that computers can serve as valuable tools in many realms, including education, but deny that machines can acquire human know-how.

In questioning the AI approach to tutoring, they attribute to AI researchers a belief that teachers' understanding of their subject and their teaching of it depends on knowing facts and rules. "Rather, expert teachers learn from experience to draw intuitively and spontaneously on the common-sense knowledge and experience they share with their students to provide the tips and examples they need." In the Dreyfuses' view, computers can teach only novices or, at best, competent performers.

What has changed to make proponents of AI more confident? John Seely Brown, head of the Intelligent Systems Laboratory at Xerox Palo Alto Research Center (Xerox PARC), is often referred to and deferred to as having a broad view of the field by people in it. Brown says that a fruitful line of AI inquiry has been pursuit of "the knowledge that comprises expertise . . . the attempt to learn how the novice approaches a problem as opposed to the expert." Five years ago the effort went into trying to build programs that replicated expert behavior. Brown says researchers are beginning to appreciate what he calls metacognitive skills, "skills that allow you to pick up new knowledge and monitor one's own use of this knowledge." Researchers asked what it would mean to take what a student has done in attempting to solve problems and create a "cognitive audit trail." This may be done, in effect, by "kibitzing" with students as they try to solve problems by using their own reasoning strategy, says Brown. When a student gets stuck, says Brown, it is possible to critique how he or she got stuck in the first place. Observing this "useful floundering" and seeing where students go wrong has enabled researchers to find patterns relevant to intelligent tutoring systems. Soloway at Yale takes a similar approach in his work to identify the misconceptions that trip up novice programmers when they seek to apply more advanced programming concepts. Brown thinks that making their audit trail visible to students and enabling them to reflect on it is a step toward answering the criticism of the Dreyfuses and others.

It is on following up on such insights that much current AI research on education is concentrated. Support comes primarily from federal agencies, principally the National Science Foundation and the Office of Naval Research. NSF has a strong track record in support of research on computers in education, having, for example, served as a major patron for the development of the BASIC and LOGO computer languages. The foundation's program was centered in its education directorate. With the decline of the directorate in the 1970's and its eclipse at the beginning of the Reagan Administration the activity languished. It was revived when the directorate was reconstituted midway through the Reagan first term. Grants awarded under the applications of advanced technologies program totalled $7.5 million in 1985.

The program director, Andrew G. Molnar, says that the NSF strategy takes into account that the development of new technologies requires a decade or more. He notes that research in cognitive science underwent a fairly recent "paradigm shift." The focus of learning how experts solve problems changed from knowledge to the thinking process.

NSF hopes to identify the most promising research conjectures. Molnar says that "for the first 2 or 3 years we had an open agenda. We told researchers 'no holds barred.' We expect that 3 or 4 years will tell us which ideas work." The plan then is to scale up the successful projects and make them usable in the schools. Molnar says the foundation is determined that such a project will have to be proved "dramatically better. If we find that it is not effective or is marginally effective it will be discontinued."

The small size of the research community working on applications of AI and cognitive science research in education—Molnar estimates the number of active researchers at about 100 worldwide—is a limiting factor. And for that small group, development funding and consultancies offered by business and the military are much more lucrative than what is available for research for the schools. The lack of interest so far on the part of vendors of both hardware and software in participating in the development of new educational technology embodying AI content could prove troublesome when the time comes for dissemination. So even if the critics are confounded and the prophets ultimately confirmed in their vision of the results of AI research being brought into the classroom, the practical problems are likely to mean some delay on the threshold. ■

JOHN WALSH

The Chesapeake Bay's Difficult Comeback

A major cooperative program to clean up the nation's largest estuary will cost billions and faces many scientific uncertainties

Solomons Island, Maryland

On a hot summer day as the Patuxent River merges lazily with the Chesapeake Bay, marine scientist Christopher D'Elia is studying one of the most perplexing problems related to the cleanup of the nation's largest estuary. The University of Maryland researcher is examining whether nitrogen wreaks as much havoc in the Bay's ecosystem as phosphorus. If it does, as D'Elia's studies of the lower Patuxent indicate, the cost of the Bay's cleanup might be increased by billions of dollars.

Uncertainty about the role of nitrogen is one of several factors that complicate a major, 2-year-old effort to clean up the Bay. There are other significant scientific questions to be answered, tough regulatory decisions to be settled, and a multitude of local, state, and federal agencies and advisory committees to coordinate. As Lee Thomas, administrator of the Environmental Protection Agency, recently noted at a Senate hearing, "It has taken years to pollute Chesapeake Bay; it will take years to clean it up."

