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ABSTRACT

In a traditional science classroom, only a portion of students walk away with a genuine understanding of the material, and even fewer are able to apply the concepts they have learned to events in their own lives. Foundations of Science (FOS) was developed in a cooperative effort between the University of Michigan and the Ann Arbor public schools to allow all high school students to develop a deep understanding and appreciation of science and technology, and to help them develop into responsible, scientifically-aware members of the community. This paper discusses the process of authentic science learning, describes a local environmental intervention in which high school students participated, and explores lessons learned from the FOS experience. (WRM)

Foundations of Science: Using Technology to Support Authentic Science Learning

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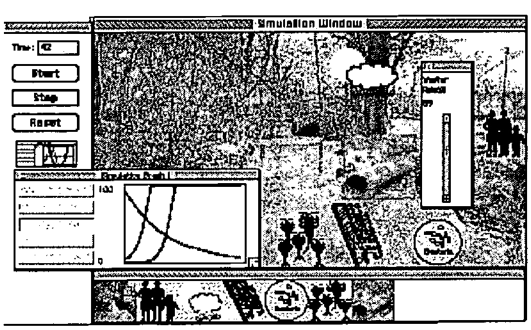
REINVENTING THE EDUCATIONAL PROCESS

Public education must undergo a drastic revision to adequately prepare students for the twenty-first century. Technology is a key component for integrating these revisions into a high school curriculum. Foundations of Science at Community High School in Ann Arbor, Michigan, is a three-year, project-based, integrated science curriculum which uses technology on a daily basis to support students as they engage in authentic science inquiry.

In the traditional science classroom, only a portion of students walk away with a genuine understanding of the material, and even fewer are able to apply the concepts they have learned to events in their own lives. Foundations of Science (FOS) has been developed in a cooperative effort between the University of Michigan and the Ann Arbor public schools to allow all high school students to develop a deep understanding and appreciation of science and technology, and to help them develop into responsible, scientifically-aware members of the community. The program integrates the traditional sequence of earth science, biology, and chemistry into a three-year, project-based course focusing on authentic science investigations. Authentic science means that students use the methods and tools of real scientists to examine real-life phenomena that have an impact on their lives and on their community.



ıs of Science classroom.

Three science teachers at Community High School had gotten tired of trying to explain to their students why it was important to learn outdated concepts through outdated methods. With the traditional curriculum that they were expected to follow, it was difficult to convey the relevance of science to students' everyday lives. They were ready for a change.

"Students often asked us, `Why do we have to learn this?' `What good is this going to do me?'" FOS teacher Madeline Huebel-Drake explains. "Our problem was that we had run out of good answers because we were asking ourselves the same questions. The traditional curriculum was not meeting the needs of our students."

The Community High School teachers--Madeline Huebel-Drake, Mike Mouradian, and Liz Stern--joined forces with professors at the University of Michigan to put together a new curriculum which would instill in students a genuine understanding of science and its relevance to their lives, as well as train them in the methods of the twenty-first century workplace. Professors Liza Finkel and Joe Krajcik brought Project-Based Science to the mixture, and Professor Elliot Soloway brought the innovative technologies of his Hi-C (Highly Interactive Computing) Research Group. Together they formed Foundations of Science .

In developing the Foundations of Science program, current opinions on the teaching of science were researched (such as Project 2061, Benchmarks for Science Literacy, A Nation at Risk, John Goodlad, Michigan Essential Goals and Objectives for Science Education). Some common themes that emerge are that traditional science curriculums fail to engage students in thinking for themselves, do not foster students' ability to communicate ideas through writing and speaking, and have little relevance to students' lives. These problems can only be resolved in a learning situation where students are the ones who are talking, writing, exploring, evaluating, and making decisions.

