine" at the University of Illinois at Urbana-Champaign (UIUC). The Weather Underground receives over 100,000 connections in an average week (Weather Underground, 1993), and the Weather Machine receives over 30,000 requests for information each day (Ramamurthy & Kemp, 1993).

By the time high school students begin to study weather, they have developed a naive sense of how to predict the weather. For the most part, they rely upon a combination of what they see when they look up at the sky and what the media tells them to expect that day. But what if they had access to the same weather data and images that the forecasters have? Imagine them looking at current on-line weather maps which can zoom in to show local weather patterns and zoom out to show all of North America. What if they had the ability to create their own satellite animations? Then imagine them using all this information and more to make their own predictions of what the weather will be like later today, tomorrow or even next week, creating their own maps and then comparing their predictions to what really happened. All of this is possible using a set of tools developed as part of the CoVis project. These tools are known as the Weather Visualizer and Weather Graphics Tool.

The Technological Setting for the CoVis Weather Tools

The CoVis project is currently working with two high schools in the Chicago area, providing them with technology and curriculum support (for a more detailed description of hardware in the CoVis classroom, see Note 1). Each CoVis computer is a Macintosh with a direct (TCP/IP) Internet connection, with standard Internet client software for electronic mail, Usenet news, FTP, and Gopher. Specialized visualization tools created by the CoVis research team take advantage of Internet connectivity to provide current weather data. The tools used by scientists, although powerful, are somewhat cumbersome for students to use. To facilitate student work, the CoVis team designed front-end software that assists students in making connections between the visualizations and the phenomena they represent (Gordin, Polman, & Pea in press).

Three specialized communication tools are provided to allow students located in different classrooms to work collaboratively on projects. The most significant tool in this respect is Cruiser, a desktop video telephone system developed at Bellcore (Fish, Kraut, Root, & Rice, 1993). Using this tool, students can hold joint project meetings across school sites. A commercial screen sharing tool from Farallon Computing called Timbuktu is used to allow students to work collaboratively on the same piece of computer software. The combination of desktop video teleconferencing and screen sharing software allows students to do synchronous collaboration and consultation with students at both schools, atmospheric scientists at UIUC, or museum and library staff at the Exploratorium in San Francisco, CA. Finally, a specialized "Collaboratory Notebook" was developed to allow for the recording of projects and the storage and retrieval of jointly created artifacts, such as weather maps (Edelson & O'Neill, 1993). Considered together, these communication tools expand the CoVis learning environment to encompass information resources, activities and colleagues far beyond the four physical walls of the classroom.

The Pedagogical Setting for the CoVis Weather Tools

Student use of the technological tools described in this article both enables and is enabled by the pedagogical context of the CoVis classroom. Science education as it currently exists in the United States removes the subject matter from real contexts. Even in-class science labs, which are intended to give students "hands on" experience, are frequently no more than cookbook procedures. The result is that students "learn little... about the conduct of science; [reinforcing] the idea that science is dull, procedural, and thoughtless" (Tinker, 1991). If we consider the traditional approach to science education as learning-before-doing or learning-outside-doing, then the best response is to design educational systems and supporting technologies that allow learning-in-doing (Pea, 1993).

Learning-in-doing in the classroom is best exemplified by the project method of doing science (Ruopp, Gal, Drayton, & Pfister, 1993). Implicit in the adoption of the project method is a view that learners need to discover and develop facts and skills for themselves, as opposed to having material "delivered" via lecture or other kinds of presentation. Another important assumption is that learning must be located in communities of practice. This is also reflected in writing and thinking on cognitive apprenticeship (Collins, Brown, & Newman, 1989; Brown, Collins, & Duguid, 1989). What materials one chooses for learning is closely connected to notions of apprenticeship learning. For the CoVis project, we provide on-line access to scientific data and tools because we believe that these sources are more authentic than textbook information about science.

