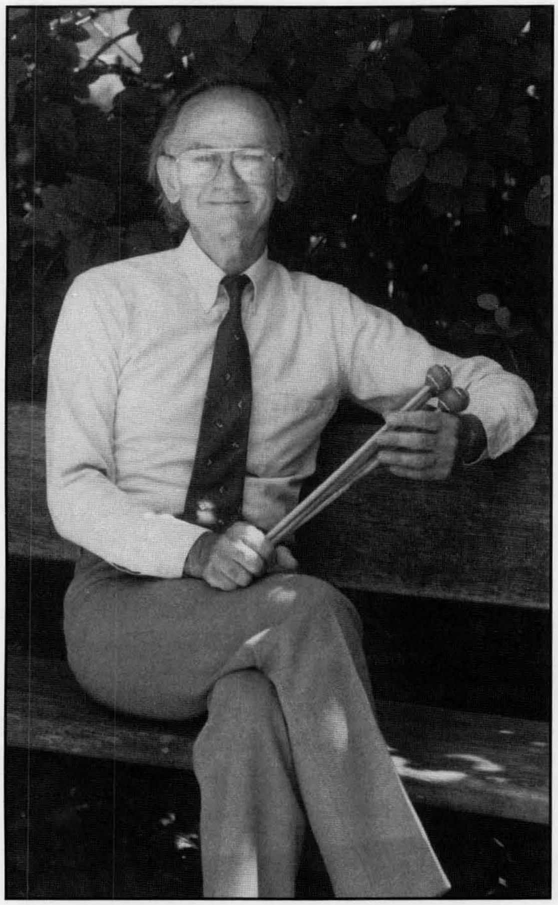

Kenneth R. Jolls

of Iowa State University

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If Kenneth R. Jolls were the main character in a novel, it would probably tell about a child who took a toaster apart and used its components to beat an intricate rhythm on the kitchen table. In real life, the young Kenneth *did* take a toaster apart (and couldn't put it back together), but his musical talent didn't surface until high school when he picked up a guitar his older brother had left behind. Still, science and music (specifically, chemical engineering and jazz) shaped Ken's novel life.

Ken started as a musician in his hometown of Raleigh, North Carolina, in the era of big bands and small combos. His first job, as a high school sophomore playing guitar in a quartet, paid $9 a night. Occasionally he worked with a vibraharp player—a relatively new instrument that had its origins in vaudeville. "I was captivated by the sound and also by the sight of the mallets—usually two, sometimes four—racing over the bars, so I began teaching myself to play," Ken remembers. He would eventually captivate his own audiences with the mallets—sometimes five of them—dancing over the aluminum bars in complicated patterns. But that rushes the story.

In the tenth grade, Ken was certain music would be his career. At school he played the tuba and occasionally solo marimba; in professional country and commercial dance bands he played the guitar and the vibraharp. After graduation he enrolled at North Carolina State "because it was there." He chose nuclear engineering as his major (his father had encouraged him to "get into something more focused") but worked part-time as a rural high school band director and played in clubs on weekends. Then he won a scholarship to the highly regarded music school at Indiana University, chosing the tuba as his major and paying his bills by playing baritone horn in the marching band and writing music for football half-time shows. He soon switched to a music theory major with a percussion emphasis that included lessons on the marimba but not the vibraharp, although he owned one by that time.

But bulbar polio intervened, and instead of returning to Indiana in the fall of 1954, Ken found himself in an iron lung in a Raleigh hospital. As he recovered he began playing again. One of the groups he played with was the Duke Ambassadors, Duke University's popular big band, and that contact with Duke students encouraged him to enroll at Duke. He earned tuition fees by playing the university's carillon, writing music for half-time shows, playing with the Ambassadors, writing many of their arrangements, and, as a senior, leading the group.

Duke also whetted Ken's appetite for academics in general and science in particular. So, Duke music degree in hand, he went back to North Carolina State to earn a second bachelor's degree, this time in chemical engineering. Dance jobs and even a stint in a country-western band on a live weekly TV show paid his bills. During his five semesters at NC State, Ken also sampled the professional world of chemical engineering through summer jobs at DuPont and Sun Oil.