AUTHENTIC LEARNING

It is only through authentic science investigations that students will claim ownership of the material, and gain a genuine understanding which will allow them to apply the concepts learned in the classroom to their lives outside of school. Authentic

science projects allow students to attain a true sense of discovery, in that they are researching real-world problems with no pre-defined answers. The projects have personal meaning for the students, so that they become genuinely engaged in the topics which they are investigating. According to Ron Marx, a University of Michigan Professor and parent of an FOS student, authentic science gets students "much more involved in learning interesting things rather than trying to memorize material that is of little interest to them and, frankly, of little interest to most people in the world."

High school students lack the resources and training necessary to conduct authentic research on their own. Professional scientists spend years studying the methods of scientific inquiry; in order to attain a genuine understanding of the content in their science courses, students need to be using these methods now. The technology embedded in the FOS classroom mediates the scientific inquiry activities in which the students participate, allowing them to begin to understand scientific phenomena without being intimidated by the processes behind it. Technological resources such as the Internet provide students with a forum in which to discuss scientific research, as well as a database in which to search for information.

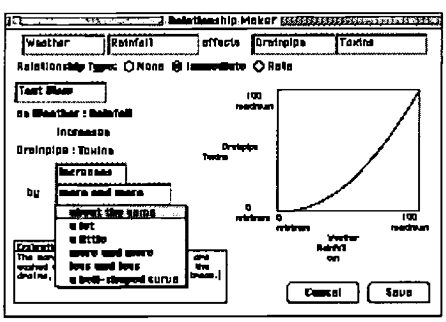


Figure 2: FOS students search the Internet for information related to their project.

Students in FOS work in groups, on projects that incorporate many different facets of science. For example, a project focusing on stream water quality had students collecting biological organism data from the stream, performing chemical tests on water samples, and doing physical assessments of the soil, vegetation, and topology near the stream. Process skills included observation and analysis of data, graphing, as well as continued enhancement of computer and writing skills. Students were able to carry out the research from beginning to end by themselves through the use of technology such as MBL (microcomputer-based laboratory) probes and hand-held Apple Newton computers.

Figure 3. Two students perform chemical tests on water collected at the AATA pond, assisted by their teacher, Elizabeth Stern.

When students are involved in authentic science research, understanding the content is a necessary part of the scientific process rather than the end goal; they must master the content in order to solve the problem at hand. Rather than seeing science as a set of definitions and facts to be memorized, Foundations of Science students have come to see science as a way to understand, and to take action in, their everyday world. As one student comments, "In Foundations, I can actually see how `science' affects my life, and how all the little bits and pieces of things I've learned actually fit together."

Students in FOS learn how to actually do things rather than simply memorizing isolated factual material. Students seek out information as they need it, from sources on the Internet, as well as on the videos, laser discs, and CD-ROMs provided in the classroom. As one student notes, "For once I seem to be actually teaching myself something instead of being fed information." Another student comments: "We actually can see and touch everything we do, we don't have to memorize charts and recite theorems and laws, we actually see what they are." And yet another student: "Actually figuring things out for yourself really helps you learn."

Students learn to convey their understanding of the material under investigation through presentations made to their peers, as well as to members of the community at large. Students are allowed to express this understanding in more than just the traditional paper-report format. Students are encouraged to incorporate movies, sound, and pictures into their presentations. Many students choose to create HyperCard stacks which contain original movies or slideshows with songs of favorite musicians playing in the background. Multimedia tools allow students who have trouble with, or are bored by, basic written reports to explore different ways to express their level of understanding. This form of presentation allows students to make the knowledge their own, and to present it in a way that demonstrates their understanding and expertise.

"I used to find science quite boring," one FOS student admits. "Now, not only am I enjoying science more, I find I'm thinking about it a lot more. The computers have opened up a lot more educational opportunities for me. I find I'm learning science, not just facts I have to memorize for some quiz."