Finally, the role of the teacher must shift. Where previously the teacher was seen as a source of information, he or she now must become a source of support and guidance. Collins, et al. (1989) refer to this as a coaching role for the teacher. In considering the pedagogical bases of the CoVis classroom, it is important to remember that technology is not required to achieve this kind of classroom structure. Technology, however, enhances what can be accomplished in such a classroom and provides a lever to assist the teachers in changing their own approach to the classroom. Certainly, without the pedagogical changes made to the CoVis classroom, the uses for the technologies would not be as interesting or productive.

A Scenario for Studying Weather

How do high school students currently think about weather? Most people have a naive understanding of the weather, built up from their own life experience. High school students gain additional insight from media sources like the Weather Channel, the daily paper, or the nightly television news broadcast. In the CoVis project, we believe that these naive conceptions are an ideal place to begin the learning process. The tools we provide are designed to support and augment an inquiry curriculum where students learn to ask and answer their own questions about atmospheric science. Through such investigations the students are able to expand their knowledge and understanding of atmospheric phenomena beyond their localized daily experience of weather conditions. They incorporate explorations of larger weather patterns, the effect of geographic formations on weather, activity and conditions in the upper atmosphere, along with a more diverse number of atmospheric measurements, to create sophisticated mental models of how weather works. The following scenario describes each of the Weather Visualizer components as they might typically be used in the classroom.

Building From Naive Knowledge

The best starting point for an exploration of weather phenomena is the sky that a student sees outside his or her window. In one of the CoVis classrooms, the teacher asks his students to spend five minutes two times a day looking at the sky, and writing down what they observe in their journals. The students are instructed to record cloud cover and current weather conditions. Additionally, they are asked to make a prediction for what the weather will be like the next time they make an observation. Over a period of about two weeks, the students begin to form a reasonably accurate (though naive) predictive ability.

Observation-based forecasting of this kind is an ancient art dating back at least six-thousand years. During this time some rather accurate weather folklore or "weather wisdom" has developed (Lee, 1976). The CoVis teacher explains some of this folklore to his students, asking them to make use of it in their own predictions where appropriate. Students explore and compare their own predictions to those indicated by the weather lore. By viewing these comparisons in light of how the weather actually unfolds, the students are able to critique both their own and the weather lore's predictive merits.

By its very nature, observation-based forecasting is useful only for short-term local predictions of small-scale phenomena. To understand weather patterns on a larger, more integrative scale, students must be able to collect and analyze weather data from outside their own personal experience. When the teacher feels that the students have formed their own beliefs about local weather prediction, he begins to expand their knowledge base of weather experience by introducing them to our Weather Visualizer.

The Weather Visualizer is a suite of tools that simplify access to information provided by the University of Illinois via its "Weather Machine." That network resource provides a broad array of satellite images, weather maps, and specialized scientific visualizations of weather data to Internet users. Our Weather Visualizer makes access to those tools easier; it simplifies the Weather Machine's interface; and it extends functionality in several significant ways designed to meet specific pedagogical needs.

The Weather Visualizer is a client/server technology that is increasingly common in university and industrial models of "distributed" computing. The tool itself resides on students' Macintosh computers. When various commands are issued, the Macintosh sends an information request to a Sun workstation at Northwestern. If the machine at Northwestern contains the necessary information, it is sent back to the Macintosh where it is displayed. If, however, more or updated data is needed, Northwestern's computer sends an information request to the Weather Machine at UIUC. All of this network access takes place in the background, without any student intervention. The student is thus better able to focus on the task of thinking about the weather, instead of thinking about network access tools.

Changing Perspective With Satellite Images

The images most students choose to look at first are satellite images (see Figure 1). Using a push-button palette interface, the Weather Visualizer provides both visual and infrared satellite images of the United States as taken by the GOES-7 weather satellite in near-real time. These images are an ideal complement to student's own observations. The same clouds that the students observed from the ground are now seen from Earth orbit — an engaging shift in perspective.