The Bay, which is not only the country's biggest estuary, but one of its most productive, stretches over 64,000 square miles, ranging 200 miles north to south and 4 to 30 miles wide. More than 150 creeks and 8 major rivers empty into it. It is a center of tourism and sport and commercial fishing, and its shores are the home of an ever-increasing number of people.

For decades, the Chesapeake Bay has also been a dump for raw sewage, toxic chemicals from factories, and fertilizer and livestock waste from farm runoff flowing from the region's tributaries. In 1983, a 7-year study released by the Environmental Protection Agency confirmed the fear of many that the Bay is suffering badly from pollution. Among the EPA findings: high concentra-

tions of phosphorus and nitrogen contaminate the Bay; algae proliferate, starving fish of oxygen; underwater grasses, an important link in the estuarine food chain, are perishing; harvests of rockfish and oysters have dropped precipitously; and toxic chemicals are fouling sediment where marine organisms feed.

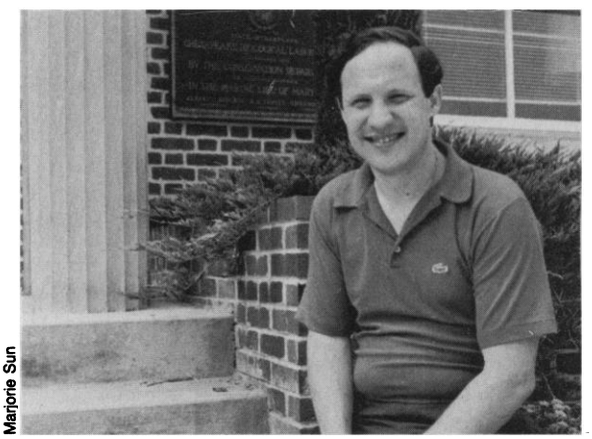
The impact of the EPA study was dramatic. In an unusual spirit of cooperation, Virginia, Maryland, Pennsylvania, and the District of Columbia agreed in 1984 to work together to revitalize the estuary and set up the Chesapeake Bay Program, a hierarchy of committees. EPA agreed to be the principal coordinator. Grass roots groups supporting cleanup multiplied like phytoplankton. One result is that states tightened regulations on sewage treatment discharges, so there is less raw sewage flowing into the Bay. Even so, the estuary is not yet appreciably cleaner.

The slow progress, which is understandable, is not for lack of will. Environmental groups compliment the governments' efforts. William C. Baker, president of the Chesapeake Bay Foundation, one of the main environmental groups tracking Bay issues (and the source of "Save the Bay" bumper stickers, becoming ubiquitous throughout the region), says that, while regulators could be doing more, "things are proceeding relatively well." Charles Spooner, director of the liaison office for EPA's Chesapeake Bay Program, remarks that "the Bay enjoys enthusiastic support. There's a deep political commitment."

Broad public support has been essential because there are so many problems to juggle. For example, new scientific findings are causing regulators to rethink pollution control plans. The studies by D'Elia have generated considerable debate among government regulators about the importance of controlling nitrogen from sewage treatment plants and farm runoff in the Bay. According to conventional scientific wisdom, nitrogen is crucial to algal growth in salt water but phosphorus is the more important nutrient in fresh water. Scientists have argued for years over which is the more important factor in estuarine ecology. Lacking solid data, state and federal regulators have concentrated on phosphorus controls primarily because they are cheaper than denitrification equipment. Last year, for example, Maryland and the District of Columbia banned phosphate detergents.

In January, D'Elia's findings won significant support when the scientific advisory panel of the Chesapeake Bay Program, which consists of 20 scientists, mainly from academia, recommended that sewage treatment plants "should implement nitrogen control in addition to phosphorus control." A reduction in nitrogen levels will improve water quality in the saline parts of the Bay, the panel stated.

The report also recommended the use of a cheaper method of nitrogen control, which relies on microbes instead of a chemical process to remove the nutrient. According to Environmental Policy Institute estimates, chemical removal of nitrogen may add $2 billion to the region's waste treatment bill. The microbial method might be cheaper than the chemical method by 20 to 30%, the scientific advisory committee reported. Citing the experience of 50 facilities in nine other countries, the report said that the microbial method is "technically and economically feasible."