LOCAL ENVIRONMENTAL INTERVENTION

The goal of teaching science is to enable students to use the knowledge that they generate, from informed community debate, to being able to find and implement solutions to local problems. Foundations of Science fosters students' natural curiosity, and directs that towards scientific inquiry. Through dealing with real-world environmental problems such as local water quality, students learn to become functioning members of the scientific community, as well as socially responsible citizens. The most extensive project that the FOS students have worked on is monitoring the water quality of Traver Creek, a tributary of the Huron River which is within walking distance of the school. The first tests and assessments were performed in the very first year of FOS, and students have continued to monitor the stream water quality in the Fall and Spring of every year.

The Traver Creek project, unlike the ready-made experiments designed to accompany a specific textbook chapter, allows students to conduct original research while investigating a problem which is relevant to their lives, and to the life of their community. Students become deeply engaged in their project when they realize that it has real-world importance. As one student commented: "Our work did more than just be graded--it made a difference."

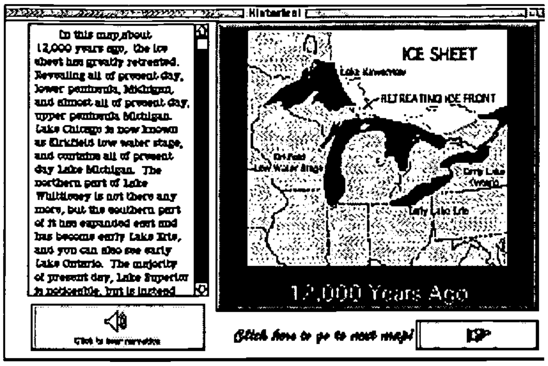


Figure 4: A screen shot of one card of a HyperCard stack created by a group of FOS students. This card is one of a series of ten that describe how the movement of glaciers created the geological formations we see in Ann Arbor today; the section on glaciers is just one of four sections which detail the various geological aspects of a park in Ann Arbor. This HyperCard stack incorporates sound, music, text, graphics, Quick-Time movies, and a 3-D virtual walk-through of the park.

At the completion of the first year of water quality tests, students presented their findings to the Huron River Watershed Council for inclusion in their report to the Michigan Department of Natural Resources. This presentation has been broadcast repeatedly on Ann Arbor's local Community Television Network (CTN). Students also published their written reports on the Internet. These can be viewed at:

http://chs-web.neb.net/classes/foundations/Found_work.html

After hearing of the water quality testing which FOS students were involved in, the Ann Arbor Transportation Authority (AATA) requested the help of FOS students in assessing the water quality of a drainage pond outside of their headquarters. The AATA was interested in turning the land around the pond into a recreation area for its employees, and was concerned that the pond had an unpleasant odor. Students performed water quality tests on May 31, 1995 and then submitted a proposal to the AATA on their findings and their recommendations for improving the quality of water in the pond. Based on the recommendations of the FOS students, a variety of plants were selected and planted in the pond on June 30. Students returned to the pond this fall to perform the tests again, and are currently assessing what effects their changes have had on the pond water quality.

WHAT WE HAVE LEARNED

In order for science education to progress beyond the methodology of the nineteenth century, we must integrate technology into the classroom. It is only through the use of technology that education will progress into the needs of the twenty-first century workplace. Technology must be combined with a new curriculum which allows students to see the relationships between the various educational disciplines, so that they themselves will be able to integrate their knowledge and be able to think and act as responsible citizens. Students must come to understand the basics of science and scientific method enough to be flexible in the way they approach new problems, so that in the future they can apply their knowledge to situations they may not have faced in the classroom.

Technology allows students to seek out answers themselves, instead of running to the teacher each time they don't understand something, or worse--passively sitting by as the teacher tells them everything they need to know. Students learn to think for themselves and discover answers on their own, with the aid of technology such as CD-ROMs, laser discs, and the many resources available on the Internet. Students also learn to support each other, facilitated by the technology, so that together they form a knowledge building, and knowledge using community of their own within the classroom.

