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Microscale Organic Chemistry Laboratory: Good News for Biologists, Too

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Introduction

The microscale laboratory technique is an important new development in undergraduate organic chemistry education. This new approach was pioneered by Dana Mayo and Ronald Pike at Bowdoin College and Kenneth Williamson at Mount Holyoke College, who started using "microscale" in their instructional labs about 1981. Since the publication of their laboratory texts (1,2), many chemistry departments have changed from a "macro" to a "micro" approach. Symposia and workshops are being held (3), and new microscale experiments are frequently found in the literature.

This essay outlines what microscale is and why chemists are excited about it. I know the dangers of bringing up a "non-biological" topic in the Bioscene, but I hope that you (and the editors) will indulge me this once, because microscale is likely to have a significant impact on biology education.

Even though the changeover to microscale will be a decision for chemists to make, biology faculty should also be aware of what is happening and should encourage their chemistry colleagues. Biology majors who take organic chemistry will benefit from microscale, and I think we will see the positive effects extending into our programs in biochemistry, microbiology, and cell biology.

What is "Microscale"?

The essence of microscale is just what the name implies: all reactions and purifications are done on a scale 10 to 1000 times smaller than usual. Where the traditional organic lab uses grams, microscale uses milligrams.

Students in microscale labs feel that their health is better protected, and they enjoy the lab more and learn more readily.

Two examples will serve to illustrate this. Consider first the oxidation of cyclohexanol to cyclohexanone, a common reaction in organic laboratory texts. Typically, students react 15 g of cyclohexanol with 15 g of sodium dichromate dihydrate (4) and analyze the products by gas chromatography (GC) and infrared spectroscopy (IR). But with microscale only 0.1 g are used. Why synthesize 10 g when 0.1 g is more than enough for analysis?

Second, consider the isolation of a natural product, caffeine. Typically, 25 g of tea leaves are extracted to purify 0.3 g of caffeine (4, 5). However, in the microscale lab only 1 g is extracted -- less than the contents of a single tea bag (1, 2).

After purification by sublimation, 15 mg of highly pure caffeine is obtained -- enough for an IR spectrum and melting point determination. On this scale, the caffeine from a single Excedrin tablet can be extracted and analyzed (2)!

Microscale Techniques

A 10 to 1000 fold reduction in the amount of material has profound implications. To start with, it demands different experimental techniques and different equipment.

For example, small quantities of liquids must be handled in conical vials (0.1 - 1.0 ml volume), and they must be transferred with a syringe, Pasteur pipette, or automatic delivery pipette. They cannot be poured! For solids, microspatulas and a balance with milligram accuracy are required.

In some cases, microscale uses scaled down versions of ordinary organic laboratory glassware, but in most cases the equipment is quite different (6). Reactions are carried out in tubes or conical vials in sand baths instead of in round-bottomed flasks on heating mantles. Conical centrifuge tubes and Pasteur pipettes replace separatory funnels for extractions. Hickman stills are used for distillation (1), and Craig tubes for recrystallization (3).

For characterization of compounds, microscale relies heavily on the GC, IR spectrometer, Abbe refractometer, and an oil-bath capillary melting point apparatus. (The latter can also be used to determine boiling points with only 3 - 4 microliters of a liquid (7).) Bench top centrifuges and hot plate-magnetic stirrers are essential equipment, and preparative GC is increasingly used.

Microscale continues to evolve, and part of the excitement of it is the continuing flow of new ideas and techniques (8-10).

What are the Advantages?

By switching to microscale, chemistry departments can improve teaching, improve laboratory health and safety, and at the same time save money!

The original motivation of Mayo and Pike was to improve laboratory air quality without a costly upgrade of the ventilation system (1), and they succeeded admirably. Smells are not a problem in the microscale lab, because reduction in the amount of starting material leads to a corresponding reduction in volatile organic solvents.

Microscale has numerous other advantages as well (1, 2, 11). Smaller quantities of chemicals and solvents mean lower costs for supplies, reduced student contact with toxic substances, lower threat to safety from explosion or fire, and less chemical waste to be disposed of. Moreover, the microscale glassware appears to be more durable, leading to lower breakage costs.

Most importantly there are pedagogic advantages. Many of the microscale operations take less time (12), so that students can do more and learn to solve more lab puzzles. The teacher can afford to let students learn from their mistakes, because hazards are reduced and because there is time for the unsuccessful experiment to be repeated.

It is also possible to expand the variety and sophistication of the lab activities. Experiments can be conducted which would be too hazardous or expensive on a

Perhaps the most important aspect of microscale is the opportunity it affords for teaching safety and environmental awareness.

larger scale, such as the condensation of benzaldehyde using a cyanide catalyst (1), and starting materials can be used which are not available commercially (11). Micro-techniques for analysis of gases open up entirely new possibilities (1).

Improvements in Learning

Perhaps the question in the back of your mind is, can sophomore college students do it? They can, and indeed they thrive on it. With microscale, students gain the greatest ability to handle lab materials in the shortest period of time.

Mayo and Pike report that when test and control laboratory groups were compared, the entire range of the class performed better using microscale (1). Other teachers who have tried microscale report similar outcomes (3). Students in microscale sections appear to master details and procedures more effectively and perform "significantly better in upper level work" (1).

Students in microscale labs also feel that their health is better protected, and they enjoy the lab more and learn more readily (3). They gain in dexterity and have a greater sense of accomplishment and self-confidence.

The benefits of microscale are perhaps greatest for biology and biochemistry majors. Because microscale borrows techniques which have been standard in biochemistry for years, the skills and experience which the sophomore student gains will be more useful to his later upper level work than the skills taught in the traditional organic lab.

One potential disadvantage of microscale is that students might not learn to use conventional equipment. This problem could be circumvented by including a few "macro" experiments in the microscale lab. However, it is generally

easier to learn to scale up than to scale down. It is probably much more important that the students learn to work precisely.

Conclusions

Microscale has tremendous advantages for students in sophomore level organic chemistry. It can be a great boon to both biology and chemistry students and give them better preparation for biochemistry and other upper level courses.

The biggest obstacle to converting from traditional organic lab to microscale (other than faculty inertia) is the initial investment in instruments, glassware, and other equipment. However, in the long run it more than pays for itself (13).

Perhaps the most important aspect of microscale is the opportunity it affords for teaching safety and environmental awareness. Chemists must teach, by their example, responsible attitudes toward the handling and disposal of hazardous substances (14,15), because some of our students will be the industrial chemists of the future. As Wendy Walton has written, "If we want the next generation to deal with hazardous waste appropriately . . . then we must teach them" (14). Converting to microscale is one of the best ways to deal with the problem of chemical wastes in academic labs (16).

In conclusion, microscale is an important step in the right direction, and one that ought to be encouraged.

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References

1. Mayo, D.W., Pike, R.M. and S.S. Butcher (1986). *Microscale Organic Laboratory*. Wiley.
 2. Williamson, K.L. (1987). *Microscale Organic Experiments*. D.C. Heath.
 3. Conference Report, *Microscale Laboratory Experiences*. J. Chem. Educ. 64: 100 (1987).
 4. Fieser, L.F. and K.L. Williamson (1987). *Organic Experiments*, 6th edition. D.C. Heath.
 5. Pavia, D.L., Lampman, G.M. and G.S. Kriz (1982) *Introduction to Organic Laboratory Techniques*, 2nd edition. Saunders.
 6. Glassware for microscale is available from Ace Glass, Kontes, and others, but many experiments can be done without special glassware. (3)
 7. Mayo, D.W., et al. (1985). J. Chem. Educ. 62: 1114.
 8. Horak, V. and R.F.X. Klein (1985) J. Chem. Educ. 62: 806.
 9. Lawler, R.G. and K.A. Parker (1986) J. Chem. Educ. 63:1012.
 10. Yu, S.J. (1987). J. Chem. Educ. 64: 812.
 11. Mayo, D.W. et al. (1985). J. Chem. Educ. 62: 149.
 12. Pickering, M. and J.E. LaPrade (1986) J. Chem. Educ. 63: 535.
 13. D.W. Mayo, R.M. Pike, and S.S. Butcher (1985). *Microscale Organic Laboratory Conversion Manual*. Wiley.
 14. Walton, W.A. (1987). "Chemical Wastes in Academic Labs". J. Chem. Educ. 64: A69.
 15. Allen, R.O. (1983). "Waste Disposal in the Laboratory: Teaching Responsibility and Safety". J. Chem. Educ. 60: A1.
 16. Young, J.A. (1983). J. Chem. Educ. 60: 490.
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Teaching In China

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Introduction

Looking in upon another culture as an outsider and then interpreting what is occurring within that culture is subject always to errors of observation and cultural bias. When a member of a western culture experiences and interprets an eastern culture the bias is greater than when he/she experiences and interprets another western culture for even the assumptions that eastern and western cultures make concerning the universals of human nature are not universal. Acknowledging that my perceptions are limited and culturally biased, I am sharing the experience of an educational exchange that occurred during the Spring of 1986. The term exchange in this context is not a one-for-one exchange but rather that our university has a sister relationship and formal guidelines for staff and student exchanges with Shaanxi Teachers University in Xian, China. Xian is an old city in central China, the former capitol and the northern terminus of the overland trade route from the mideast.