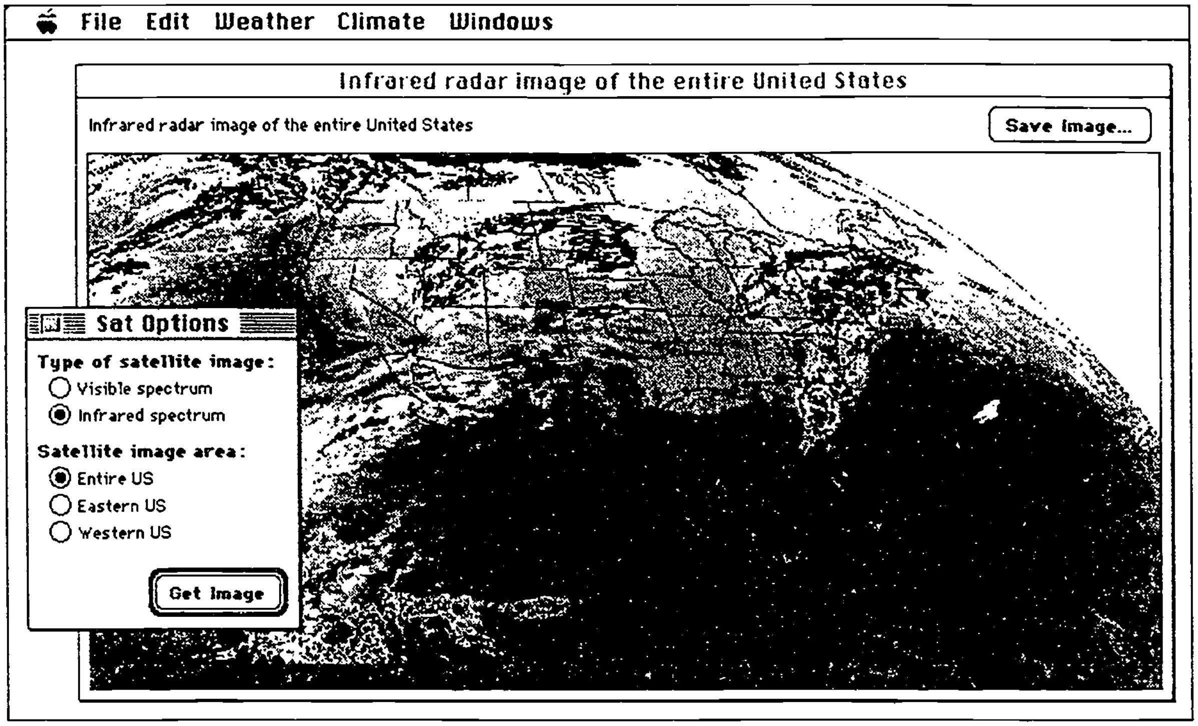

Figure 1. A satellite image from the Weather Visualizer with the palette used to generate current images.

The satellite images extend a student's view dramatically. Not only can they see the cloud cover above their current location, they can also see cloud cover over the rest of the nation. The infrared images allow students to gauge how high the cloud tops are, a good indicator of potential precipitation. If the student animates a series of images, those clouds can be set in motion.

Using the Weather Visualizer, students can make forecasts for areas beyond their own location. Large-scale weather patterns, such as mid-latitude cyclones, become apparent. Students begin tracking and making predictions about the formation and life cycle of these large-scale weather patterns. Though not apparent from local observations, they nonetheless affect local weather phenomena. Students compare the large-scale weather pattern predictions to their local weather data collection and prediction efforts and begin forming correlations between their local weather experience and the large-scale weather patterns.

Student-Customized Weather Maps

The information in a satellite image is a direct representation of atmospheric conditions. This directness, however, means that the students must make their own interpretations of what is visible in order to make predictions. There is no information present in the satellite image about precise temperatures, dew points, surface conditions, or wind speed and direction (although the last two could, in a rough fashion, be calculated from an animation). At this point the teacher continues to build on the student's naive understanding by introducing another representation that includes this additional information. WxMaps are specialized weather maps produced by software written at the University of Illinois. These maps are generated by a UNIX program using data from the National Weather Service called Domestic Data Plus (DD+). The UIUC software, although very powerful, has a difficult to use command-line interface. The Weather Visualizer puts a graphical front end on this UNIX software, allowing students to construct their own WxMaps by checking off various options (see Figure 2).