Marjorie Sun

Christopher D'Elia. *His studies indicate that nitrogen may be a more important pollutant than phosphorus in the Bay. However, controlling nitrogen may add up to $2 billion to the region's waste treatment costs.*

EPA officials acknowledge that nitrogen may play an important role in Bay cleanup and that the microbial process may work, but they have not yet made any explicit policy changes. At the Senate hearing, which was held by the governmental affairs subcommittee on 24 June, Thomas suggested that specific figures for nutrient loadings should be set, but he did not specify what the goals should be or who should set them. Meanwhile, Virginia is setting up two pilot plants to test the bacterial method, and Maryland is spending about $20 million to retrofit treatment plants located on the Patuxent with nitrogen controls.

Government officials, including Richard Eichbaum, head of Maryland's Bay activities, say that, without better scientific answers to other problems, it will be difficult to develop effective regulations. He says that the effect of many of the chemicals that have been dumped into the Bay remains unclear. He and his Virginia counterpart, Keith Buttleman, are also uncertain how clean the Bay must be to restore the finfish and shellfish populations. One of biggest questions, according to Spooner of EPA, is to what extent sediment releases phosphorus into the water. Even the paths of some of the nutrients into the estuary remain uncertain, complicating efforts to give some areas priority over others.

To help solve these questions, EPA and academic scientists are developing several computer models to help track the dispersion of nutrients in the Bay and to predict how reductions in pollutants will change water quality. But reports on two of the three models under development will not be presented to the the Bay program's Executive Council for another year. Moreover, Baker of the Chesapeake Bay Foundation and Charles Fox, who monitors Bay activities for the Environmental Policy Institute, are skeptical whether these models will really provide reliable information. Fox contends that the Bay "is too complex to put on a computer and that models are always challengeable in court" if they are used as the basis for regulation. They also appear to be a subject of some dispute within the scientific community. The agency's first model was abandoned because it failed to pass muster with a panel of outside scientists who reviewed it.

Although the modeling has been helped by such independent scrutiny, much of the EPA-sponsored Bay research lacks outside peer review, according to D'Elia and others at the University of Maryland's Chesapeake Biological Laboratory at Solomons Island. The Bay program's scientific advisory group, which first met nearly 2 years ago, did not play an active role in making recommendations until it published the controversial nitrogen report, which was based largely on D'Elia's studies.

D'Elia contends that the agency spends too much money on Bay monitoring. He himself receives $200,000 from EPA to conduct monitoring. He says, "I'm happy to have the money, but the monitoring can be cut in half and still do the job." The agency's efforts are "overambitious and a waste" because "it is measuring everything under the sun," he adds. "We should be trying to understand some specific things," such as

variations in nutrient concentrations over long periods of time. But, in response, Spooner says that "we need as much data as we can get right now to calibrate the models. Our scientists working on the models say, 'Don't cut back in monitoring stations.' We too are as anxious to collect data for as little expense as we can."

In addition to the unresolved scientific questions, there are some sticky political problems involving land use around the Bay. It is clear that nutrient pollution from agricultural use must be cut back, particularly in Pennsylvania. But as Paul Swartz, director of Pennsylvania's Bureau of Soil and Water Conservation, puts it, controlling pollution on farms "is a difficult political problem."

Part of Swartz's job is to convince farmers to control runoff, a big challenge because little of Pennsylvania actually borders on the Bay. Yet the state is the primary contributor of nonpoint nutrient pollution. Half the land in the state drains into the Susquehanna River, Swartz says. In the area around the lower part of the river alone, there are more than 12,000 farmers. This area accounts for 41% of the state's total nutrient pollution in the Bay. "Our selling point to the farmer can't be 'save the Bay,' " he says. "The Bay is not the same to Pennsylvania as it is to Maryland or Virginia." The state's sales pitch is that farmers will save money by preventing fertilizer erosion and will prevent more ground water contamination.

Under a new state program, Pennsylvania provides money to entice farmers to use soil and nutrient conservation techniques. But so far the state has allocated only $2 million for the program and is funding farmers in just 6 out of 39 counties. Swartz only has four people in his office to coordinate the program with the help of local workers. He predicts that the state may eventually need $300 million to control the nutrient problem.