Chinese Educational System

The benefits of the People's Revolution to Chinese education are unmistakable. Before 1949 more than 80 percent of the population could neither read nor write. Now there are hundreds of millions of pupils in primary, secondary, and tertiary schools throughout the nation. The whole country can be thought of as an enormous school where every citizen spends part of

his time learning and another part passing on knowledge to someone else. Everywhere one goes in China one sees people reading books and newspapers or making notations. There can be no doubt that literacy has produced a new-found joy in living.

Before 1949 more than 80 percent of the population could neither read nor write.

If one visits a kindergarten in China, he/she is impressed by the self-assurance of the children. They stand up and sign or dance without a hint of shyness or embarrassment, and the observer is enchanted by their candidness. This is one of the few occasions in China when it is probably best not to understand Chinese; the performance raises doubts for some observers when they learn that many of the songs are little more than political slogans. Chinese children are remarkably well-behaved both inside and outside the classroom. Rarely does one hear a Chinese child cry; they run, play, sing, and dance, but rarely appear to be misbehaved in public. Their good behavior has been attributed to handling, touching, fondling, and affection given in their early years, a practice that is centuries old. Good behavior, whatever its

cause, is so characteristic of Chinese children that it is assumed by Chinese adults to be normative and characteristic for children's behavior the world over. Abuse of children by adults, a problem all too familiar to Americans, was incomprehensible to the Chinese.

Primary School

Children usually start primary school at the age of six, depending on whether openings are available. They are subject to firm but not harsh discipline and regimentation. Compared to American education, far greater emphasis is placed on collective activities, on construction of physical objects and on manipulating objects physically. Items constructed from sand, erector sets, plastics, stones and wood occupied classroom perimeters. Aquaria, growing plants, germinating seeds and objects made of paper mache were also visible. Group projects constructed from reusable materials had a remarkably untemporary look; some showed evidence of recent partial revision, others seemed to have been weeks or months old.

Both primary schooling and secondary education are six years in length. Both are compulsory according to officials, but the reality seems to be that somewhat more than half of Chinese students complete secondary school.

Secondary Education

Secondary education in China is referred to as middle school. Children are about age twelve when they begin. In middle school there is study of literature, science, mathematics, foreign language, geography, history and political study. I had so little contact with middle school students that comment concerning the process of educating in these years is con-

jecture. From my experience with middle school students who subsequently became college students, I concluded that education in world geography was considerably superior to education in that discipline in the United States. I never met a Chinese student who lacked a reasonable conceptualization of the shape, size and ecological regionalization of the United States or any other continental land mass. I was surprised at college student knowledge of their own country's history and how little I knew about that history from my own schooling. Many Chinese students had some knowledge of western writers and western history, but this knowledge lacked a philosophy of history/literature.

A "humanities approach" was not evident in any comments made by students I talked with.

A "humanities approach" was not evident in any comments made by students I talked with. I discovered without intending to that my knowledge of history and literature was really my interpretation of history and literature and that culture binds (and blinds) that interpretation.

Chinese students claimed there were conspicuous differences in the achievement levels of secondary students in the cities as compared to those from the country. Rural students were claimed to be at a marked disadvantage academically on tests that give access to college-level education.

Tertiary Education

The uppermost level of educational hierarchy in China is attendance at a tertiary institute such as a university, specialized

institute, technical university, or teacher-training college. About a million students currently attend tertiary institutes. Tertiary education has suffered a severe identity crisis from changes in political policy over the past two decades. Since tertiary institutions occupy an exposed position in Chinese society, they were buffeted by pressures resulting from differing doctrinal viewpoints in the communist party. During the Cultural Revolution (1966-1976), universities and institutes of higher learning were criticized by communist party members for turning out an "elite" of technicians and bureaucrats who were insufficiently motivated by political ideology. It was further claimed that sons and daughters of bureaucrats, military officers, and party cadres were gaining entrance to universities in preference to other members of society. As a result the tertiary level of education was changed. Entrance examinations were abolished, student numbers were reduced and courses were shortened from five to three years. Selection procedures for beginning students were revised so that worker-students who had completed two years of industrial work after middle school could apply for tertiary education provided they had the support of their fellow workers. If they had worked more than five years before starting their studies, they could even continue to receive their wages while at the university; otherwise they would receive a state stipend of 15 yuans (\$5) per month. In American dollars, this is a miniscule sum, but in Chinese currency it is about one-fourth the salary of university staff members and it comes in addition to the costs of education which are borne almost completely by the state. In short, the emphasis in tertiary education during the Cultural Revolution (1966-1976) was on political ideology and not on academic or technical expertise.

I discovered that my knowledge of history and literature was really my interpretation of history and literature and that culture binds (and blinds) that interpretation.

In 1983, but not in 1986, I saw hundreds of college students memorizing political ideology; I presumed this exercise was for subsequent recitation or testing. Their study resembled that of American college students "cramming to pass" for an upcoming examination in a university-required course; it lacked conviction. I was impressed also in 1983 that Chinese students generally seemed broadly and knowledgeably committed to their country's political and economic ideology, including family planning. One English speaking student in 1983 stated that "The most important thing is not whether we all have TVs, but how to realize the Four Modernizations." He ticked off the national goals that everyone seemed to have internalized: modernization of agriculture, industry, defense, and science. "If we achieve the Four Modernizations we can have a happy life." He added, "I believe that." By 1986, zealotry for political ideology was no longer evident on any of the three campuses I visited. The opinion was sometimes ventured by staff and students alike that the Cultural Revolution had lost China millions of tertiary graduates at the time when the nation needed them most.

About 270,000 middle school graduates now enter China's universities each year without undergoing prior farm or factory work. Candidates must pass qualifying entrance examinations, and all

vacancies at institutes of higher learning are now filled on the basis of these tests. As an additional assurance of educational accomplishment, students must complete comprehensive examinations before graduating.

The singleness of mind with which most Chinese students pursue their university educations is difficult for Americans to grasp. Rock and disco sounds are rare; students seem not to date or dance; keggers and drug abuse are incomprehensible; premarital sex is synonymous with expulsion. One 1983 exchange teacher from Germany stated "I'm spoiled here, I'll never have such diligent students again." Less definitive, but carrying a similar message, were the comments of a Massachusetts couple who were concluding a year's faculty exchange at Shaanxi Teachers University in Xian. "The rules are that foreign exchange faculty members may not have sexual, political or religious exchanges if they're going to remain invited." "Even so", said the wife, "this has been the single most significant year of my entire life, and I'm the mother of 5 grown children, so I've done quite a bit of living."

Most Chinese intellectuals are underemployed.

Classes meet 6 days per week and all tertiary students have some facility with a second language. In the early 1980's 2/3 studied Russian and 1/3 studied English, but that balance had exactly reversed by 1986. One middle-school educated hotel worker stated "the language of commerce is English; we must understand it; read it and write it, if we are to compete in a world of commerce." University students in language courses often use their day off to meet tourists with whom they practice

English. In 1983, I was delivering a lecture in English on animal imprinting to some 150 Chinese students at South China Agricultural College in Nanning. It was clear to me from the students' facial expressions that both the concept and my language were foreign to them. I had been speaking for an hour, so concluded my topic reasonably gracefully and asked if there were questions or comments from the audience. I assumed it was Chinese courtesy that had kept the students' non-comprehending eyes so closely trained on my face as I spoke. The first student who spoke said "Please go on, you speak English like they do on the TV; most of our visitors speak Australian English." Quite obviously I was an itinerant English teacher; my stock as a "speaker of English" increased in value between 1983 and 1986.