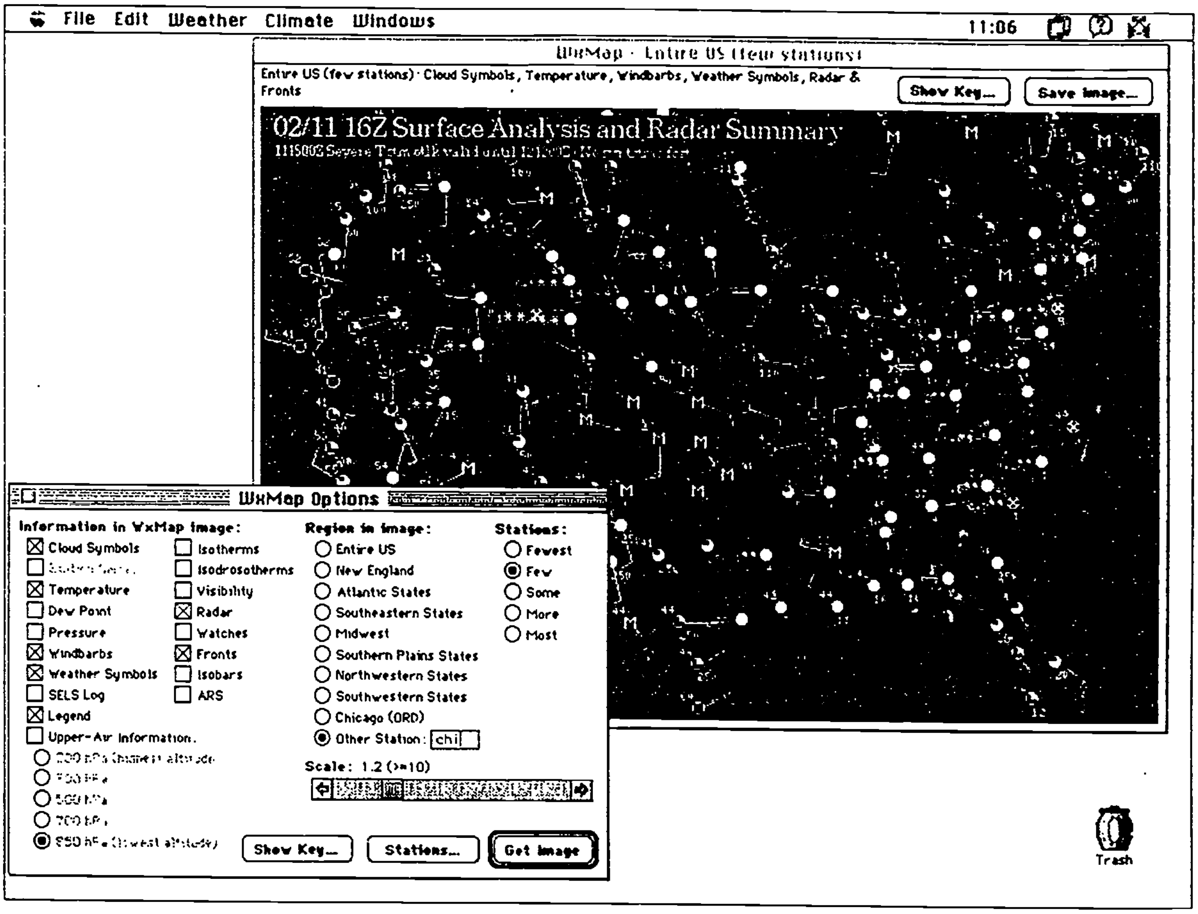

Figure 2. A customized weather map with the palette used to generate current maps.