Maryland and Virginia have similar programs to encourage farmers to practice conservation. Last year, for example, the Maryland legislature established a commission consisting of 25 members of local communities and gave it the final authority to judge local development plans involving land within 1000 feet of the shoreline. The program goes into effect next year. Virginia "takes a more traditional approach" in land-use planning, says Buttleman, who is administrator of the Council on the Environment, an advisory group to the state. Although he acknowledges that Maryland's program to control local development "would make it a lot easier to plan centrally, politically we're a long way off in Virginia from doing that."

Few of the key players in the Bay program say there is a shortage of funds for Bay research. The states' combined spending on Bay research and monitoring totals about $47 million annually, with Maryland the biggest contributor. EPA's annual budget for the Bay has been $10 million and most of this is devoted to monitoring, research, and cost-sharing grants to states. Congress is currently considering the program's reauthorization as part of the Clean Water Act and will likely renew the funding at the same amount through 1988.

But the need for more money to improve sewage treatment will clearly increase as specific goals are set for nutrient loadings, a circumstance complicated by a federally proposed phaseout of federal grants to construct sewage treatment plants. Since 1965, the federal government has provided $2.44 billion for sewage treatment plants, but the Administration now wants to phase out these grants and shift the cost to state and local governments.

Somewhat surprisingly, Fox of the Environmental Policy Institute says that in his opinion the phaseout might not be a bad idea. (The Institute has not taken an official position on the matter.) Under the EPA grant program, he contends, sewage treatment plants were built in areas where development should not have been encouraged. State and local governments may plan for development more wisely if they have to shoulder the cost, he believes. Virginia and Maryland have already picked up some of the slack and have increased the amount of money available for construction loans.

The Bay program has entered what state and federal officials call the implementation phase, and there is much discussion about what broad action should be taken next. The Chesapeake Bay Foundation has urged the states and EPA to revise or set new water quality standards for known toxic chemicals, to fit sewage treatment plants located in the most highly enriched tributaries with nitrogen controls, to support a ban on phosphate detergents in Pennsylvania and Virginia, and to increase funds to encourage farmers to practice conservation measures. Baker of the Foundation lauds the cooperation among the various committees, but remarks that progress in cleaning up Bay "is like rowing 3 knots against a 4-knot current."

In view of all these concerns, which will take time and money to solve, Baker says that "the big job is to see if the public's interest, which has driven this [effort to save the Bay], will be maintained." Eichbaum concurs. "Whether society will sustain its enthusiasm is a very serious question." Bay cleanup is a complex problem, he says, but for now, "The pot is boiling. The program is evolving nicely." ■ MARJORIE SUN

Briefing:

Air Force to Mothball Vandenberg, Reduce Reliance on Shuttle

The Air Force has announced a detailed plan to cut its reliance on the space shuttle for launching military satellites. The plan, which will cost $2.6 billion over the next 5 years, will require about a dozen unmanned rocket launches a year by the early 1990's; until recently, the shuttle was expected eventually to ferry all military satellites to orbit.

The new plan, announced by Air Force Secretary Edward C. Aldridge, Jr., also involves a 6-year delay in opening the military's brand-new shuttle complex at Vandenberg Air Force Base north of Lompoc, California. The facility, which has so far cost $2.8 billion, was originally scheduled to begin operations with a shuttle flight last month. But all shuttle flights were suspended in January following the explosion of the Challenger and are not scheduled to begin again at least until February 1988.

The Vandenberg facility will be placed in "operational caretaker status" until 1992. This is less drastic than several other options under study, including virtually closing the facility until the mid-1990's (*Science*, 4 July, p. 15). It will require a cut of about 40% in staff and save almost $1 billion over the next 5 years.

The day before the Air Force announced the plans to reduce its reliance on the shuttle, the Economic Policy Council, a Cabinet-level body, sent a recommendation to President Reagan that would achieve the same result for civilian launches. The council, reportedly over the objections of the National Aeronautics and Space Administration, argued that the shuttle should be barred from launching commercial satellites and instead should fly only military and scientific missions that could not be launched by other means.

This recommendation is designed not only to cut down the huge backlog of satellites that has built up since the shuttle was grounded but also to stimulate the development of a private launch industry in the United States. It would, however, result in substantial lost income for NASA and further exacerbate the already disastrous economics of shuttle operations.

The council's recommendation is part of a broad White House assessment of space policy, which will also tackle the vexed issue of whether to build a replacement for the Challenger. NASA has been arguing strongly for a replacement orbiter, which would cost some $2 billion, but the Office of