Government Jobs

By 1986 the Chinese government permitted students at tertiary education levels to state their preferred institute and subject major(s). They no longer assigned students to institutes or courses without the student's consent. Students could express opinions on what they would like to do following graduation but the reality is that students have few choices in matters of employment. It was the most frequently expressed concern of the students I met. Almost all students expressed strong support for Deng Xiaoping and top party leadership but almost all also expressed reservations about party leadership below the top. Repeatedly I heard of the inertia within the system and of power struggles within existing educational, military and industrial hierarchies. Repeatedly students expressed the view that resistance to change and/or modernization was caused by middle level administrators (straw-bosses/professors/generals) who clung to

privileged and/or political positions within the old system and who were sabotaging modernization while ostensibly implementing it. Students with whom I visited (with only one exception) identified with those graduate students studying abroad who did not return to their homeland. Students were pessimistic, bitter and relatively hopeless about their foreseeable futures as workers. Although young intellectuals are relatively rare, the Chinese economy is not directed at all toward valuing their skills. Students expressed dissatisfaction that they would be rewarded with neither salary, status, nor job choice for having tested into one of the coveted and extremely limited places at an institute or university. The recent attention by the party leadership to the successes of private entrepreneurs and peasant collective entrepreneurs seemed to have exacerbated student resentment.

Entrepreneurs

If university graduates reject their state-assigned jobs and become private entrepreneurs, they are required to sacrifice college diplomas and any record that they attended a university. This rule is enough to dissuade most students from attempting entrepreneurship since state-assigned jobs at least are a sure thing. The non-agricultural private sector for all its media-touted successes, has many failures and is a scary no man's land for those with academic success but who are without private funds and who are experientially naive. Denied the possibility of modest wealth as entrepreneurs, young Chinese might reasonably hope to exercise their talents by contributing to China's modernization effort. In fact, they are denied this satisfaction and it is this limitation that produces the greatest resentment. Most Chinese intellectuals are underemployed.

It is a cynical joke among Chinese how little work there is done on the job. One industrial worker expressed his bitterness "We all squeeze on the buses in the morning, but as soon as we've punched in we spend an hour in the bathroom and another hour changing into our work clothes. We all have to keep diaries, and at the end of the day we all write nonsense about how oh so very busy we were today."

There can be no doubt that literacy has produced a new-found joy in living.

This anger is probably the primary reason for China's so-called *ren cai wai liu* - its brain drain. Is it surprising that someone who received a doctoral degree in physics in the United States would be loath to return to teach a fixed physics curriculum to secondary or tertiary students under the supervision of a conservative and rigid school bureaucracy? It is not the large car and house that are the seductive charms of life in the United States for a Chinese person; it is the well-founded fear of a meaningless career in China, and the promise of an intellectual one in the United States. While the government officially has urged pursuit of the "Four Modernizations," it has frustrated individuals' efforts to do it. It has spouted fine words about democracy and political participation, but then has often denied students even the most elementary participation in matters that affect their own and China's future.

Another tough problem facing universities is what to do with the large number of professors, now in their late 30's and 40's, who have no academic qualifications and who are given no teaching assignments. Each university has staff members

who got there during the Cultural Revolution without academic credentials and who have continued to hold these positions. The Chinese leadership is concerned about this, but it doesn't want to create bitterness by throwing people out. The irony is that avoiding bitterness of tenured workers has produced bitterness in students. If U.S. reports were even approximately accurate, student patience had become exhausted by the close of 1986 and good-natured but serious demonstrations of protest occurred. Although the protests were illegal and soon terminated by the party, the message of protest apparently was taken seriously, for the 1987 party congress enacted policies that broadly liberalized student academic options but narrowed retirement options for bureaucrats.

Visiting Professors

Visiting professors typically live in a "foreign experts' building." The accommodations, luxurious by Chinese standards, consist of two to several rooms with bath and include a refrigerator, a heater and an air-conditioning unit. Surprising to me was that there was no evident resentment of the double standard in living accommodations among my Chinese colleagues. They said, "Foreigners have their ways and their habits. They need what they've become accustomed to. We understand and accept this."

The university itself is a compound and subject to elaborate security. Shaanxi Teachers University was surrounded by a 6-8 foot high brick wall with gatekeepers at each entry/exit. On the campus itself there were additional wrought iron and brick fences with gates and additional security personnel. Gates were locked at 11 p.m. and re-opened at 6 a.m. If I was not in by 11 p.m. or wanted to get out before 6 a.m. I had to rouse keepers of two gates. They

slept in the gatehouses, and were remarkably tolerant of disruption.

Most staff and students live within the campus compounds. My housing was a 2-bedroom apartment in the Foreign Experts Building. I ate in the visitor dining service adjoining my building, rode a rented bicycle, exercised with the Chinese in early morning and tried in China to live as the Chinese do. Usually I described my day as lecture preparation all morning, teaching all afternoon and practicing English with students all evening. That was an overstatement, but not by too much. I made it a point to keep busy; to keep records of persons I met who wanted to pursue education in the States; to practice English with prospective students; to discuss Chinese perceptions of their own and my country; and to facilitate their applications to American graduate schools. All the activities I did seemed worth doing to me and each helped to enrich my China experience.

Visiting Students

A small but growing number of foreign students, including Americans, now come to China to study, some for technical training but the majority to increase their understanding of the Chinese people and language. Some students from developing nations also study in China as part of a program to produce technicians for Third-World countries. Foreign students in China get a closer glimpse of Chinese society than almost anyone else. Many write and all speak Chinese; some are ideologically receptive to the Marxist philosophy and the Communist system; others are drawn by curiosity or to the apparently simple but basic values of life in China.

A group of 10 students from the United States and a second group of 10 from Japan ate their meals in the same dining facility where visiting staff ate. The students

seemed generally to accept the spartan living conditions, poor food, and lack of outside entertainment, but they did object to attempts by government authorities to stifle friendships. The students frequently commented that the Chinese authorities were evasive and secretive. One discussion with American students described the experience of China as going through an emotional tunnel, beginning with initial euphoria and then passing successively through a phase of self-questioning, lurking doubt, determined goodwill, seething frustration, and ending in either active or passive aggression. Some students returned to the United States early, blaming themselves for taking China too seriously and for having believed that it offered more for humanity and its problems than it could deliver. I visited with professors from America on three widely separated campuses while I was there and all expressed many of the same feelings that the students had expressed. In addition, professors expressed anger that their areas of academic expertise had been treated cavalierly by their Chinese hosts. Teachers of mathematics never expressed this reservation to me but those who taught English, geography and sciences did. I never felt that my treatment was cavalier, but that was partly because I had correctly ascertained beforehand that my value to the Chinese was greater because I spoke good English and understood its grammar and construction than that I was a biologist.

Travel in China

Visiting professors are allowed time and some money to permit travel within China while they're there. I anticipated this opportunity and maximized it. Upon first arrival, I traveled to Xian by rail through South China's rice bowl, most of it then planted to cool-weather produce.

My train travel was sleeper class (4 persons per cabin) with meals in a dining car. Sleeper class train travel costs about the same as flying but the value received in sights was worth the cost in time (56 hours).

"Foreigners have their ways and their habits. They need what they've become accustomed to. We understand and accept this."

I never grew tired of South China's rice paddies with their hundreds of water buffalo and thousands of peasant workers. It was a holiday and an education in agricultural conservation and land use all rolled into one.

I also followed the overland trail (silk route) from Xian as far into West China as rail would take me. In the West China city of Urumqi I stayed on the campus of Xinjiang University and had an Islamic Uygur student as my guide and interpreter. She had majored in English and I was her senior practicum.

The Uygurs are Turkish speaking descendents of the people who conducted the silk/tea trade. She escorted me to the Nanshan Grasslands where the nomadic Kazakh people live. The Ghenghis Khan invasions into eastern Europe were by ancestral Kazakh and Cossack (now outer Mongolian and Soviet) peoples. Even today they are such superb horsemen that it made invasions of eastern Europe by men on horse seem plausible.

On the way to Urumqi I stopped in Dunhuang to see the Mogao Caves. These are the remains of a Buddhist monastery abandoned in the 12th century and

rediscovered in 1900. In spite of myself I became absorbed in the symbolism of the Buddha and its historical, religious and philosophical messages.