Students in the Foundations of Science program are no longer sitting with their hands quietly folded listening to a teacher drone on and on; rather, they are active in the classroom, in their homes, in the field, studying important issues such as local water quality, and developing scientifically-rich understandings of biology, chemistry, and earth science. The FOS teachers, the faculty and students from the University of Michigan, the Ann Arbor Public Schools administration, and the FOS students and their parents are constantly working together to rethink their goals and tasks. Through Foundations of Science and ScienceWare we have created and are sustaining an educational innovation that is serving our students well.

Last year, the students in Foundations of Science and the students in a traditional biology course were administered the same test. Although they had covered the same material, the students in the Biology class were given lectures, while students in FOS worked on projects. The FOS students demonstrated their deeper knowledge of the material by performing equally well on the multiple choice questions, and creating essays which were far more sophisticated with regard to interpreting data and reaching conclusions than those of students in the regular Biology class. As Madeline Drake comments: "Essentially what happened was the kids in FOS were able to intelligently discuss and analyze the sample data given to them on the test. It illustrated a greater depth of understanding because of the amount of time spent on what the various pieces of data mean. You can never spend a long time on anything in a content driven Biology class because you have too much you have to cover; it's very superficial."

Not only does the Foundations of Science format allow for a deeper understanding of science content, but it also provides a environment in which all students can learn. "Hands-on activities teach everyone the same things," says an FOS student, "whereas memorizing facts from a book doesn't work for about half the people in this class."

Throughout all the hands-on activities in the FOS classroom, students attain an understanding of science and scientific methods which would be impossible in a traditional classroom setting. Students in Foundations of Science gain a new appreciation for science which they might not have had without moving beyond the dry lectures and textbooks chapters into the realm of hands-on scientific inquiry. "There's a new level of cooperation," comments Madeline Huebel-Drake, "students who apparently didn't like what they were doing, didn't like science, are now very interested in it."

In Foundations of Science, skills such as creative thinking and decision-making are developed, and students learn to work together to determine the problems and possible solutions in the questions under investigation. Students learn the importance of being responsible citizens as they examine the effects that irresponsible behavior have had on their local environment. Through the study of the water quality at Traver Creek and the AATA pond, students have become involved with such community organizations as the Huron River Watershed Council, the Michigan Department of Natural Resources, and the Ann Arbor Transportation Authority. But students in Foundations of Science are not only attaining invaluable experience in real-life science, they are also using the tools and the methods that will prepare them for the twenty-first century workplace.

SIDEBAR:

Scienceware: Technological Tools For Authentic Science Inquiry

Authentic science inquiry is an essential component of the Foundations of Science (FOS) classroom. However, the complexity of the tools and procedures used by professional scientists would overwhelm most high school students. Technology has given us the ability to create software tools that support high school students as they conduct authentic research. We have provided FOS students with portable computers, and have designed a suite of educational software tools to support them in all aspects of their investigations, including project planning, data gathering and analysis, visualizing and modeling data sets, creating multimedia presentations, and publishing research findings on the Internet. This software--ScienceWare--provides FOS students with the scaffolding necessary to engage in complex tasks as their skills and understanding progress to higher and higher levels of expertise.

The ScienceWare suite currently includes: PlanIt Out, a collaborative project planning and organizational tool; NIMBLE, a data collection tool which allows water quality data to be collected directly from water to computer via Apple Newtons and various probes; RiverBank, a database for water quality monitoring; Viz-It, a data visualization tool; the Classifier, a tool for building classification trees; Model-It, a tool for creating models and simulations of dynamic systems; RiverMUD, a virtual community centered around scientific modeling; Media Genie, a tool to assist in incorporating sound, pictures, movies, and hypertext links into a HyperCard stack; and Web-It, a tool that translates ClarisWorks documents directly into HTML for publication on the World Wide Web. Model-It is perhaps the most unusual of all these tools, in that it allows high school students to create models of dynamic systems by themselves and without limitation. Dynamic modeling is an activity which high school students rarely have the chance to see, let alone participate in themselves. Model-It makes dynamic modeling accessible to students without the need for advanced mathematical training.