The WxMap images display a variety of conditions at each reporting National Weather Service station in North America, and interpolated data generated from all the stations (for a complete listing of variables provided by the WxMap software, see Note 2). Students can focus their observations by region or city, select the density of reporting stations, and zoom in or out on their area of focus. By default the WxMap tool displays current conditions, but data is available from the past forty-eight hour period.

The station information provided by WxMaps allows students to study weather data across the continent that are similar to what they are collecting at their own location. They can explore the relationship between large-scale weather patterns and local weather conditions at various points in North America. As they explore weather conditions in other locations, students consider the effects of local geographic formations on weather phenomena (e.g., lake effect snow in Chicago) on their predictions.

Moreover, the teacher asks the students to expand their thinking about weather from surface effects to patterns in the upper air. WxMaps are capable of showing upper air conditions, such as jet stream wind patterns, using data gathered by weather balloons released twice a day at each station. The teacher asks the students to compare these upper air maps to the surface maps so that they may begin to think of the atmosphere as a three-dimensional space. Through exploring this three-dimensional space, the students learn that patterns of atmospheric phenomena occur not only in horizontal directions, such as the general west-to-east movement of the jet-stream over the U.S., but also in vertical patterns such as rising and sinking masses of cold and hot air.

Making Personalized Maps with the Weather Graphics Tool

With the finer-grained data provided by the WxMap tool, students begin to make more detailed predictions of the weather. The CoVis teachers, seeking ways to support this prediction activity, requested a tool that would allow students to make maps representing their predictions. In response, the CoVis team developed the Weather Graphics Tool. This tool is actually a plug-in extension to Aldus SuperPaint 3.5, a widely used graphics tool for the Macintosh. Our plug-in provides SuperPaint with a palette containing "stamps" for all the weather symbols represented in WxMap. We also devised a number of blank maps for students to use, one map for each region plus national maps, half with and half without weather station names. These maps are stored as Macintosh stationery pads.

To use the Weather Graphics Tool, a student selects a base map and uses it to launch SuperPaint. Then, using the plug-in palette, students select various weather symbols and place them on the map. There is a special palette for constructing the standard station model (see Figure 3), which is then placed by clicking on the map like any of the other stamps. After constructing the weather map, the student can store it for later comparison to a map generated by WxMap. The ability to create maps using the Weather Graphics Tool is motivating to students because the maps they create are as professional looking as those generated by the WxMap software.

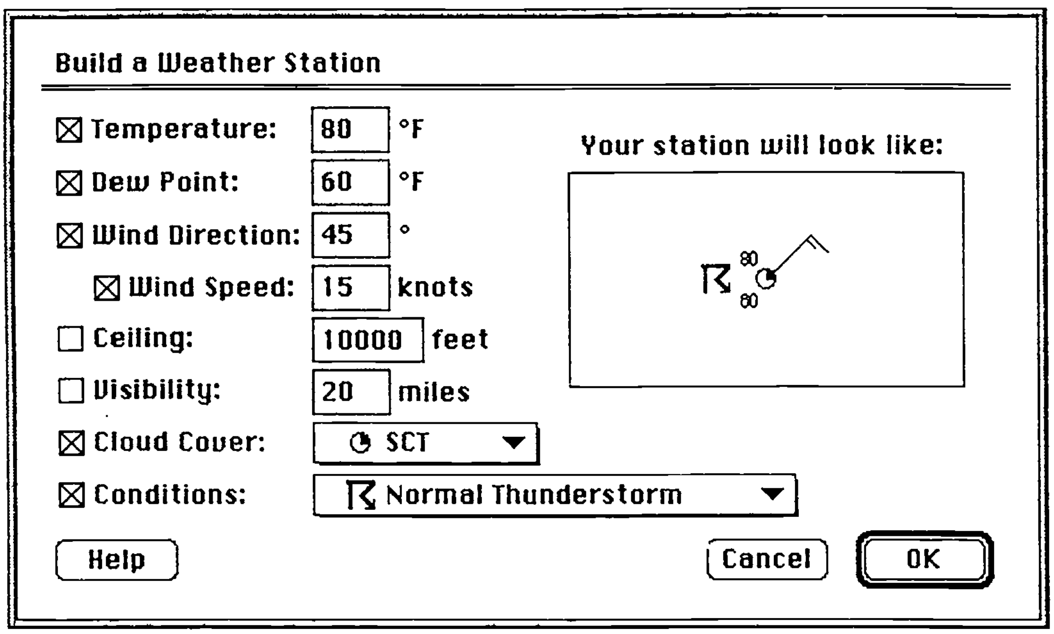

Figure 3. The palette used to generate a standard station model in the Weather Graphics Tool.

