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SCIENCE WRITING NOTEBOOK

By

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ABSTRACT

SCIENCE WRITING NOTEBOOK

By

Janet M. Flegg

This thesis contains four articles written about scientific activity at Michigan State University. The author wished, through writing these articles, to learn more about interviewing, writing, and getting published. The articles cover aging and neuroendocrinology, a communication device for a child with cerebral palsy, a computer that helps teach blind people to write, and some research on science education. Care was taken to make each article as scientifically accurate and as readable as possible. An introduction explains how each article came to be written and what the author learned from writing it.

ACKNOWLEDGMENTS

Thank you to those scientists who spent so much time with me, telling me about their research, explaining it to me, and critiquing my writing for accuracy: Richard Steger, J.J. Jackson, Charles Anderson, and Edward Smith.

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INTRODUCTION

This is not a conventional master's thesis. Rather than a thorough treatise of a topic, it is a series of science articles, each of which stands alone. Through writing these four articles, I hoped to practice and learn more about science writing. (By science writing, I mean writing about science for a lay audience.) I learned a lot--most of it the hard way. Because I did so many things wrong, I was only able to get one of the four articles published.

I'll go through each article in turn, in the order they were written, explaining how I came to write the article and what I learned from it.

The Michigan State University science editor told me about some neuroendocrinology research going on at MSU and suggested I write about it. I arranged a meeting with one of the researchers, Dr. Steger, told him about my thesis and asked if I could do an article about his research. He liked the idea. Most scientists I've spoken with welcome the idea of free publicity, especially if they are allowed to critique the final product before anyone else sees it.

Dr. Steger was extremely helpful. He gave me many reprints to read, and we arranged to meet again after I had read the reprints. When I interviewed Dr. Steger, he took the time to explain his work to me. After I had written the article ("What Makes Us Age?"), he fixed a few minor inaccuracies and complimented me on it. His co-workers were pleased with it too, and they asked for copies.

However, I was unable to get it published. After receiving several form rejection letters, I wanted to know what was wrong with the article. I wrote to Ms. magazine and asked why they had rejected it. Ms. wrote back and said that although the research was interesting, the results were preliminary. They were only interested in sure, final results. It took me a while to believe that few magazines are interested in fascinating conjecture and interesting speculation, but my experience since writing, "What Makes Us Age?" has drived home the point.

I decided my next article had better be about something more concrete. I heard about some applied computer work the MSU Artificial Language Laboratory was doing and investigated that. J.J. Jackson told me all about the SAL Board, a device researchers at the lab had developed to help a child with cerebral palsy communicate. He also gave me lots of articles to read about the lab and its work.

J.J. was so happy with the article, which, incidentally, never got published, that he asked me to do another one. He and a colleague had programmed a computer to help teach blind people to sign their names and write. Again, he gave me articles to read. Then he showed me the program in action and let me try it out myself. He enjoyed being interviewed and gave me lots of information.

When I finished the article, I took it to him for review. The person who co-developed the program happened to be in town. J.J. asked him and another colleague to review the article too. We went to a conference room. I had to read the article aloud, while they stopped me at almost every sentence to debate the appropriateness of specific words or to decide if the right meaning had been conveyed. That meeting impressed upon me the power of the written word. Those men really cared about which words were used to describe them and their research. While I hope not to have to read all my articles out loud for review, I realize that I must write them with care and attention to detail, that I must consider the implications of what I write.

Although I sent both articles out to several publishers, I could not get them published. Perhaps more persistence would have paid off, but I suspect not. I've done a lot of thinking about these two articles, and I think I know where I went wrong: It's a matter of audience.

My audience for both articles (and my first article too) was the general public. That's a large audience, and few publications reach it. I tried newspapers and got a couple of nice rejection letters. Then I tried computer publications. Again, I got nice rejection letters, but was told the articles were not appropriate. What I neglected to realize was that most magazines and periodicals have a specific, limited audience in mind and have a specific, preferred writing style. And only a few accept free-lance submissions.

With all this in mind, I approached my fourth article. Through my job as editor for the Institute for Research on Teaching, I learned of some research on science education. The two researchers coordinating the research project were receiving requests for information from teachers, and had nothing to give them. My boss was making plans for an in-house publication series based on research on teaching and aimed at teachers. I had a specified audience and a possible publisher; I offered to do an article. The researchers, Charles "Andy" Anderson and Ed Smith, liked the idea because they needed just such an article to give to teachers and to use in the teacher education classes they taught. I checked with my boss to make sure the article would be published if I wrote it and was assured that it would be.

Andy and Ed gave me their proposal, progress reports, working papers, and a couple of published research articles to read and told me about their research project. I wrote the article, and it was published and used (although the proposed series for teachers never came to be).

From writing this thesis I have learned the importance of sending out query letters and making sure there is a market for an article before writing it. I've learned that if I want to get my articles published, I must write about concrete results and not about educated speculation. Knowing my audience and writing to it is absolutely essential. And I've learned that what I write can have definite effects on people. It can change opinions, inform people, and influence decisions. It must, therefore, be as accurate, timely, and readable as possible.

WHAT MAKES US AGE?

When Ponce de Leon searched for the fountain of youth in the early 1500s, he probably envisioned innocently bubbling waters that could banish wrinkles, gray hair, and stiff joints forever. He never found the magical fountain and people still have to deal with the effects of aging.

Recent research in neuroendocrinology is digging at the roots of aging by examining the internal, unseen changes that take place as our bodies age. Some experimental drugs that counteract these changes have given old rats youthful vigor and restored their reproductive capability. Researchers are gaining insight into the changes that take place with age and making guesses about ways to prevent them or at least hold them at bay.

Every body system ages and the aging of the neuroendocrine system seems to be responsible for many of aging's effects. The neuroendocrine system includes the brain, hypothalamus, nerves, and all ductless glands, such as the pituitary and thyroid. It regulates, among other things, growth and reproduction; it regulates when adolescence will begin and when reproductive capability will falter and stop.

Richard Steger thinks the hypothalamus is the key part of the system, and the most instrumental part where aging is concerned. Steger is one of a team of scientists at Michigan State University's Neuroendocrinology Lab studying aging of the reproductive system in female rats. Steger and his associates observe abnormalities and watch to see how the system reacts in an effort to understand how the normal system functions and changes with age.

They want to find out why changes in gonadotropal and steroid regulation take place with aging. These are the changes that result in such things as menopause, and there are a number of medical problems associated with menopause that scientists don't understand well enough to suggest treatment for.

Steger studies the changes caused by aging in the female rat's reproductive cycle. In spite of some differences, he believes analogies can be made to people. In both rats and people, the cycles become irregular with age and then cease altogether. Female rats' cycles become irregular around the age of 10 months, while women's cycles usually become irregular when they are in their late 30s or early 40s. Birth defects increase in offspring as the mother's cycles become irregular.

"Now that women are delaying having a family until later in life, this is becoming a more significant problem," Steger noted. More and more babies are being born to women whose cycles have become irregular.

Steger thinks there is a connection between cycle irregularity and birth defects, but not all scientists agree with him. Some people say birth defects occur because the ovaries are getting old, explained Steger. All the eggs a woman will produce are already formed before she is born, although they are not fully developed. Some people believe that stresses on the eggs--the effects of such things as radiation, disease, and injury--accumulate with age and cause abnormalities.

"That's quite a viable hypothesis," says Steger, "but I look at it another way." The undeveloped egg is fairly stable, but it becomes very sensitive just before ovulation, when it finishes its development. "There's a critical time between development of the egg, mating, and fertilization," says Steger. "If cycles are irregular, then the normal developmental sequence between the beginning of egg development and fertilization could be disrupted. It has been proven time and time again that this can be a cause of birth defects."