As part of my homeward journey I went to Tibet. By some stroke of good fate I was in Lhasa (Tibet's capitol) on Buddha's birthday, something of an equivalent of Christmas in a Christian country. I trekked with the Dali Lama Buddhists (the Tibetan sect) through their largest temple and later through their largest monastery.

Not insignificant to me was the cultural understandings I was able to glean while in Xian from visits with colleagues and graduate students in my classes. One colleague had worked in a medical clinic in Xian for 8 years of the cultural revolution. As a medical clinician, he had conducted tests to determine the gender of fetuses and he also had conducted research on cottonseed oil as a male contraceptive. He had come to know the medical community of Xian well and he gave me 2 superb tours of Chinese medical services, with special emphasis on Chinese folk medicines (massage, rolfing, acupuncture and herbal).

Several persons shared experiences of their own and of their families during the difficult days of the cultural revolution (1966-1976). For me, there is no academic experience that compares with the reports of first-hand experience, and there is no perception of culture more plausible than that of individuals who are part of that culture. In short, I'm saying I got more than I gave by the exchange experience and I'm grateful to China, the Chinese and my university for making it possible. I have few illusions about my usefulness to the Chinese as an exchange biologist. I knew, because I had been there previously, that Shaanxi Teachers University was no intellectual utopia and certainly not a physical one. I knew of the claustrophobic congest-

tion of too many persons using too little space; of the odors of "schoolhouse" and of too many people serviced by too few facilities; of too much night soil grime and too little shine; of too many foot paths of hard earth and too few of concrete; of too many thermoses but too little water; of the inscrutableness of the Chinese mind but also of the courtesy and fundamental decency that characterizes the relationship of Chinese persons to each other and to foreign visitors. It's not an experience for everyone, but it was for me.

Helpful Organizations

The following organizations can provide information to faculty members seeking opportunities to teach at higher-education institutions in China:

1. The Committee on Scholarly Communication with the People's Republic of China includes among its projects a Visiting Scholar Exchange Program, which provides support for short visits to Chinese universities. While the program is for researchers in the natural and social sciences, engineering and the humanities, it offers opportunities for scholars to give lectures and conduct seminars if they are an integral part of a research project. The September 1985 issue of China Exchange News, the committee's quarterly magazine, contains a special section on the Fulbright Scholar Program in China. For more information, contact C.S.C.P.R.C., National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington 20418; (202) 334-2718.
2. The Chinese Embassy accepts applications from academics interested in teaching positions at Chinese universities. For information, contact Yang Meng, Education Division, Embassy of the People's Republic of China, 2300 Connecticut Avenue,

N.W., Washington 20008; (202) 328-2535.

3. The Institute of International Education maintains the Register for International Service in Education, or RISE, a computer-based information service that matches foreign institutions seeking American experts with academics and other specialists seeking positions abroad. For information about teaching opportunities at Chinese universities, contact Sandra L. Cervera, RISE, I.I.E., 809 United Nations Plaza, New York 10017; (212) 984-5344.

4. The National Committee on United States-China Relations publishes a list of

U.S. institutions that offer programs for teachers in China and the organizations that screen applicants. For a copy, contact Barbara J. Congelosi, N.C.U.S.C.R., 777 United Nations Plaza, New York 10017; (212) 922-1385.

5. The U.S.-China Peoples Friendship Association accepts applications from academics interested in teaching English as a second language at Chinese institutions and screens the candidates for the Foreign Experts Bureau in Peking. For information, contact Annie Wang, U.S.C.P.F.A., 2025 I Street, N.W., Washington 20006; (202) 368-5883.

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This is a detailed presentation of the various stages of the life cycle of the eyefluke of birds, Philophthalmus. Living, preserved, and graphic material are used to illustrate these stages. Detailed coverage is given to the adult organ systems, the egg making process, egg hatching, miracidial host finding behavior, cercarial movement, cyst formation, and excystment of the juvenile worms.

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A Fractal Model of Leaf Growth

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The Question

How do we recognize different types of leaves? Clearly we do so based upon their differing shapes. The leaves of one plant species are shaped differently than those of another, and we classify the plants accordingly. But to what extent do the leaves of the one type of plant share a shape that differentiates them from those of another type? Leaves do change shape as they grow, and even when we consider leaves from the same plant the profile of the smaller leaves is quite different from that of the larger leaves. For example, the smaller, younger leaves are usually broader in relation to length, with fewer lobes or serrations, than the larger leaves. Therefore, the leaves of a plant do not share a common "shape," if by shape we mean the three-dimensional volume the leaf occupies in space or the two-dimensional area it would cover if flattened out.

What do we mean, then, when we refer to the "shape" of a leaf? This seems like an elementary question, yet it is crucial in view of the role leaf shape plays in taxonomy and the study of plant growth and development. Many of the characteristics used to classify plants depend largely on the shapes of their leaves. The changes that occur during a leaf's development are also often expressed in terms of shape. In this paper we will examine the shape of leaves from a novel perspective, that of

fractal geometry. In light of the recent success in the formation of models of mountains, watersheds, and other natural phenomena using fractal geometry, we will interpret the idea of leaf-shape in terms of **fractals**. This interpretation not only has applications to the description and classification of plants, but also allows a simple explanation for certain allometric relations and provides the basis for a set of models of leaf morphogenesis.

Fractals

Fractals, so named by Benoit Mandelbrot, (1) possess features that may at first seem to be pathological. There are several standard measurement procedures that work on ordinary objects, such as planes and cubes, to 'count' how many dimensions are needed to contain the object. These procedures generally work on all such ordinary objects and yield the expected dimensions, but when used on fractals, they yield results quite different from the expected. For example, the dimension of these objects are commonly not integers. Fractals can have any dimension D , where $0 < D < 3$, but D is not necessarily equal to 1 or 2.

If having a nonintegral dimension were the only unique feature in common for this group of figures, one could simply assume

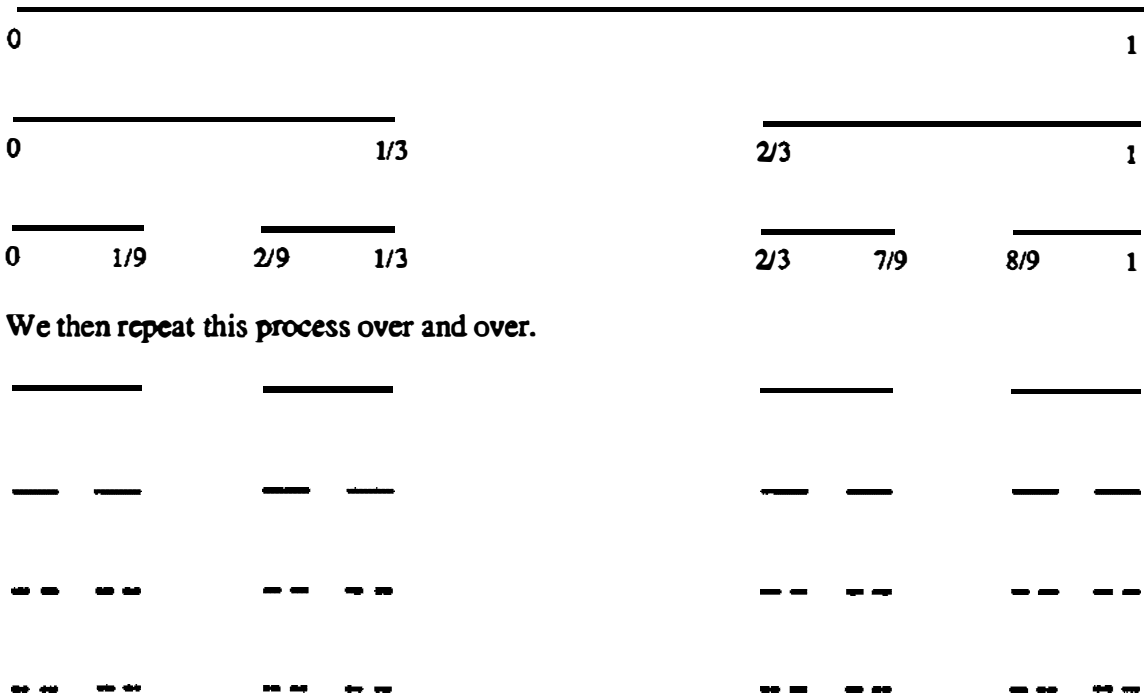
our method of determining dimension was deficient. However, these shapes share other notable aspects. First, fractals can be generated by iterative or recursive processes, unlike standard geometrical figures that are described in concise geometrical terms as the loci of equations or inequalities. Second, they also have the related property of self-similarity; i.e. they contain subsets which are smaller copies of themselves. But the purpose of this paper is not to delve deeply into the nature of fractality. Instead, let us consider some of the fractals commonly found in the literature and how they might offer insight into the modelling of leaves.