In order to make such detailed predictions, the students must consider the relation of various atmospheric conditions and processes to future weather at any given time and location. To do so, they must begin to integrate the knowledge they have gained thus far, and like professional weather forecasters, make decisions about which weather indicators have more weight in any given weather scenario.

Teachers like the Weather Graphics Tool for the role it plays in prediction activities, but they also envision other uses for it. For example, it is very easy to create weather "scenarios" using the Weather Graphics tool and ask students to explain what they see. The tool allows teachers to easily create impossible scenarios, which require students to explain why a certain combination of phenomena could not exist in reality. Also, maps generated using the Weather Graphics Tool are easily added to students' evaluation portfolios.

Advanced Interpretation — Six-Panel Images

As students learn how to make more accurate weather predictions, they are also learning more about the representational language of atmospheric science. This learning is driven by the higher-level goal of improving their forecasts, and thus happens in the background of the learning activities. For students who have mastered the interpretation of WxMaps, there is one more type of image available from UIUC. This image, commonly referred to as a "Six Panel" image, displays six atmospheric variables mapped as color across a map of the United States. These six variables are temperature, dew point, pressure, wind direction, wind velocity, and moisture convergence (see Figure 4). The six panels represent a great deal of information presented in an efficient manner. As a result, they are difficult for novices to interpret. There are, however, direct benefits to investing the time to learn how to interpret the Six Panel image. Moisture convergence is a particularly useful variable, because it indicates where there are gathering "pools of moisture" in the atmosphere that could contribute to future precipitation.