There are, of course, other factors involved. Every system in the body has effects on every other system. And individual parts of a system affect the entire system.

The female reproductive system is complex, but it can be simplified to the brain, hypothalamus, pituitary gland, ovaries, and uterus (see Figure 1). The brain sends signals to the hypothalamus, which is itself a part of the brain. Researchers aren't sure exactly how this is done, but neurotransmitting chemicals such as dopamine, norepinephrine, and serotonin seem to play a part.

These chemicals somehow stimulate the hypothalamus and cause it to produce and release LHRH, a hormone that promotes release of LH (leuteinizing hormone). LHRH acts on the pituitary gland, which reacts by secreting LH and FSH (follicle stimulating hormone). (LH plays a part in ovulation and FSH plays a part in egg development.) LH and FSH stimulate the ovary, causing it to produce estrogen and progesterone and to ovulate, or release an egg. Estrogen and progesterone stimulate the uterus to prepare its wall for implantation of the egg and the maintenance of pregnancy's early stages.

The ovary sends feedback messages to the hypothalamus. The estrogen it produces stimulates LHRH release by the hypothalamus. The pituitary responds to that by secreting more LH and FSH. This, in turn, increases secretion of estrogen and progesterone, which increases LHRH production at the hypothalamus, and so on until a threshhold is reached and an egg is released from the ovary. The surge of LHRH production stops then. Scientists do not yet know exactly what stops it, but some have conjectured that the

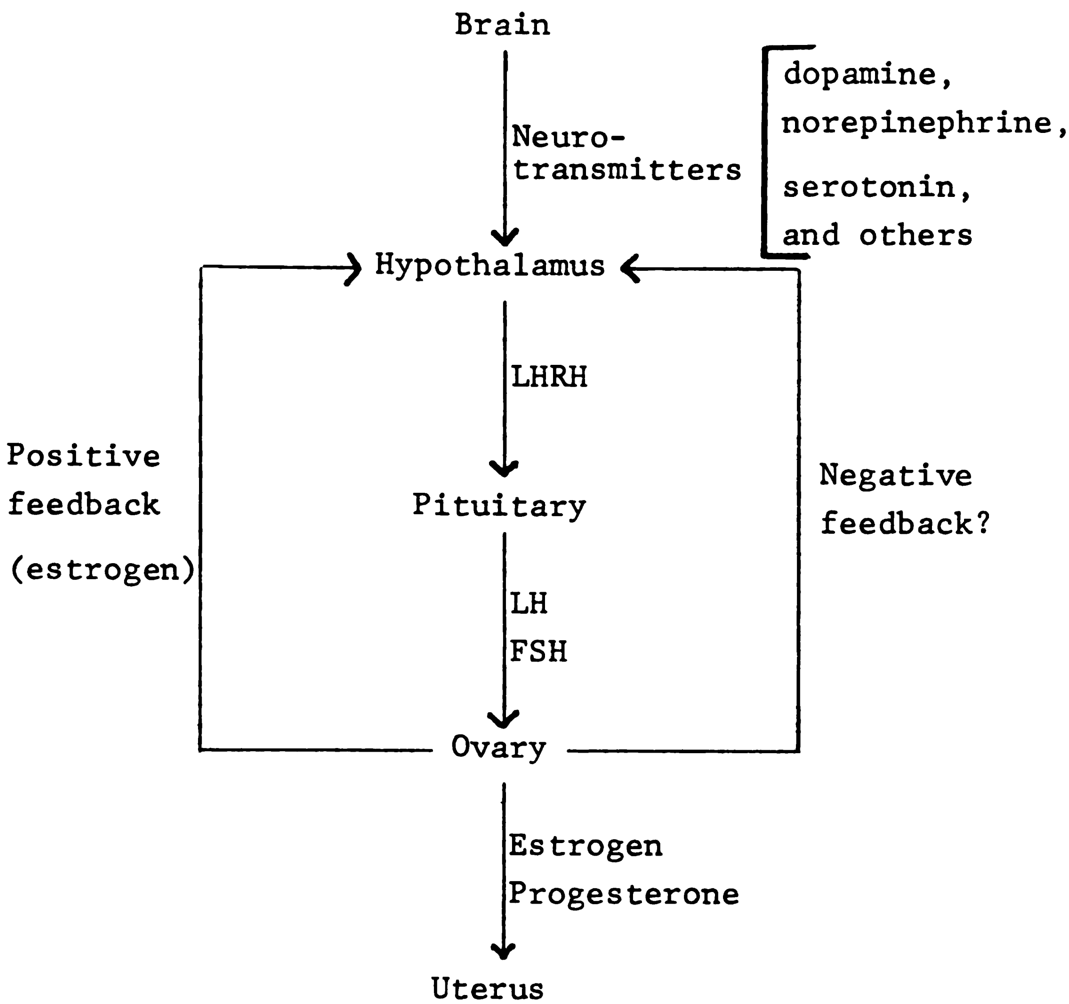

Figure 1. Female reproductive system.

ovary might send a negative feedback message to the hypothalamus. This cycle repeats itself many times during a women's life.

An abnormality in any part of the system can have major effects on the way the whole system works. For example, explained Steger, if the ovary is removed, it cannot provide feedback to the hypothalamus. There is nothing to tell the hypothalamus to stop secreting LHRH, so it does not stop. This is essentially what happens in menopausal women, said Steger. The ovary stops making estrogen and progesterone. As a result, the LHRH level goes way up. But it is not known yet whether the disfunction is in the ovary, hypothalamus, uterus, or any other part of the system--or a combination of parts.

Any number of things can go wrong as the system ages. The pituitary may not respond to LHRH, or the hypothalamus may not respond to feedback from the ovary. Said Steger, "If any part is abnormal, the system functions abnormally or stops functioning altogether."

And unusually high or low hormonal levels can result in all sorts of side effects. LHRH was recently found to stimulate mating behavior in rats. Progesterone and estrogen affect such things as mating behavior, maternal behavior, and body metabolism, to name just a few. Steger and his colleagues are currently studying the effects progesterone and estrogen may have on the level of neurotransmitting chemicals in the hypothalamus.

"Basically, what we think happens as the system ages," said Steger, "is that there are alterations in neurotransmitter levels. As women age, their LHRH, LH, and FSH levels change and this throws their whole system off balance. Estrogen and progesterone levels change and women experience the symptoms of menopause: hot flashes, possible bone loss, irritability, and more.

The same types of changes take place in males, although they are not as striking. LHRH production decreases, as does production of LH and FSH. In males, this results in decreased testerone production.

Changes in neurotransmitter levels in the hypothalamus with age affect far more than the reproductive system. The hypothalamus regulates metabolism, body temperature, thyroid activity, the heart, circulation, respiration, and more.

The hypothalamus is the focus of Steger's research on aging. Huang, Steger, Bruni, and Meites concluded in a 1978 article in Endocrinology that, "The major cause for cessation of regular estrous cycles in old rats lies in altered hypothalamo-pituitary function."

Naturally, there are many people who disagree. Donner Denckla, a visiting scientist at the National Institute of Alcohol Research, claims the pituitary secretes a death hormone which begins to work at puberty and eventually causes us to self destruct. He has rejuvenated old rats by removing their pituitary glands and giving them the pituitary hormones essential for life in their drinking water. Denckla admits, however, that it would be absurd to suggest removing a person's pituitary gland to get rid of the death hormone. He is looking for something that will block the effects of the hormone.

Steger is skeptical of Denckla's work. "His ideas have never been published in the scientific literature and subjected to peer review," said Steger. That is the ultimate test of a scientist's work. It must be made public and must withstand scientific scrutiny before the scientific community will accept its validity.

And even if the death hormone does exist, it could theoretically be under hypothalamic control. There are no easy answers. We don't even know all the questions yet.