The Cantor Set

In the nineteenth century, Georg Cantor was examining certain types of pathological infinite sets. He discovered the set

now known as the Cantor Set, and this set is now considered to be a canonical example of a fractal. To construct this set, begin with a closed interval on the real line, say $[0,1]$, and remove the open interval $(1/3, 2/3)$. We call this set the "open middle third," because this interval is one third the length of the original interval $[0,1]$. At each step in the construction, we remove the open middle third from each closed interval in the previous set. For the second stage, we would take out $(1/9, 2/9)$ and $(7/9, 8/9)$.

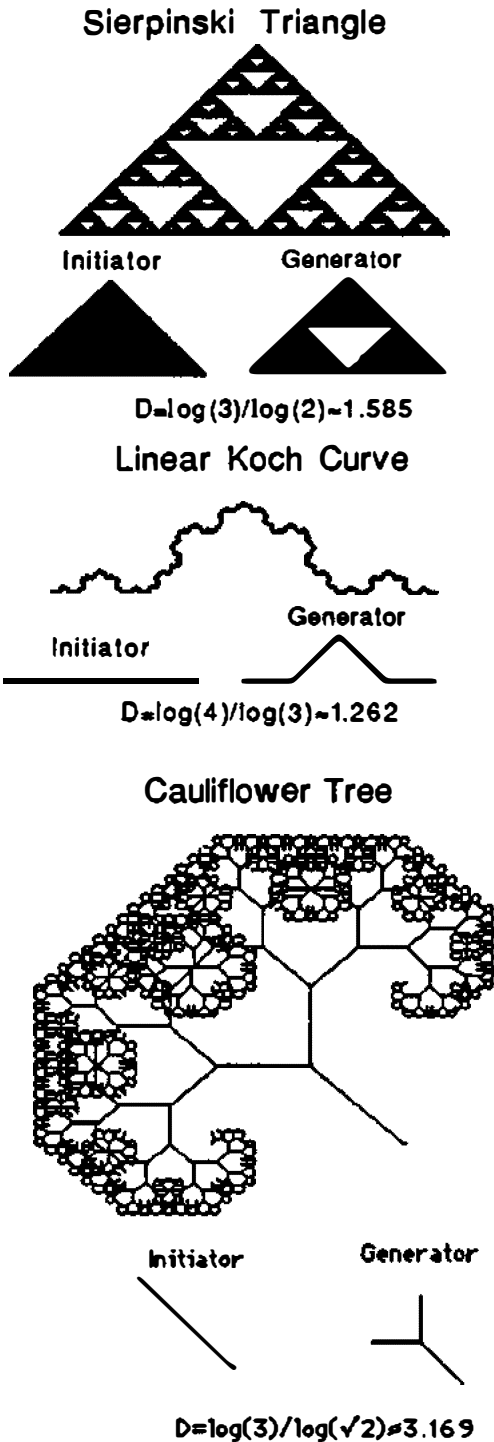
In the end, we have the Cantor Set. If we attempt to determine the dimension of this set using naive ideas about the dimension of points and lines, we obtain contradictory results. All of the points of the Cantor Set are completely disconnected from one another, and the dimension of a set of isolated points is zero. However, there is a one-to-one correspondence be-



We then repeat this process over and over.

Figure 1: Cantor Set. Canonical example of a fractal designed in the 19th Century by Georg Cantor.

Figure 2: Famous Fractals. For each example, the initiator, generator, and dimension are indicated.



tween the points in the Cantor Set and the points on the entire interval $[0,1]$. In other words, the Cantor Set has some of the same properties as a line segment, so it seems as if this set should have dimension one. Thus, a case could be made for this set to have a dimension of zero or a dimension of one. However, according to the standard dimension-determining procedure, the set has neither integer as its dimension. This object has dimension $D \approx 0.6309$, a number greater than zero but less than one.

Iterators and Generators

In the above construction of the Cantor set, at each stage we replaced a closed interval by a pair of closed intervals, each $1/3$ as long as the original. The initial closed interval is the initiator of this construction, and the pair of smaller intervals is the generator. At each stage in the construction, we replace each segment resembling the initiator by a generator of the appropriate scale.

By considering different initiator/ generator pairs, we can create an enormous variety of different images; almost all of these are fractal. In fact, because of their inherent self-similarity, we can also determine their dimension. In the Cantor set, the generator contained two copies of the initiator which were $1/3$ as large, and the dimension was $\log(2)/\log(3)$. In general, if we examine an image whose generator contains N copies of its initiator, each r times as large, the dimension of the object will be $\log(N)/\log(1/r)$. (2)

Iterated Function Systems

Images such as these are interesting as abstract mathematical constructs, but how can they be used to help us describe leaf

shape? Our last example in Figure 2 has some similarity to the appearance of cauliflower, but further generalization seems necessary before we can conceive of using these figures to describe a wide variety of leaves.

We can make such a generalization by looking at the relationship of the initiator to the generator as a set of functions. Each copy of the initiator in the generator is exactly the same as the original, except that the copy is scaled, relocated, and/or reoriented. Each of these copies is then the image of the initiator under a linear function.

As an example, let us first consider how we could encode the Cantor Set by a set of linear functions. If we start with $[0,1]$, we can define $f_1(x) = (1/3)x$ and $f_2(x) = (1/3)x + 2/3$. Now, if we examine $f_1([0,1]) = \{f_1(x): x \text{ in } [0, 1]\}$, we obtain $[0,1/3]$. Note that this line segment is a scaled copy of the original initiator of the Cantor Set. When we apply f_2 to $[0,1]$, we obtain $[2/3,1]$, the second copy of the initiator of the Cantor Set. These two intervals, $[0,1/3]$ and $[2/3, 1]$, represent the application of the generator to the original interval. Therefore, in order to encode the Cantor set, we define the initiator as $I = [0,1]$, and the generator as $G = f_1(I) \cup f_2(I)$. Similarly, we can very easily find a set of generating functions for other regular shapes.

Now that we have shown how to find a group of generating functions, exactly what relationship do they have to our original picture? If we map the initiator by

Fractal geometry is a new method of analyzing natural phenomena, and it can explain details other theories ignore.

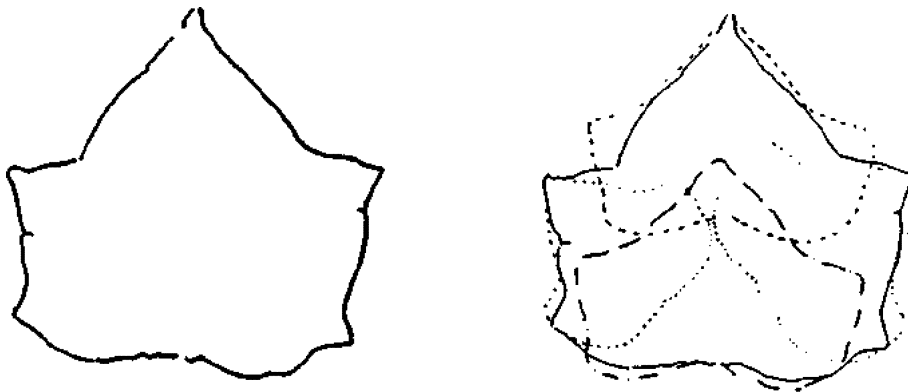
each function in the generating set and then took the union of these images, we obtain the generator. Let us call this process applying the set of functions to the initiator. Applying the functions is equivalent to one step in our initiator generator-style construction. Therefore, if we repeatedly apply the functions enough times, the result will be the same as that of the original construction -- that is, the end result will be our picture.

However, we don't even need to start with the initiator; any point or set of points will work. The functions contain all of the information necessary to specify the picture. If we begin with any area and apply the functions repeatedly to these points, we will eventually obtain the intended picture. Since all of the points are effectively 'drawn into' this picture by this repeated application, this pattern is called the attractor of these functions. Indeed, any set of such functions, when applied in this manner, has an attractor; and the attractors are usually fractals. The functions that generate a particular fractal are called its iterated function system, or IFS, characterization.