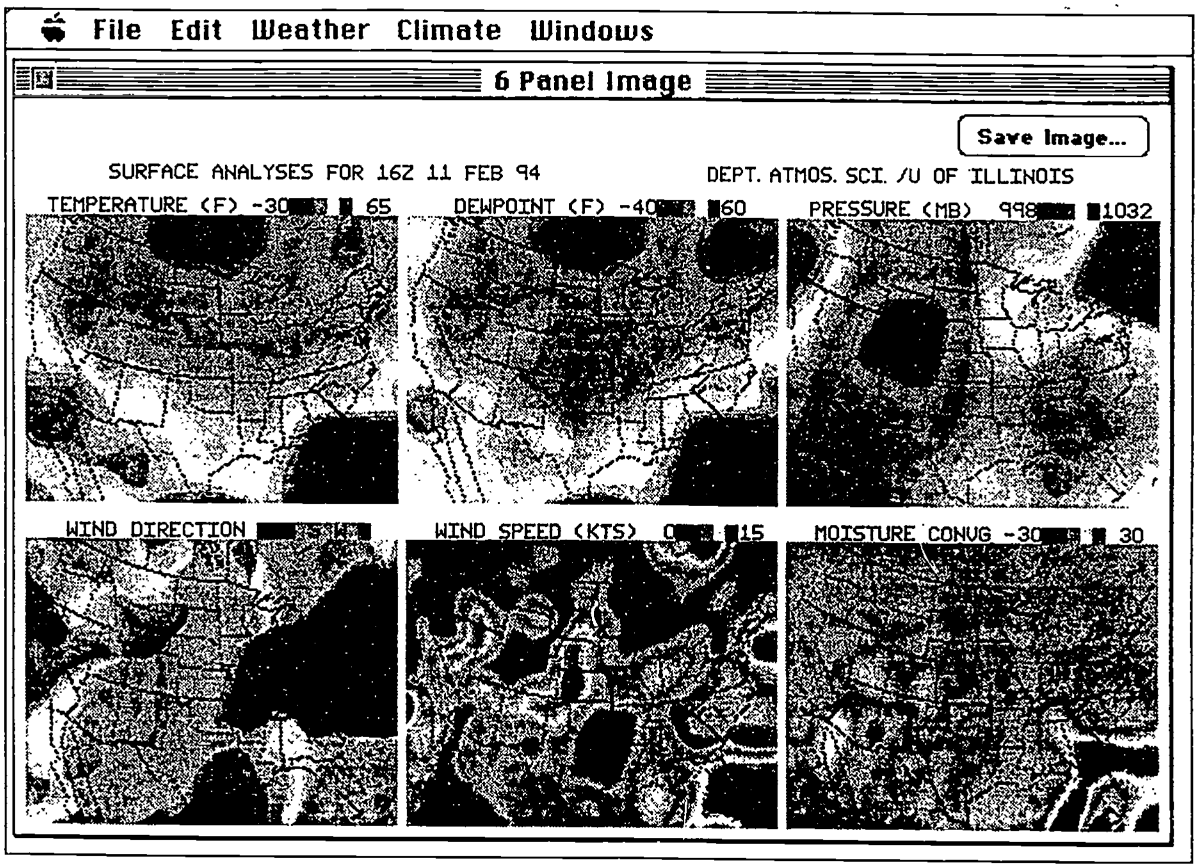

Figure 4. A six-panel image showing temperature, dewpoint, pressure, wind direction and speed, and moisture.

Conclusion

When students have the ability to work and think with the same tools that scientists use, remarkable things can happen in the classroom. Topics that were previously dry become animated and exciting for students. Instead of memorizing the station model and its interpretation as facts to be repeated on a test, students put the station model to use in illustrating forecast maps that they construct using the Weather Graphics Tool. They can look at live satellite photos and animations for a unique perspective on the sky. WxMaps and Six Panel images make it possible to understand a broad array of reports from weather stations across the country. When tools such as these are used to build upon what they already know, students have a starting point for exploration that is internally motivating.

The combination of the CoVis weather tools and the pedagogical approach of the CoVis classroom links the learning of science more closely with the practice of science. Students in the CoVis classrooms learn more than science, they learn what it is like to do science. This is an important step on the path to making science education both more relevant and enjoyable.

Notes

(1) In the 1993-94 school year the CoVis project involves 282 students in twelve classes at two Chicago-area high schools. There are six teachers: four Earth Science, one Environmental Science, and one Science, Technology, & Society. Each classroom (one per school) is equipped with five Macintosh Quadra 700 computers with 8mb of RAM and 16 inch color monitors, one laser writer, and video projection equipment. Each Quadra has a Cruiser station next to it, composed of one 13 inch NTSC television monitor, microphone, speaker, and wide-angle NTSC television lens. There is one additional Quadra at each high school for students to access outside of their class hours. Internet and video network connections for both high schools are provided by primary-rate ISDN connections to Northwestern's network backbone and the public-switched telephone network.

(2) The WxMap software reports the following variables: clouds, station names, temperature, dew point, pressure, wind velocity, wind direction, current weather conditions, visibility, radar, watches, fronts, isobars, isotherms, and isodrosotherms. Upper air analyses are available at 850, 700, 500, 300, and 200 hPa. Additionally, the WxMap software can display the Automated Radar Summary and the daily Severe Local Storms (SELS) log, both products of the National Weather Service.

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Acknowledgements

The authors would like to thank Joey Gray for his programming and design work in the development of the CoVis weather tools, and Eric Baumgartner for his work on the Weather Graphics Tool. Thanks to Roy Pea, Louis Gomez, Danny Edelson, and Steve Hall for their comments on earlier drafts of this paper. We gratefully acknowledge Aldus Software for providing SuperPaint to the CoVis project, Apple Computer, Farallon Computing, Sun Microsystems, and the support of National Science Foundation Grant MDR-9253462 in work related to this paper.