Although the mechanisms of aging are still a mystery, researchers have far more of the clues now than they did a few years ago. John F. Marshall and Noberto Berrios have recently done some interesting experiments on motor ability in aging rats. They administered L-dopa, a drug that stimulates production of the neurotransmitter dopamine (thus increasing LHRH, FSH, and LH secretion) to aging rats and found it dramatically rejuvenated their motor ability.

L-dopa is presently used to treat Parkinson's disease in humans. For some women, a side effect of such treatment has been restoration of vaginal bleeding after menopause, said Steger. Whether this indicates a restoration of menstruation remains unknown.

Naloxone is another drug which causes an increase in LHRH, FSH, and LH secretion. Nalaxone blocks the action of opiate peptides, substances produced in the body that have essentially the same effects as morphine. Morphine and opiate peptides relieve pain, emotional suffering, and decrease secretion of LHRH, FSH, and LH. They also have effects on sleep patterns and pain perception, which change markedly with age. Since the level of opiate peptides increases with age, naloxone may have a somewhat rejuvenating effect on the body.

But L-dopa and naloxone can hardly be considered the main components of the long sought for liquid in the legendary fountain of youth. Discovery of a modern fountain of youth is a long way off, if ever. The mechanisms and possible functions of aging just aren't understood well enough yet.

THE SAL BOARD

Imagine how frustrating it would be to be unable to talk. Until recently, Sal Omadigan, a Lansing-area middle-school student with cerebral palsy, had to live with that frustration every day. Now he can use the "Semantically Accessible Language" (SAL) Board, developed for him at Michigan State University's Artificial Language Laboratory, to communicate through speech, alphanumeric display, and print.

The SAL Board is the first talking and printing communication device to perform language processing, says J.J. Jackson of the Artificial Language Lab, and it is the first such device to have intelligence incorporated into it. Yet it is compact enough to fit on a wheelchair as a lap tray, and it can be powered by the same battery that powers a motorized wheelchair.

The SAL Board is a computer-based communication system consisting of a microprocesser, a printer for orthographic output, a light-emitting diode (LED) display, a Votrax voice synthesizer board, an input switch matrix, and a power supply.

Before he got his SAL Board, Omadigan answered yes and no questions by touching his nose for yes and bowing his head for no. He could also communicate a wide array of ideas with his Blissymbol board, says Jackson. The board displays symbols which Omadigan pointed to in order to "talk" to people. He is capable of using the standard alphabet, but Blissymbol communication is quicker and less tedious for him. (Blissymbols are a sort of picture language used by more than 10,000 people world-wide for communication.)

Omadigan was limited by the number of symbols on his board. Also, reports Yvonne Danjuma of the Artificial Language Lab, he "was dependent on another person being available to 'read' his Blissymbol communication. Moreover, each of his responses were subject to this second person's interpretation."

Sue Ravlin, Omadigan's speech pathologist, spearheaded the development of the SAL Board that enables Omadigan to produce speech. Now he can communicate better with his school teacher and everyone around him.

Omadigan inputs what he wants to say by touching the appropriate symbol on the SAL Board and maintaining contact for a couple of seconds. The SAL Board uses Blissymbols, but provides a greater selection than Omadigan's earlier board.

An "opposite" symbol allows Omadigan to select the opposite of each symbol on the board. A "make action with" symbol allows him to make verbs out of nouns.

Thus, explained Jackson, he can touch "hot" and "opposite" to indicate cold, and "leg" and "make action with" to indicate "walk."

Words and phrases can be stored in the memory of the SAL Board's microprocesser as sequences of "orthophones," says Danjuma. This is "a specialized notion developed at MSU that, in combination with the rules of phonology, allows the computer to generate both orthographic and phonetic representations of the selected symbols."

Once he has inputted what he wants to say, Omadigan has his choice of three output devices: a printer for written material and an LED display, both of which use the standard alphabet; and a Votrax voice synthesizer.

The Votrax voice synthesizer is a <u>true</u> voice synthesizer, stresses Jackson. It is a phoneme-based synthesizer. It uses no prerecorded human voice. Thus it produces an electronic analog of human speech.

The SAL Board doesn't limit Omadigan to stilted sentences like, "I want go school," and " I not want go." That's where its computer's intelligence and semantic language accessibility come in.

The computer automatically figures out the correct verb conjugation (Omadigan indicates whether he wants future, present, or past tense), the spelling and pronunciation of noun plurals, case of pronouns, verb complements, and articles. It therefore outputs sentences like, "I want to go to school," and "I do not want to go."

Although the system was initially designed specifically for Omadigan, new versions are being made for students in other Michigan school districts. Each board must be custom made to accomodate the motor capabilities of each individual student. The board is constantly being improved; it is still in the early stages of development.

The development of the SAL Board has been funded by MSU, the Vandervoort Foundation, Northville (Michigan) Public Schools, and Wayne, Ingham, and Alpena-Montmorency-Alcona Intermediate School Districts.

For further information, contact the Artificial Language Laboratory, Computer Science Department, Michigan State University, East Lansing, Michigan 48824.

TEACHING THE BLIND TO WRITE

Please sign here. That's one of the most common phrases heard in public life. We sign our names on job applications, receipts, checks, and form after form. Signing our names is second nature to most of us, but not to everyone. Many blind people cannot, without special training, sign their names fluently and legibly. J.J. Jackson of the Michigan State University Artificial Language Laboratory has been working on a computer-based training program that gives them that special training.

Handwriting is a learned motor skill based mainly on visual feedback, says Jackson. Yet sighted people can still write legibly and fluently with their eyes closed. They can rely on "muscle memory" because they know what it feels like to write. It is that feeling, that "muscle memory," that Jackson wants to impart to blind people.

He is doing it through a system of instruction that Iain Macleod of the Australian National University designed while he was on sabbatical at Michigan State University. Macleod and Jackson developed the system together, and Jackson, himself blind, was also Macleod's first subject-participant. Jackson learned to sign his name legibly and fluently using the system, and to form and connect letters without having to rely on a physical guide with which to position his hand. Today Jackson supervises the system, now in the evaluation stage of its development.

Essentially, the system provides feedback to a student through tactile and auditory cues. These cues replace the visual feedback sighted people use when they learn to write.

The student traces patterns, which have been programmed into the system, by writing with an electronic, spark-emitting pen on a sensitized plastic tablet that allows the computer to monitor the pen's movements. The system can then give feedback on how close the student's pen movements are to the model paths of the pattern. The system will accept some variation from the model paths, but, says Macleod, "It gently and consistently promotes conformity to the model such that a trainee's initially distorted letters become better and better formed with practice."

Even with visual feedback, it takes a lot of practice for someone to learn handwriting skills, and a student must start with simple exercises before really learning to write. This is just as true for visually impaired people as it is for sighted people. One of the first exercises students using the system are asked to do is to simply trace back and forth on a horizontal line. But that's really not as simple as it sounds, especially for a student who has never written without using a hand guide. Other beginning exercises include a series of loops, a diamond, and a square.

Once the student has mastered simple geometric shapes, s/he can move on to more complex ones, and then on to letters. Eventually, the student's handwritten name is put into the system as a pattern the student can learn to trace.

The components of the system include a digitizer graf pen (essentially an electronic pen), a vibratory wristband, a quadrophonic tonal system, and a Votrax voice synthesizer.

The digitizer graf pen emits a spark at its tip. The student writes on a tablet with long microphones along two sides at a perpendicular angle to each other. The microphones pick up the sound of the spark. By measuring the delay between the time the spark is emitted and the time the microphone picks up the sound, the system can tell what kind of line the student is drawing. The system can then give the student feedback as to whether s/he is writing "on track."

The student is given directions by a synthesized voice, and feedback through vibration and sound.