Through modeling, students learn to analyze complex systems, reason about causes and effects, and understand the scientific content under investigation. Using Model-It, students can take the ideas they already have about how relationships between different objects and factors work, and realize them as a complex dynamic system. Students are then able to run a simulation to see if the model they have constructed runs according to their original ideas. Constructing dynamic models can help students understand complex phenomena as interconnected systems and develop an understanding of how scientists use models to test and revise hypotheses. Model-It is a prime example of how ScienceWare brings the tools and methods of professional scientists into the realm of understanding of high school students.

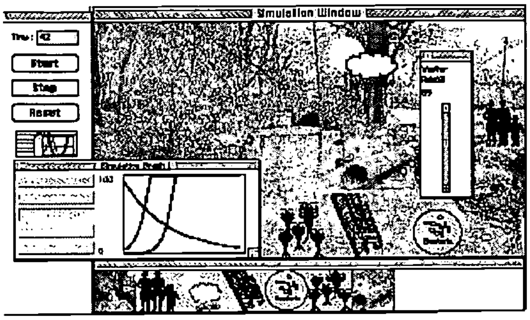


Figure 5. The Simulation Window of Model-It displays the system under investigation. In this example, the ecosystem of Traver Creek has been modeled. To build a model, students create objects, such as the stream itself, people living near the stream, organisms living in the stream, weather, and a drainpipe flowing into the stream. Students then define factors for each object (e.g., rainfall is a factor for weather, and toxins are a factor for the drainpipe). Students use the Relationship Maker (Figure 6) to define how the various factors of each object in the system affect one another. After all the objects and factors have been defined, students can run a simulation, and monitor the changes that occur over time using the simulation graph. Students can also manipulate the levels of each factor (e.g., rainfall, as shown here) by using the meters that are available for each factor.

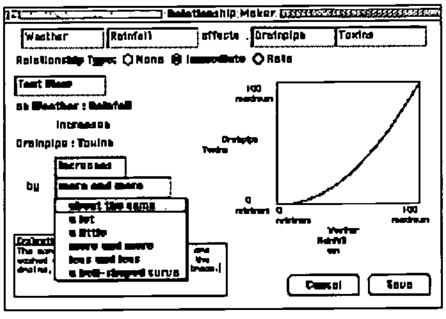


Figure 6. The Model-It Relationship Maker gives students two options for creating a relationship between factors. The text view, as seen here, enables students to define relationships in such simple terms as "increases about the same". This way, students do not have to have an advanced knowledge of mathematics in order to create the relationship they have in mind. A table view is also available, so that students can enter in the actual numbers they would expect to see.

ScienceWare enables students to use and understand scientific methods, but other technological resources are available to assist students in their research . The FOS classrooms are wired with Ethernet capability, and have access to the Internet via ISDN lines to the University of Michigan. Internet browsers such as Netscape guide students through the many resources on the World Wide Web, and e-mail readers such as Eudora allow students to communicate with each other and with other students and researchers around the world. FOS students have access to an extensive library of videos, laser discs, and CD-ROMs as additional resources, and to HyperCard and ClarisWorks for creating reports and presentations.

The use of technology in the classroom forwards our goal of allowing students to conduct authentic science inquiry on their own, but it also immerses students in the tools and methods of the twenty-first century workplace. As one student comments: "You hardly ever find a business without a computer in it somewhere. These integrations of sciences and computers help the students like me in this class to be more prepared for the future. It helps to give us a head start on the skills we will need in the real world." Students are also provided with such supportive technologies as video and sound digitizers, video microscopes, and still and motion pictures cameras. In the words of FOS teacher Mike Mouradian, these students "use the tools that are appropriate today rather that the tools that were appropriate fifty years ago."

How do students feel about all the technology? One student extols the value of the communications capabilities the computer provides: "The computer means I have access to millions of people and things and resources in general for help when I'm doing a project." Another student comments: "The computers were a big part in helping us learn in this class. The computers let us use high-tech technology to put our projects together. We learned a lot about computers and I think that learning about computers is learning science."

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