Back to Leaves

After such a long technical detour, we are ready to come back to our question. Is it reasonable that leaves have fractals, IFS patterns in particular, as shapes? On one level, surely not. A leaf is composed of cells which at least seem to be three-dimensional objects, so there is no hope. But we would not be completely wrong to interpret leaves as flat, two-dimensional objects, thinking that the shape had more to do with the leaf's area than its volume. What would we mean if we said that the leaf shape were two-dimensional? One interpretation, the one we will use here, is that the basic pattern determining the leaf's shape is planar, but that the leaf itself is

Figure 3: Covering a Leaf: Starting with a shape like the leaf on the left, we can cover it as shown on the right.



some three - dimensional approximation to this pattern, subject to various external restrictions and environmental modifications. Thus, we may see leaves as possessing a two-dimensional determining pattern. Similarly, they could have a fractal determining pattern.

Fitting IFS's

With this premise and interpretation of shape, in order to determine whether leaves could have IFS patterns, we first need to find if there are IFS images that closely approximate the shapes of real leaves. It turns out such images do exist, but we should use some caution. Barnsley, Ervin, Hardin and Lancaster (3) showed that there are IFS shapes arbitrarily close to any standard shape, and they also demonstrated a method to find these approximations. This is, for us, both good news and bad. Good news, because given a leaf, we can find a fractal very close to it. This means that if other evidence supports a general fractal/IFS model, we have some very good candidates for special models of particular leaves. Bad news, because the existence of such patterns does not tell us anything about leaves. If IFS patterns had more in common with leaf shapes than with other shapes, we would have infor-

mation to link the two concepts. Obviously, this would give us more information, but it is not the case.

For the moment, let us emphasize the good point. Barnsley, et al. (4) give a very good heuristic for finding a fractal very close in shape to some given object. Their method is what might already seem to be the obvious one - covering the original image with copies of itself (Figure 3).

This process seems simple enough, but is difficult to do by hand. Barnsley and Sloan (5) discuss a computer program that encodes images in this manner.

Given the covering by copies, called a collage, we can construct the functions for an IFS. We do so by finding the functions of the original picture that give the copies as images.

It comes as no surprise that this set of functions can be derived, but it is surprising how few functions are needed to produce excellent images of certain leaves, as in this model of a black fern. (See Cover)

$$\begin{aligned}
 f_1(x, y) &= (0, .16y) \\
 f_2(x, y) &= (.2x - .26y, .23x + .22y + 1.6) \\
 f_3(x, y) &= (-.15x + .28y, .26x + .24y + .44) \\
 f_4(x, y) &= (.85x + .04y, -.04x + .85y + 1.6)
 \end{aligned}$$

Allometry

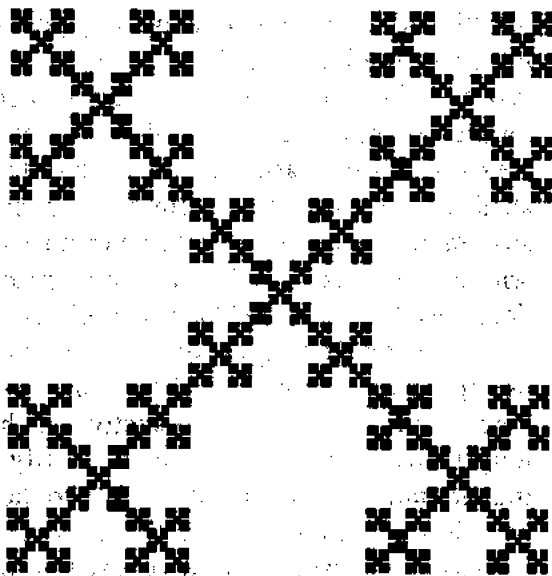
Another potentially significant property of fractal models of leaf growth is their ability to explain allometric relations. Allometry is the study of the quantitative relationships between different measures of the parts of an organism or their changes throughout development. Quite often in allometric studies relations of this form appear:

$$\log a = C + m \log b,$$

where a and b are two different measures of an organ and C and m are constants. For instance, one example would be when a is the length of a leaf and b is its width. This relation is called the simple allometry relation, because of the relative simplicity of its formula.

Several explanations of the simple allometry formula have been suggested and are discussed in Reeve and Huxley (7), though none of them are particularly biologically robust. In addition, all of these explanations assume the two measures compared have the same dimensionality.

Figure 4: The 'X' Fractal.



That is, they explain only special cases where a and b are both measurable in the same units, such as when a and b are both masses or both lengths, and fail to explain allometric relations of different types of measures. The formula can extend to other situations, for example those relating mass and length.

Fractal Interpretation

To see that this allometry relation makes sense in fractal terms, let us first verify that this mass vs length relation is a general characteristic of fractals. To start, let us look at what happens at integer D . Since it is difficult to deal with lines or planes with definite mass, we can look at appropriate three-dimensional approximations to these. Consider a wire, a sheet, and a cube of copper.

If we triple the length of the wire, it becomes three times as long, and three times as heavy. If we triple the length of each side of the sheet, it will have nine times the area and will be nine times as heavy. The cube will become 27 times as heavy if we triple its side. In each case the mass increased to 3^D times its original value.

Now let us consider an object of non-integer D . The fractal below (8), defined in initiator/generator terms, is a good example. Since its generator contains five copies of the initiator, $1/3$ as big, it has $D = \log(5)/\log(3)$.

If we look at just the central 'X' we can imagine that it has some mass. However, because of the fractal's self-similarity we see that the whole is just a copy of this central piece with each side being 3 times the size of the central 'X'. The large picture contains 5 copies of the central 'X', so it must be 5 times as heavy. Using common logarithm laws, we find that

$$3^{\log(5)/\log(3)} = 3^{\log_3(5)} = 5.$$

Generalizing this relation for every positive real number D , the formula

$$M = M_0 3^D$$

should hold, where M_0 is the mass of the original section and M is the expanded mass. Similarly, when L_0 is the original length and L is the expanded length, this equation generalizes to

$$M = M_0 (L/L_0)^D.$$

Equivalently

$$\begin{aligned} \log(M) &= \log(M_0) + \log([L/L_0]^D) = \\ &= \log(M_0) + \log(L^D/L_0^D) \\ &= \log(M_0) + \log(L^D) - \log(L_0^D) \\ &= \log(M_0/L_0^D) + \log(L^D) \\ &= \log(M_0/L_0^D) + D \log(L). \end{aligned}$$

Or, letting $C = \log(M_0/L_0^D)$, we have a special case of the simple allometry formula:

$$\log(M) = C + D \log(L).$$

Experimental Support

This formula implies that an exponential relation exists between the mass of a biological object and a measure of its length. We decided to investigate whether or not this relationship held true for leaves, and if so, whether the D calculated for each species had any significance.

As our sample, we selected five different yet related houseplants: needlepoint English ivy (*Hedera helix*), two varieties of Boston fern (*Nephrolepis exaltata*), and two varieties of Lantana (*Lantana camara*). We removed as many leaves as possible from each plant (approximately 20) and measured the mass (M) and length (L) of each leaf. We applied a least squares fit to the data of the equation

$$\log M = D \log(L) + C$$

where $C =$ constant of proportionality.

Our goal was twofold. First, we wanted to determine if there is a value D for each plant consistent for all the leaves of that plant, regardless of whether those

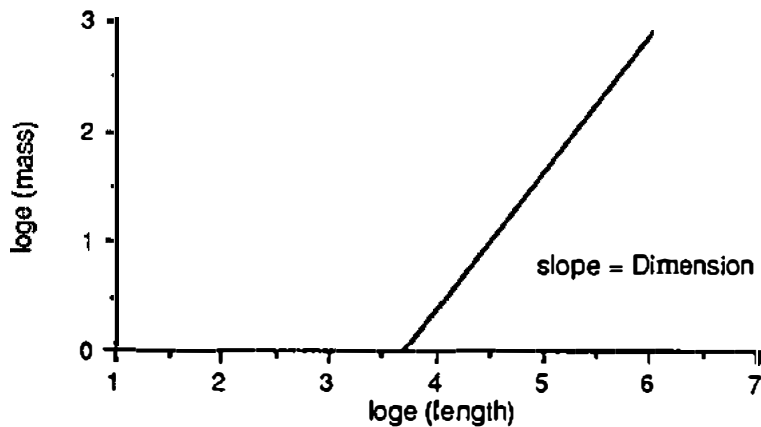
leaves are young shoots or established, mature leaves. Second, we wanted to see what meaning, if any, D might have for the interpretation and classification of leaves.