A Votrax voice synthesizer gives the student commands. For example, "pen down" indicates that the system is ready, and the student should begin writing. Other commands include "go right," "sweep up," "loop left," and "down right." The synthesized voice also labels the shapes and letters the student is to trace.

As the student traces the shapes and letters, s/he is given additional direction and feedback through vibration. The student wears a vibratory wristband on the hand s/he writes with. It has eight small vibrators placed equal distances apart from each other on the inside of the band. If the vibrator at the top of the wrist is activated, the student knows s/he should move the pen straight up on the tablet. If the vibrator on the lower left corner (down left) is activated, s/he knows the pattern requires a line to the left and down 45° from the horizontal. If the student's pen moves off-track, the vibrators will cue the student how to get it back on-track. The primary purpose of the vibrators is to guide the student, to let him/her know in which direction the path to be followed is going.

The tonal system indicates the position of the student's pen relative to the line of the pattern through sound. A high-pitched tone indicates the pen is above the model path, and a low-pitched tone indicates the pen is below the path. An even blend of the two tones indicates the student's pen is neither too high nor too low relative to the line being traced.

There are two speakers, one to the student's right and one to his/her left. If the tone comes mainly from the left speaker, the student knows his/her pen is to the left of the line it is supposed to be following. If the tone comes mainly from the right speaker, the student's pen is to the right of the model path. If the tone is of the same volume from both speakers, the student's pen is neither to the right nor to the left of the line being traced. The primary purpose of the tonal system is to inform the student how far his/her pen movements are from the model path while s/he is doing the exercise.

When the student completes the drill, the system prints out his/her average distance off-track and the time of execution. The synthesized voice says this out loud so the student can have immediate feedback.

The commands and feedback can be changed to suit the student's level. A beginning student may only use the commands and the vibratory wristband at first to get used to receiving input from the vibrators. When the student is used to reacting to the vibrations, the tonal system can be added. As the student progresses, the voice synthesizer can be set to stop giving detailed descriptions and instead simply label the required letters.

The system can vary its tolerance for error too. The student begins by making letters about two inches high, and later learns to make smaller letters. The system may be sensitive to 1/4-inch errors, 1/8-inch errors, or whatever is appropriate for the student's level.

In conjunction with their computer training, students practice writing with paper and pencil. A sighted person evaluates their progress. It is important that they get a continuity of motion and do not become dependent on the system for constant feedback, says Jackson.

It takes a while for a blind person to pick up what it feels like to sign his/her name legibly using the system. A student usually works on the system for about an hour a day for three or four days a week, says Jackson. It takes about six weeks of instruction for the student to begin to write his/her signature fluently, and 10-12 weeks for him/her to really feel comfortable with it. The student may need periodic refresher courses if s/he does not use the new skill very often.

Using the system, students can learn to draw geometric shapes, sign their names, and form and connect the letters of the alphabet free-handed. All these are useful skills.

Knowledge of letter shapes enables blind people to jot down quick notes. For example, when a blind person is on the phone or needs to write down a number, s/he may not have immediate access to a braille typewriter or a tape recorder. Familiarity with letter and number shapes makes quick note-writing possible. And it is good for a blind person's self-image, and the image s/he conveys to others, to be able to sign his/her name quickly, legibly, and without a hand guide in public situations. The computer-based system has a number of advantages over current methods of teaching handwriting to the blind, says MacLeod: "(1) It leads the trainee along the strokes, forming letters in a predefined order and direction without confusion from preceeding or succeeding strokes, (2) continuous feedback is provided while the exercise is being performed, (3) instruction can be largely self-managed, and (4) with its emphasis on free-hand letter formation and connection, the system offers potential for improved speed and fluency of handwriting compared with methods based on the use of guides and constraints."

And the system can be used for more than handwriting instruction. Lower functioning handicappers, who have loss of vision in addition to mental retardation, might be taught directions with, says Jackson. The vibrators and tones might teach them, for example, what it means to go right or left, and help in their eventual orientation and mobility.

So far, four people have received handwriting instruction on the system in addition to Jackson. Jackson is anxious to extend the training to more people. Currently the system is on a PDP 11/34 minicomputer, which is about the size of a pop machine. Macleod and Jackson eventually plan to replicate the system on a microcomputer that will be portable enough to be stationed in a classroom where many people can benefit from it.

For further information, contact Artificial Language Laboratory, Computer Science Department, Michigan State University, East Lansing, Michigan 48824.

PROBLEMS AND POSSIBILITIES OF SCIENCE EDUCATION

Students Learn Little Science

Science is getting lost in the back-to-basics movement. Amidst a growing concern that children learn the basics of education--reading, writing, and arithmetic--science has become a low-priority subject to be taught only when there is extra time. And it seems there is little time left in which to teach science, especially in elementary schools. According to Stake and Easley (Note 1), less than half of the students in the United States receive even one full year of quality science instruction during their first six years of school. Of all the major curriculum areas, science receives the least attention. Thus students have little chance to develop an interest in or a basic understanding of science during their early school years.

Yet it would seem that today's technology, the widespread use of computers, for instance, would make a general knowledge of science highly desirable if not essential. Nuclear power, pollution, genetic engineering, chemical food additives, depletion of the ozone layer, and solar energy are just a few of the topics reported in newspapers, in magazines, and on television that cannot be fully understood without a strong science education. Political leaders must make decisions about these topics without fully understanding their implications. People must vote on issues related to these topics without really knowing what their vote could mean. Children ask their parents questions about science, about the world they live in, and cannot get satisfying and accurate answers.

People are naturally curious about the "whys" and "hows" of the world around them, and it is certainly not for lack of interest that they do not study science. Nonscientists and nonengineers often enjoy media presentations that focus on science and technology (National Science Foundation and Department of Education, Note 2). The popularity of public television science programs like Nova and of documentaries like those reporting the work of Jacques Cousteau attests to high public interest. As evidenced by the proliferation of science magazines like Omni and Science 81, it is obvious that people do want to read about science. Science museums draw large crowds, science-fiction movies play to large audiences, and large numbers of people would rather read science fiction than anything else, yet there is a growing, nation-wide scientific illiteracy (NSF & Dept. of Ed., Note 2).

Though interested in science, some people find it alienating. With its intricate mathematical formulas and its complex terminology, science sometimes seems beyond the scope of the average person. So although some people would like to learn about science, alienation prevents them.

Why do people feel alienated by science? Why don't people understand science? One reason might be inadequate science education, particularly for those students who do not choose science-related careers.

By the time they enter secondary school, students have already begun to specialize by tracking themselves into either college preparatory or general education courses. Those in the college preparatory track will usually be expected to take more science courses than those in the general education track. Students who plan to pursue careers in science or science-related fields will take science courses, but most other students will avoid them because they are "too hard." Students not planning careers in science and engineering seldom study science beyond tenth-grade biology. In part, this is because many colleges have lowered their entrance requirements and few schools require advanced science classes for graduation. The result is that by the age of 16, many young people have cut themselves off from the opportunity of taking college-level science classes and the possibility of entering most science-related careers (NSF & Dept. of Ed., Note 2). More seriously though, they have denied themselves a working knowledge of science.

It's not easy to get that working knowledge. In both junior and senior high schools, the content of science courses "gives extensive and almost exclusive attention to preparation for future coursework leading to professional careers in science" (NSF & Dept. of Ed., Note 2). The focus of science courses is often theoretical rather than practical, and, therefore, not meaningful to students who will not pursue science-related careers. Because in such courses science is not made applicable to a student's daily life, students may choose not to study science. The National Science Teachers Association notes,

> much of the secondary school science curriculum is mismatched to the interests and needs of the majority of students in our schools who will not pursue scientific or technological careers. (NSF & Dept. of Ed., Note 2)

Students opting for careers not directly related to science, then, are receiving almost no science education in elementary school and choosing to take as few science courses as possible in secondary school. The decreasing priority being given to science and mathematics in secondary schools (NSF & Dept. of Ed., Note 2) may make it easy for them to take few science courses or at least severely limit what courses they can choose from.

Students aren't the only ones who have trouble understanding science; their teachers find it difficult too. In elementary school, where children are first taught some basic scientific concepts, science is a challenging subject to teach. Many elementary-school teachers don't feel they have the science background to meet their challenge.

Elementary School Teachers Ill-Prepared to Teach Science

Teachers are themselves often dissatisfied with the science education they provide. They feel inadequately prepared to teach what they believe is an important subject. For those teachers who would rather not teach something than teach it badly, that dissatisfaction can lead to even less class time spent on science (Smith & Anderson, Note 3).

Teachers are as much a product of the educational system as are their students. They, like their students, received little science instruction in elementary school. By the time they were in secondary school, some of them had already decided that not only was science a hard subject, it was too hard for them. Therefore, they avoided science classes. When they entered college, they may not have had the required science and mathematics background to take regular science classes. Besides, the regular science classes were too detailed and theoretical for their needs. And even if they wanted to take more detailed science classes, their advisors may have advised against it. So they took science classes for teachers, classes that were often neither challenging nor interesting; in some respects, they were condescending. Certainly, those classes did not make science meaningful or relate it to everyday life.

Because few people have made a sincere effort to make science make sense to them, some teacher-education students don't find science meaningful. Perhaps no one has ever explained to them, in a clear and exciting way, the intricacies of photosynthesis. In a confusion of lenses, lights, and mirrors, perhaps the basic concepts of optics were never fully covered, and so they find optics makes no sense.

In science classes for non-science majors, the few labs provided are often rushed through with incomplete directions and faulty equipment. Students do the labs to get the correct data, the "right answer," and to finish all the steps rather than to illustrate a concept or prove a point. It is not surprising that these students approach science instruction in a similar manner when they become teachers. Because they themselves don't always find scientific concepts meaningful or logical, they cannot always teach meaningful science lessons.

Student Preconceptions Influence Learning

Children bring to school their own preconceptions, their own explanations of how the world works, and some of those explanations are wrong. It's hard to shake those misconceptions, yet that is exactly what meaningful science instruction does. In most science instruction, the teacher presents facts and theories and assumes his or her students will accept them. What is not taken into account is the fact that children already have theories that they believe. If there is room for more than one interpretation of the data, children will keep their own interpretation. If science instruction contradicts their theories, they may disregard the instruction or not understand it. Children tend to stick with their own theories, and their misconceptions may prevent them from understanding what they are taught. Their theories, if not dealt with, may render science lessons meaningless.

Light is Not Just a Condition

Smith and Anderson (Note 4) report, for example, a common misconception children have about light that can interfere with their learning. Light travels in a straight line through space and has predictable properties. People see objects because light travels from a light source (e.g., the sun), hits an object, bounces off it, and travels to their eyes (see Figure 1).

But most children think of light as a condition rather than as something that can travel. They think light shines on things and brightens them so they can be seen

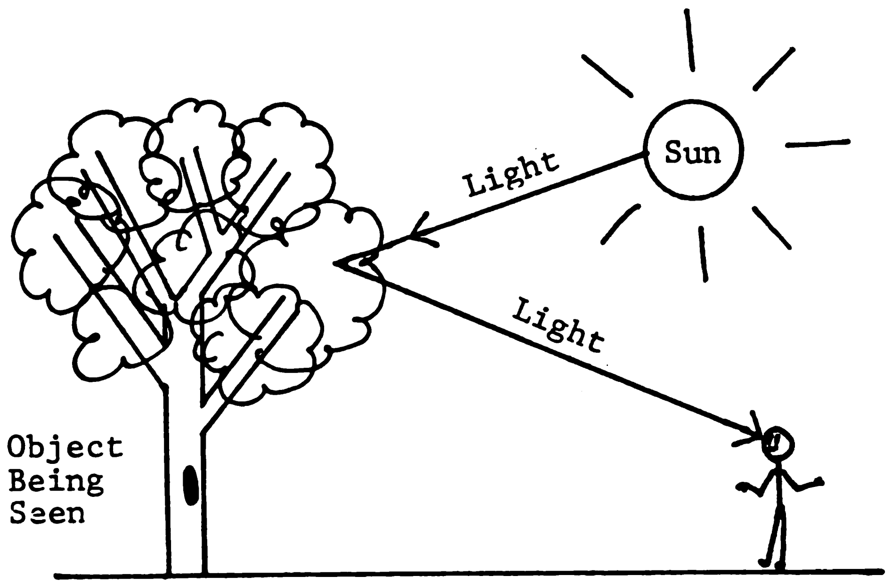

Figure 1. How light enables people to see things: Light reflects off objects and travels to people's eyes.

(Smith & Anderson, Note 4). They think of seeing as the direct perception of an object rather than as the perception of light bouncing off that object (see Figure 2). Therefore, when children are taught about optics (the study of light and of how such things as lenses, prisms, and mirrors work) and asked to predict what light will do, they get confused. Because they've already decided that light is a condition, optics makes no sense to them. As David Hawkins (Note 5) says, they don't have anything in their mental files on it. It is nonsense to them. Effective science instruction must begin with what children already know, or they will have no context in which to understand that instruction.

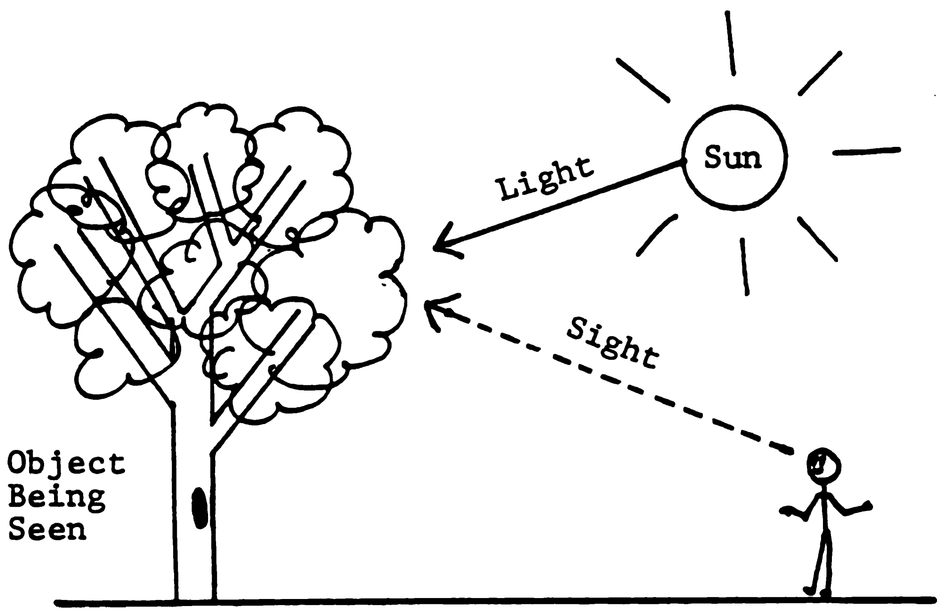

Figure 2. Common misconception about light and sight: Light brightens objects so people can see them.