Mass was measured using a standard analytical balance, correct to 0.0001 g. Our primary assumption in this part of the procedure was that the density of matter, largely determined by the distribution of water, was fairly constant throughout all the leaves of the same plant, and that the potential loss of any mass due to evaporation was negligible within the timeframe of removing the leaves until completion of our measurements.

To obtain sufficient accuracy we devised a special technique to measure L . Our primary tools were an overhead projector, a transparent ruler, a transparent piece of plexiglass, and a flexible measuring tape. We began by fixing the overhead projector in a given spot and projecting the transparent ruler onto the blackboard. By measuring the distance between the markings on the projection of the ruler, we could calculate the relative scale of the projected object to the shadow projected on the blackboard. Comparing the distances between markings on different parts of the blackboard allowed us to avoid any possible distortion introduced by the projection process. We then placed the leaves to be measured onto the overhead, under the plexiglass. By measuring the length of the shadow and using the determined conversion factor, we were able to determine L with greater precision than would be practical if we had measured the leaves directly.

The formula simply requires that we use some linear measure of the leaf. As long as we are consistent, exactly which length we measure is, theoretically, immaterial. The best fit of the data to the equation should still yield the same D . For ease of measurement, we chose to use the length of the stem and midvein of the

Figure 5: Graph of $\log(M) = D \log(L) + \log(C)$ M=Mass of Leaf; D=Dimension; L=Length; C=Constant of Proportionality.



leaf, from the point where the leaf joined its branch to its tip. We also chose this length because we assumed it was less altered by environmental factors such as injury, or curvature of the leaf due to sunlight.

From the data from each plant, we calculated D for the leaves by fitting our data to the equation given above. Although log/log graphs traditionally have a high degree of correlation (9), we were surprised by our data's extremely high level of agreement with the theoretical equation. The data fell almost perfectly on a straight line, as seen in Figure 5.

Our lowest correlation coefficient was .986, with a $P < 0.005$. Since the coefficients were this high for all five of our plants, we can assume the allometry equation is accurate.

Given our data (Figure 6), we conclude that the allometry formula holds for plants similar to our test plants. Since we have established that this sort of allometry follows from a fractal interpretation of leaf shape, we have some support for this model of shape.

In this interpretation, the different leaves of a plant are simply different 3-dimensional approximations to the same

fractal pattern in different sizes. We can explain this simple allometry by noting that D of the fractal shape of the leaf should be constant. If we assume the same shape underlies all of the leaves of a plant, D should be consistent for each plant. The data bear out this assumption. The Ds determined, however, are not integers, so we must conclude that the underlying patterns of leaves are fractals.

Another aspect of the data, more closely related to plants, comes from different varieties of the same species. Their D were much closer to each other's than to the other plants'. If D were characteristic of the plant type, we would expect this, as related plants should have similar characteristics. Therefore, D of the leaves could provide a new taxonomic character for the classification of plants.

IFS Models and Development

Given this general support for fractal models of shape, it is interesting to consider models for the mechanism by which the shape arises and is maintained. Fractal images are easily produced by IFS's, so let us look at how an IFS model may be used to interpret growth and shape maintenance.

Figure 6: Leaf Dimension Data

D = Dimension; r = Correlation Coefficient; n = Number of Leaves; p = Probability.

<u>Plant</u>	<u>Data</u>
Needlepoint Ivy English Ivy <i>Hedera helix</i>	D = 1.18 r = .995 n = 21 p < .005
Whitmanari Boston Fern <i>Nephrolepis exaltata</i>	D = 1.40 r = .989 n = 14 p < .005
Young's Fern Boston Fern <i>Nephrolepis exaltata</i>	D = 1.47 r = .987 n = 6 p < .005
Red Lantana <i>Lantana camara</i>	D = 1.71 r = .992 n = 19 p < .005
Bronze Lantana <i>Lantana camara</i>	D = 1.80 r = .986 n = 12 p < .005

The image that an IFS determines is its attractor, obtained by infinite iteration. But there are other, equivalent, ways of looking at attractors which can be the basis for some interesting models of the growth and maintenance process in leaves. Two interpretations of an attractor give rise to rather simple models:

1) The attractor is the image of some initial points under repeated application of an IFS, and 2) The attractor is what an IFS maps back into itself.

The first of these characterizations is the basis for a very straightforward model.

Before looking at this model, it helps to understand the idea of an IFS as a recursive information passing scheme. The idea here is that given the functions and a point, any point, we can generate the entire attractor. If we start with a single activated point and the functions, then we should be able to continue to construct the pattern. To simplify things, let us assume our initial point is in the pattern. Using the functions, this point can determine the location of some other points. These points belong in the pattern because each is the image of the original point under one of the functions. The original point then activates these points. These points are now in the pattern, and they determine other points in the pattern by means of the functions. By iterating, in the end we will have all of the points in the pattern activated. We can model the cells of the leaf as these points, the activation process could then be some physical/chemical exchange which promotes cell production at a specific location or maintenance of a cell already there.

The second of these interpretations follows the first and more directly considers maintenance. Once this network of cells is created, each passing information to others, it can be seen as a first approximation to the pattern. This set of cells, however, is not stable. Cells grow and die in this pattern and yet the leaf still maintains its shape. If we assume the pattern begins as an approximation to the attractor of some IFS, then when we apply the IFS functions we gain a closer approximation. Thus, if the information passing occurred as in the previous model, cells closer to the attractor would have more cells activating them than those far from the attractor. The leaf shape could be maintained if the cells with more cells activating them stayed healthier and divided more readily, while those with fewer cells activating them died off or slowed in reproduction.

There are also several more equivalent characterizations of attractors, so it is plain that an IFS model of leaf shape will not provide a unique basis for a single, strong model of growth. But in general these models possess some common features that fit well with the current theory. Each model, requires the cells to use very little data to produce the shape of the leaf. All that is needed is some means for the cell to "send a message" according to each of the IFS functions. The process is completely homogeneous; there is no need for cell differentiation with respect to growth. That is, there are no 'foreman' cells which contain the entire leaf's 'blueprint' and govern the growth of the leaf. Since no evidence exists for this sort of differentiation, and it would require more genetic and environmental information in total, it seems good that these models remove the necessity for this assumption.

Conclusion

In conclusion, we believe that leaf shape can be understood in terms of fractal patterns for the following reasons:

First, Barnsley's Collage Theorem (12) gives models of certain leaves which match the real leaves very well without being too complicated. Other methods for specifying leaves, involving the fitting of Fourier coefficients (13) for instance, require much more data to determine the leaves shape and the IFS.

Second, the extension of allometric laws to relations between measures with different dimensions is explained well in fractal terms. In light of our data these relations seem to be present and the classical explanations of allometry fail to explain them. Fractal geometry may allow a more thorough understanding of allometric relations in the leaf.

Third, an IFS model of leaf shape provides a basis for good models of growth and maintenance with good qualities. The homogeneity and low amount of information these models require makes them preferable to more complicated mechanisms.

In view of the support for a fractal model of leaf shape, we can definitely suggest a fractal interpretation of leaves as logical. But we can only make this suggestion in general. There are several open questions on what form this model might take, which must be left to further study. These include:

Are leaf venation patterns a logical fractal approach to the entire leaf's shape? Do the Barnsley images reflect the deeper structure of the leaf shape in any meaningful way? Are the dimensions of leaves determined in different ways related, or do they apply to different aspects of the leaf?

The work included here offers possible directions in which to look in answering some of these questions. Because of the relative youth of the subject matter, however, many of these questions have yet to be considered.

Acknowledgements

This paper is the result of an independent study project on the topic of Mathematical Models in Biology. We would like to gratefully acknowledge the support and encouragement of our two mentors in this endeavor: John Jungck, professor and chair of the Department of Biology at Beloit College; and Jim Phelan, chair of the Mathematics Department at Boylan Central Catholic High School, Rockford, Illinois. Somehow, they always managed to ask the right questions. More importantly, they gave us the opportunity to discover the questions for ourselves.