Air is Not Just Empty Space

Another misconception that many students cling to, according to Hawkins (Note 5) is the concept that air is just empty space. Hawkins reported that this misconception caused considerable confusion for some students during a lesson on how barometers and siphons work. (Barometers and siphons work on the principal that air can exert pressure on a liquid in a tube and push that liquid through the tube. A barometer is used to predict the weather by measuring air pressure. Siphons are used to move a liquid from one place to another; siphons are often used to empty the water out of above-ground pools, for instance.) Because the children didn't believe in air as a tangible substance, they could not possibly understand the explanation that air can exert pressure on a liquid and thus make that liquid move through a tube. Because they didn't believe in the arrows shown in Figure 3, they couldn't believe the explanation. No matter how many times a teacher repeats that explanation, the students will not understand it because it doesn't make sense to them. The teacher feels frustrated because (s)he cannot successfully teach the lesson.

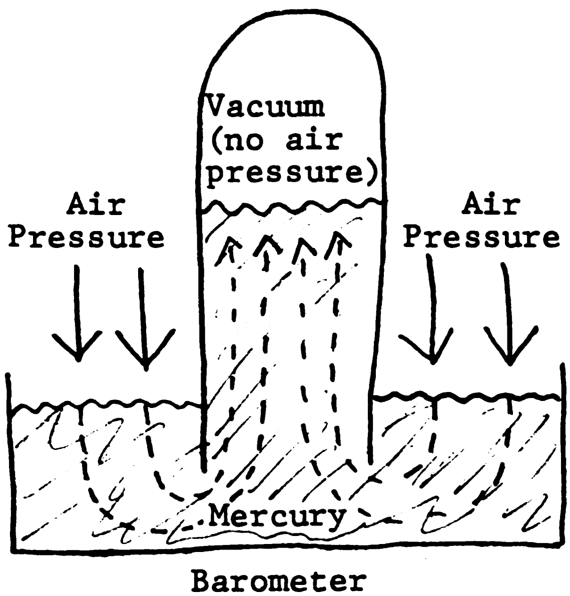

Figure 3. How air pressure makes a barometer work.

The children end up thinking themselves dumb because they cannot understand barometers and siphons, although they are really quite capable of understanding them. Effective instruction would start with the students' misconceptions; it would begin by proving to the students that air is a tangible substance that does exert pressure.

Use of Textbooks and Packaged Curriculum Materials

In an effort to help teachers deal with the complexities of science instruction, including student preconceptions, science educators have written science textbooks and packaged curricula. These materials attempt to provide teachers with everything they need to teach science effectively, including background information about topics the teacher might not have previously studied.

In grades four through six, 90% of the teachers depend on prepared science program materials (Weiss, Note 6). In some school districts, specific packaged curriculum materials are mandated. These materials provide carefully laid out science curricula and lesson plans. The materials give instructions for doing experiments and sometimes include the necessary equipment and supplies. Logically sequenced and complete curricula in themselves, packaged materials are an extremely useful tool. Chief among the reasons for which they are helpful, even essential, is time.

If there is little time to teach science, there is even less time to plan science lessons. Yet science activities, with their eyedroppers and mirrors, their bean plants and petri dishes, require more careful planning than most other lessons. Teachers don't have time to do the kind of planning they know is needed, so they rely on packaged curriculum materials to do much of that planning for them.

The activity-based programs so widely advocated by science educators keep students busy. To keep track of those busy students and keep them on-task, the teacher must be even busier. (S)he must see that enough materials are available, distribute them, tell students what to do, answer questions, monitor use of the materials, make sure that students complete assignments, and give directions for and monitor clean-up. Under such circumstances, reliance on packaged materials becomes a necessity. Any examination of elementary-school science education must therefore begin with an examination of packaged curriculum materials and how they are used.

How Are Program Materials Used?

Program materials bring structure and order to a complex subject, and teachers and/or administrators, sometimes with the help of parents, may choose from a number of good programs the one they feel is most appropriate. A popular program is the Science Curriculum Improvement Study (SCIS), an activity-based program including a kit with materials for a sequence of "hands-on" activities, a teachers' guide, and student manuals in which hypotheses, observations, and conclusions are recorded. With SCIS as one of their objects of study, two researchers working jointly with the Institute for Research on Teaching and the Science and Mathematics Teaching Center at Michigan State University, Edward Smith and Charles Anderson, have spent a great deal of time observing science instruction in elementary schools. Their reports of competent teachers using SCIS detail how program materials are actually used in classrooms.

One Classroom as an Example

Sendelbach and Smith (Note 7) observed a sixth-grade classroom in which 32 students were taught a five-week SCIS unit on the oxygen-carbon dioxide cycle (for a complete report of this case study, see Smith & Anderson, Note 3; Sendelbach & Smith, Note 7). The unit was designed to teach students about the exchange of gases between plants and animals (see Figure 4). Plants take in carbon dioxide and give off oxygen in the light. In the dark, they take in oxygen and give off carbon dioxide. Animals always take in oxygen and give off carbon dioxide.

The children did a series of experiments designed to illustrate this concept.

The first experiment was preparation for the second; when the children blew through a tube that had been placed in a container of bromthymol blue (BTB) and water, bubbling

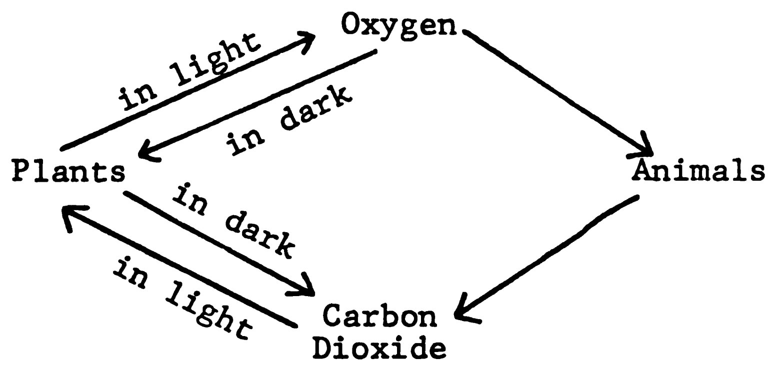

Figure 4. Gas exchange in plants and animals (the oxygen-carbon dioxide cycle). (This diagram was printed in the teacher's guide.)

their breath through the liquid, they saw that the liquid changed color. The teacher explained that BTB changes color when it reacts with carbon dioxide. (BTB is a chemical indicator. A chemical indicator is a chemical that changes color when it reacts with a specific substance; it indicates the presence of that substance by changing color. BTB indicates the presence of carbon dioxide when it changes color.)

To test that idea, the teacher had her students do an experiment designed by SCIS to show that it was indeed carbon dioxide that caused the color change and not some other gas, like oxygen.

Using the experimental set-up shown in Figure 5, the teacher put BTB in the cup. (Because she found the directions in the teacher's guide unclear, she was not aware that the soda water should also have had BTB added

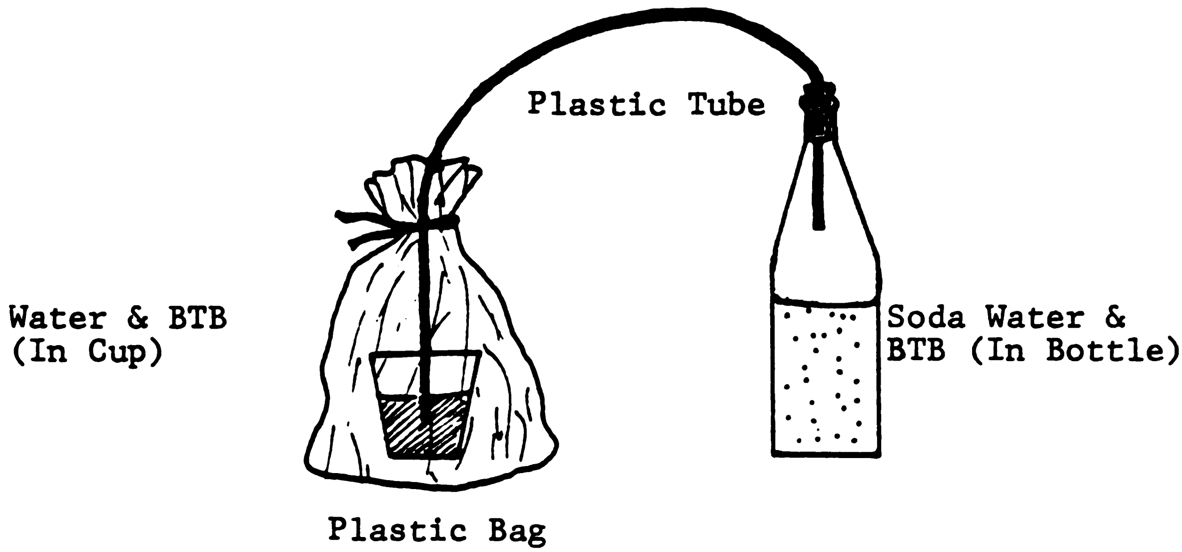

Figure 5. Set-up for soda-water experiment.

to it.)

The students observed that the BTB and water solution in the cup changed color. This was because carbon dioxide (the bubbles in the soda water) escaped from the soda water, passed through the tube, and bubbled up through the liquid in the cup. It had to be carbon dioxide that caused the color change because no other gas could enter the system, but not all of the students were convinced. Some of them still held the misconception that oxygen is needed to change BTB back to blue after it has reacted with carbon dioxide. But to actually change BTB back to blue, the carbon dioxide must be removed (see Figure 6).

The final experiment done by the children illustrated the effects of light on the gases plants and animals use and produce. In separate vials containing water and BTB,

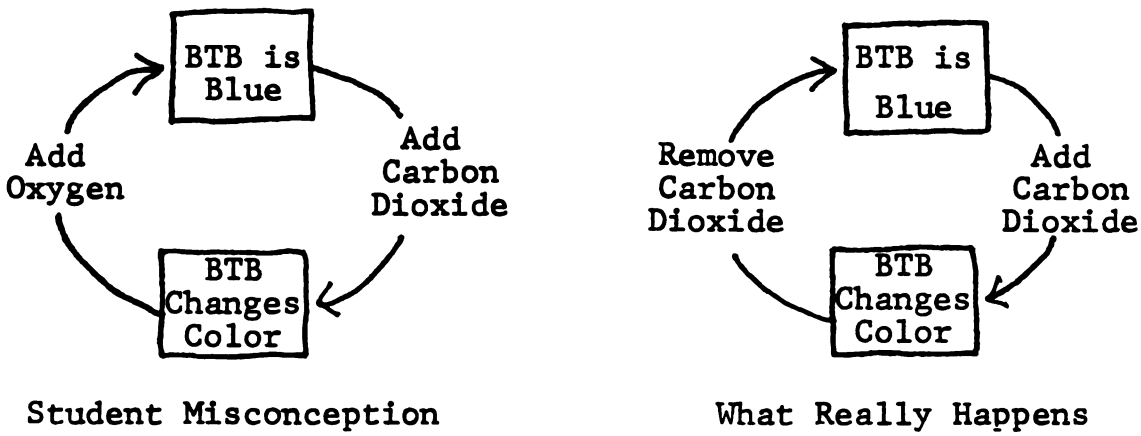

Figure 6. Student misconception versus reality of BTB color changes.

the children put snails and Anacharis (a small green plant that grows in water). They put some of the vials in the light and some in the dark (see Figure 7).

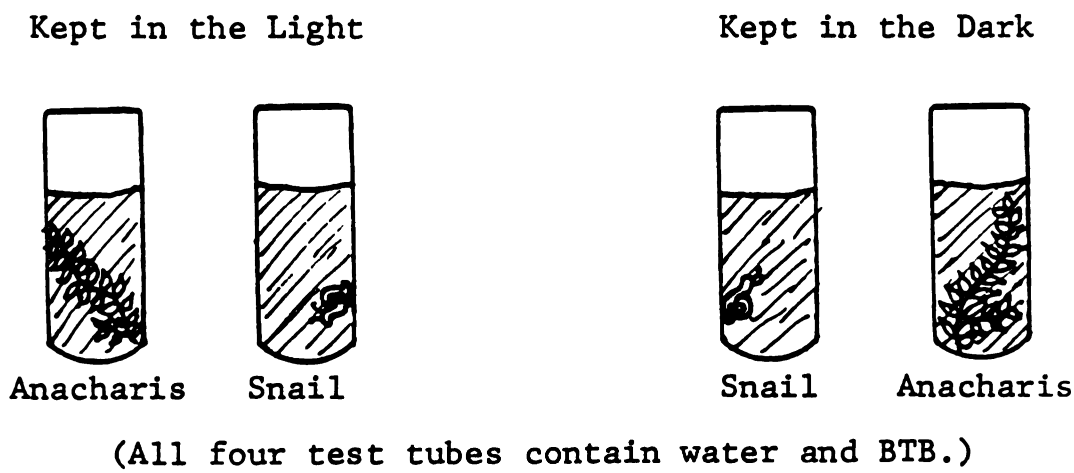

Figure 7. Experiment showing effects of light on gas production.

BTB changed color in the test tubes with snails in them and in the test tube of Anacharis kept in the dark. It stayed blue in the test tube of Anacharis kept in the light.

From this experiment, the students saw that animals give off carbon dioxide in light or dark and that green plants give off oxygen in light and carbon dioxide in the dark. (The fact that plants are always respiring and thus producing some carbon dioxide at all times, even in the light, was not covered in this unit.)

Did the Students Understand the Material?

Multiple choice tests given to the students after the unit showed that most of them didn't understand the material. Report Smith and Anderson (Note 3):

> Four students gave evidence of believing that animals always give off oxygen, seven students gave evidence of believing that plants always give off oxygen, three of those students gave evidence of believing both propositions, four students gave evidence of believing that oxygen changes the color of bromthymol blue, and two students gave evidence of believing all three propositions. . . .Only three students gave evidence of holding the correct conception of gas exchange in plants. Only three students gave evidence of holding the correct conception of the effects of oxygen and carbon dioxide on bromthymol blue. No student held correct conceptions of both.

A good teacher using a good program was not able to impart to her students an understanding of the oxygen-carbon dioxide cycle. What went wrong?

First, because of problems with the teacher's planning procedure and unclear presentations in the teacher's guide, report Smith and Anderson (Note 3), she didn't understand the logic behind two of the activities.

She didn't realize that the soda-water experiment was intended not only to show that the BTB and water solution changed color when carbon dioxide was bubbled through it, but to show that the soda water and BTB solution changed color when carbon dioxide escaped from it. The key point was that the soda water and BTB solution changed color because carbon dioxide left it, not because oxygen entered it. Because the teacher missed this point, she did not put BTB in the soda water; the experiment was incomplete. On one occasion she stated that oxygen turns yellow BTB back to blue, which is false.

Also, she didn't understand that green plants can only produce oxygen in the light. Therefore, in the experiment using Anacharis and snails, she expected no difference in color between vials in the dark and vials in the light. Poor printing of the diagram in Figure 4 contributed to this misunderstanding. The arrow showing that plants use oxygen in the dark was unclear, and the teacher thought it was a printing error.

The subtle modifications the teacher made in experimental procedure deemphasized or altered the program's meaning. Thus the students did not learn the material well.

Program Material Difficulties

According to Anderson and Smith (Note 8), there are three aspects of the SCIS program, which are also common to other programs, that may create teaching difficulties: complexity, fragility, and unclear learning outcomes.