References

1. Mandelbrot, Benoit B. (1982). *The Fractal Geometry of Nature*. San Francisco: W.H. Freeman and Company, p. 15
2. *ibid.*, p. 37
3. Barnsley, M. F.; Ervin, V.; Hardin, D.; and Lancaster, J. (1986). Solution of an Inverse Problem for Fractals and Other Sets. *Proceedings of the National Academy of Science, USA*, 83, 1975-1977. p. 1975
4. *ibid.*
5. *ibid.*, p.222.
6. *ibid.*, p. 1977
7. Reeve, E.C.R., and Huxley, Julian S. (1972). Some Problems in the Study of Allometric Growth. In Huxley (1972). p. 267-301.
8. Invented by Tamas Vicsek of the Hungarian Academy of Sciences. cf. Sander, Leonard M. (1987). Fractal Growth. *Scientific American*, 256 (January), 94-100.
9. *Journal of Theoretical Biology*.
10. Mandelbrot. p. 157-161.
11. West, Bruce J, and Goldberger, Ary L. (1987). Physiology in Fractal Dimensions. *Am. Sci.*, 75, 354-365.
12. Barnsley. p. 1975.
13. Kincaid, Dwight T., and Schneider, Robert B. (1983). Quantification of leaf shape with a microcomputer and Fourier transform. *Canadian Journal of Botany*, 61, 2333-2342.
14. West and Goldberger.

Additional Resources

1. Barcelos, Anthony (1984). Fractal Geometry of Mandelbrot. *College Math Journal*, 15, 98-114.
2. Barnsley, Michael F., and Sloan, Alan D. (1988). A Better Way to Compress Images. *BYTE*, 13 (January), 215-223.
3. Gleick, James (1987). *Chaos: Making a New Science*. (New York: Viking).
4. Huxley, Julian S. (1972). *Problems of Relative Growth*. (New York: Dover Publications).

TENTATIVE AGENDA

AMCBT MEETING

SEPTEMBER 22-24, 1988

BELOIT COLLEGE

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THURSDAY, SEPTEMBER 22:

EVENING

6-8PM Reception Logan Museum of Anthropology
Meet your colleagues and share refreshments. We will also offer a behind the scenes tour of Beloit's internationally known collection. The Logan Museum of Anthropology was begun with artifacts collected in the 1890's. The tour will be led by Henry Moy, Director of the Beloit College Museums.

8PM Opening Speaker Godfrey Auditorium

FRIDAY, SEPTEMBER 23:

MORNING SESSIONS

8:30-9:15 Concurrent Sessions Various Locations

Tackling the Literature of Science Mathers Room A
Sister Renee Costanzo
Cardinal Stritch College

An overview of a progressive plan to introduce biology majors to scientific literature in a small liberal arts college.

Clarence Darrow and Critical Thinking Mathers Room B
Laddie J. Bicak

To biologists, the name Clarence Darrow and "the Dayton Case," or Scopes trial, are nearly synonymous. As pertinent as this case is to the teaching of biology, the work of Mr. Darrow offers other insights to critical thinking.

From Forest to Home Weeks Lounge
Bill Brett
Indiana State University

A curriculum designed to get students to appreciate the amount of forest required to build a home and heat it with wood and the ramifications of these requirements when extended to the U.S. population.

Video Microscopy

Chamberlain 400

Dale Fast
St. Xavier College

We would like to provide a sharing session here so that we may all benefit from your success and not-so-success with this technique. If you would like to share your materials please contact Dale Fast at St. Xavier College, Chicago, Ill. 60655

10:15-11:00

Concurrent Sessions

Various Rooms

Galapagos Islands

Mathers Room A

Sister Marion Johnson
St. Xavier College

Slides and narration/discussion on her recent trip.

Sound Computerized Instruction

Mathers Room B

John P. Messick
Missouri Southern State College

Where Should We go In Teacher Education?: Panel Discussion

Weeks Lounge

Ann Larson, Moderator
Sangamon State University

Teaching Writing to Undergraduates: Panel Discussion

Chamberlain 400

R. L. Wallace
Ripon College

FRIDAY, SEPTEMBER 23: AFTERNOON
PARTICIPANTS WILL BE GIVEN A CHOICE BETWEEN
CONCURRENT WORKSHOPS AND FIELDTRIPS.

FIELD TRIPS

Prairie Trip

Newark Prairie

Dr. Dick Newsome
Beloit College, Dept. of Biology

We will visit one of the remnant prairies in the Beloit region to view variations in species compositions and to discuss controlling factors, ecological research, management problems and conservation issues.

Area Food Processing

Monroe and Beloit, WI

Dr. Roc Ordman
Beloit College, Dept. of Chemistry

We will visit several of the area food processing plants, examining both their processing areas and research laboratories.

Canoe Trip

Dr. Dick Stenstrom
Beloit College, Dept. of Geology

Brodhead to Monroe, WI

A canoe trip down one of the small rivers between Brodhead and Monroe.

Fossil Hunting Trip

Carl Mendelson
Beloit College, Dept. of Geology

Local Rock Quarries

Several back road quarries waiting to show their treasures to you!

WORKSHOPS

1:15 - 2:45 **Concept Mapping: Lecture** **Various Rooms**

Concept Mapping A Strategy For Teaching and Learning

Laine Gurley-Dilger
Rolling Meadows High School, IL

Mathers Room A

2:45 - 3:45 **Concept Mapping: Computers** **Various Rooms**

Computer Remediation for Concept: Map Instruction

Laine Gurley-Dilger
Rolling Meadows High School, IL

Computer Lab

2:00 - 5:30 **Concurrent Sessions** **Various Rooms**

Respiratory Assessment Labs

Harold L. Wilkinson
Millikin University

Mathers Room B

Techniques and Application of Radioisotope Tagging and Autoradiography MI 200

Albert R. Gordon
Southwest Missouri State U.

FRIDAY, SEPTEMBER 23:

EVENING

6 - 8 pm **Reception** **Pearsons Hall**

8 pm **Dinner and Main Speaker** **Pearsons Hall**

Dr. Jim Stewart
Science Education, UW Madison

Jim is the recipient of the Science Education paper of the year which he received at the most recent NSTA meeting. He will speak on aspects of current science educational research about problem solving, conceptual change in students, and students' alternative conceptions.

SATURDAY, SEPTEMBER 24: MORNING SESSIONS

9:00 - 9:45 Concurrent Sessions Various Rooms

You Can Make SENSE TOO!

**C. Robert Wikel, Doane College
Richard Wilson, Rockhurst College**

Mathers Room A

Will share their experiences with some sensible, working programs and services for area in-field teachers.

Teaching Evolutionary Biology to Non-Majors: Panel Discussion

**Malcom P. Levin, Moderator
Sangamon State University**

Mathers Room B

Student Biology Organizations: Panel Discussion

**Jerry Foote, Moderator
University of WI, Eau Claire**

Weeks Lounge

Neuroscience Activities

**Kathleen Parson
Macalester College**

Chamberlain 400

10:00 - 10:45 Concurrent Sessions

Various Rooms

Tackling Student Attitudes in the Sciences

**Alfred Pogge
Quincy College**

Mathers Room A

Student Research and Funding Opportunities

**Bill Doemel
Ann Doemel
Wabash College**

Mathers Room B

The Biology of AIDS

**Susan Speece
Anderson College**

Weeks Lounge

SPECIAL NOTES

There will also be special interest tables at meals for subject area groups to meet.

Transportation is easy to Beloit by Interstate and there is convenient transportation to and from O'Hare airport about 9 round trips a day.

Application for Membership

ASSOCIATION OF MIDWESTERN COLLEGE BIOLOGY TEACHERS

NAME _____ DATE _____
TITLE _____
DEPARTMENT _____
INSTITUTION _____
CITY _____ STATE _____
ZIP CODE _____
ADDRESS PREFERRED FOR MAILING _____
CITY _____ STATE _____
ZIP CODE _____
PHONE NUMBER _____

MAJOR INTERESTS:

- () 1. Biology
- () 2. Botany
- () 3. Zoology
- () 4. Pre-professional
- () 5. Teacher Education
- () 6. Other

RESOURCE AREAS:

RESEARCH AREAS:

Have you been a member before? _____ If so, when? _____

Mail To

**Edward S. Kos
Executive Secretary, AMCBT**

**AMCBT Central Office
Department of Biology
Rockhurst College
Kansas City, MO 64110**

CURRENT DUES ARE \$10.00