Complexity. Elementary school classrooms in which science lessons are going on are complex settings in and of themselves. If 30 students are doing an experiment, there's a lot happening and a lot that the teacher must keep track of. According to the SCIS time line, at any one time during the school year, there may be several program activities in progress at once. The students might be growing bean plants for one experiment while finishing up graphs for another. And the classroom routines a teacher needs to set up to sustain SCIS activities are complicated. The soda-water experiment was indeed complex, so complex that the teacher had trouble understanding the directions.

Fragility. SCIS cannot withstand much abuse or static. If something goes wrong, it breaks down. At times, it presents an information overload to teachers and students, more information at once than they can handle. And there is so much going on during the program activities that classroom management problems arise. If a shipment of living organisms (e.g., plants, snails) is late or if the organisms die, the class gets behind on everything, and the teacher may have to omit something later on, sometimes something that is crucial to the concept being taught. Seemingly minor deviations from the program materials can have major consequences for student learning.

Because the teacher did not put BTB in the soda water, her students were not able to observe the color change that should have resulted from the carbon dioxide leaving the soda water (the BTB should have gradually returned to its blue color as the amount of carbon dioxide in the soda water decreased). As a result of this, some students were not convinced that carbon dioxide made the BTB change color; they still thought oxygen did it.

Unclear learning outcomes. It is not always clear from the SCIS materials what each activity's projected learning outcomes are. Isolated statements tucked away in the "Background Information" section of the teacher's guide are not enough to make learning outcomes and relationships between activities clear, especially considering the fact that many busy teachers don't read the "Background Information" sections.

The only stated objective for the oxygen-carbon dioxide cycle unit was a vague one: Students were supposed to learn about the exchange of gases between plants and animals. The smaller, more specific goals were not clearly stated in the teacher's guide, goals like having the students realize that BTB changes color when it reacts with carbon dioxide. Without achieving this and other supporting goals, students could not fully understand the unit.

Possible Program Material Improvements

Smith and Anderson suspect the main problem with packaged curriculum materials to be a "failure of communication" between the teacher's guide and the teacher. The teacher's guide is poorly coordinated with real-life classroom planning. It doesn't allow for management problems or late supply shipments. Learning outcomes are not clearly and explicitly stated, and the contributions of each activity toward achieving these outcomes are seldom made explicit. The two researchers believe that alterations in both the teacher's guide and in actual planning procedures could make science instruction more meaningful.

Smith and Anderson have begun informally developing alternate versions of teachers' guides. Some possibilities they consider promising are the construction of chapter overviews that include information about student preconceptions and desired learning, presentation of long sequences of activities as groups of shorter sequences, and the use of a three-column format in which information about procedures, likely results, and student learning is juxtaposed.

Information about student preconceptions is especially important. Student preconceptions are a pivotal factor in science education; recognizing and dealing with student preconceptions may be the key to effective science instruction.

What Can a Teacher Do?

Identify Student Misconceptions

Teachers need to understand their students' misconceptions and correct them, or the students will never really understand the material. While teacher's guides can give help with this, they cannot provide all the answers. Each teacher must deal with his/her students, who may have their own unique misconceptions. First a teacher must identify student misconceptions.

Teacher collaboration. Hawkins (Note 5) said that teacher collaboration is an effective strategy for finding out what students' misconceptions are. An intervening, active participant (the teacher) and a relatively passive observer (a researcher or a fellow teacher) can do it. The observer watches students closely and tries to determine what their misconceptions are. On the basis of observations by the participant and the observer, the participant can then try teaching differently. The observer watches the effects of any change and discusses them with the teacher.

Student writing. Another way teachers can identify student misconceptions is through student writing. Most student writing during science lessons is merely used for accountability. By writing a series of definitions, students prove they have read the assigned chapter (or at least the definitions). By writing numbers in the blanks and answering a few questions, student prove they have done the assigned experiment. But writing can also be used as a means of communication between student and teacher.

A teacher can learn a great deal about student misconceptions by asking students to explain, in writing, a scientific concept or natural phenomenon. Every child must contribute; no one can be overlooked. And unlike fast-paced discussions, writing can be reflected on and thought about by the teacher. Writing can thus serve as a record of student misconceptions. Once a teacher knows what those misconceptions are (s)he can try to correct them.

Writing can also stimulate student thinking. Asking students to explain what they have learned in writing forces them to think about what they have learned. To explain to the teacher in writing what they have learned, they must first think about the material and explain it to themselves. Such writing can also serve as a check whereby the teacher can see if the students really have learned the material.

Smith and Anderson will, in 1981, begin a study of writing in science to examine how writing may be used in science instruction and the effects on instruction that writing may have (Smith & Anderson, Note 9). Said the two researchers, "We are especially interested in the potential use of writing tasks to enhance students' conceptual learning in science."

Better teacher's guides. Writing in science and teacher collaboration can be helpful, but both assume that the teacher understands the scientific concepts (s)he is teaching. However, teachers, like all adults, may have the same misconceptions their students do. If science curriculum materials are well-written, teachers may be able to correct their own misconceptions as they use the materials.

Smith and Anderson (Note 3; Note 4) suggest that clearer, more informative teachers' guides could help teachers correct their misconceptions, but such guides will take considerable time to research, write, and produce. In the meantime, Smith and Anderson (Note 4) suggest three things teachers can do to improve their science instruction based on the strategies of successful science teachers they have observed.

Focus on Conceptual Change

The first of these is to focus on conceptual change. By paying close attention to what students' preconceptions are and contrasting those with the conceptions being taught, teachers can improve both their students' and their own understanding of why certain experiments are done or certain chapters are read. This may also help teachers to better understand their own conceptual difficulties. A teacher might, for instance, stress those concepts students may have incorrect preconceptions about by contrasting what the experiments show with what people might think would happen. Asking students to predict what will happen in an experiment is an excellent way of finding out what student preconceptions are.

Take, for example, the soda water and BTB experiment discussed earlier. In this experiment, BTB gets bluer when carbon dioxide escapes, in the form of bubbles, from the BTB and soda water solution. This is clear evidence against the misconception held by many students that oxygen changes BTB back to blue. But students may not see this as clear evidence against their preconception unless they first commit themselves to that preconception. And the teacher cannot stress the experimental results as evidence against a student preconception unless (s)he knows that some of his/her students have that preconception.

Use Student Learning to Connect Lessons

Smith and Anderson also suggest that teachers use student learning rather than procedures to connect lessons. Rather than regarding lessons as a sequence of activities to be done or pages to be read, teachers might construct a "story line" based on student learning. Each activity or reading assignment adds an idea or fact to a developing conceptual framework. Stressing the development of that conceptual framework instead of the procedures by which it is developed may make science instruction more meaningful.

In the series of experiments presented earlier in this paper, for example, the story line focuses on carbon dioxide. BTB indicates its presence, plants and animals produce it in the dark, animals produce it in the light, and plants use it in the light. If a teacher has a firm grasp of the story line, (s)he can make informed judgments on lesson details and procedures.

Use Integrating Frames

The two researchers' third suggestion is closely linked to their second. In order to construct a "story line," each lesson must have what Smith and Anderson call an "integrating frame." Procedures, results, and learning ought to make up an integrated whole. Making this difficult is the fact that teachers' guides may separate statements about procedures, results, and learning, even though they pertain to the same experiment or activity. Thus, teachers must work hard to see how everything fits together and to convey that integrated whole to their students. By stressing those parts of each lesson that link them to other lessons, the integrating frames, a teacher can integrate instruction. The question, "What does the BTB and soda water experiment tell us about carbon dioxide?" helps students to connect that experiment logically with other experiments they've done concerning carbon dioxide.

Effective science instruction is difficult, but it is not impossible. And it is worth striving for. Most children enjoy science, and they are anxious to learn about it. They need good science education because science increasingly touches their lives. If they have at least a basic understanding of science, they will have no need to feel afraid of or threatened by it.

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