One of his favorite professors, Kenneth O. Beatty, suggested graduate school, and Ken was soon working for Thomas J. Hanratty at the University of Illinois. "Tom was one of the great formative people in my life," Ken says, "but he wonders to this day how I 'kept the music hidden.' I didn't *think* I was hiding it," Ken says—he played frequently during those years, including once for Bob Hope. "I was playing the piano," Ken recalls, "and he asked if I could play *Thanks for the Memory.* My response was, 'What key?'"

Ken was one of the first of Tom Hanratty's students to work on the now-famous diffusion-controlled electrode technique to measure mass-transfer rate and shear stress in flowing liquids. In Ken's case, the system was a packed bed. The apparatus was a glass column six feet tall and twelve inches in diameter, filled with 11,000 1-inch glass marbles. Most of their research involved electrochemical measurements, but they also did some visualization studies using dye to confirm the onset of turbulence. Their work became part of the basic packed-bed literature and is still cited.

The first year of graduate school was awful, Ken says. "There I was, a musician, in Harry Drickamer's class, of all places, competing with *real* chemical engineers. But when I passed the oral prelim, I realized I would get that PhD." He did, and a subsequent series of interview trips landed him a job at the Polytechnic Institute of Brooklyn.

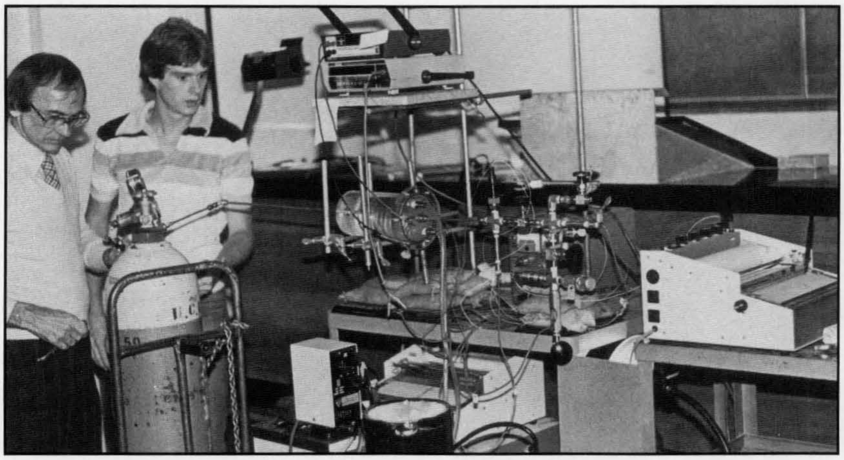
When his new department head, Jim Conti, asked him what he wanted to teach, Ken replied, "Anything but thermodynamics." But Ken's first course assignments had him facing thirty-five New York City seniors three times a week to teach them—thermodynamics. "Fortunately, I had the second edition of Smith and Van Ness," Ken says, "but I was never more than two or three pages ahead of the students." John McFeeley, now a senior manager at Polaroid who considers Ken the "most significant influence in my professional career," recalls some of Ken's initial teaching devices: "Maxwellian demons, the Ideal Rubber Band Law, and even the little-publicized Zeroth Law of Thermodynamics."

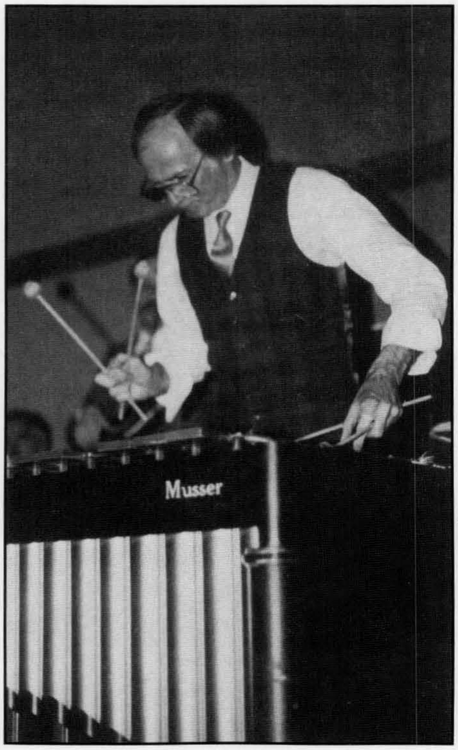
A few useful revelations resulted from that year, Ken says: "I realized I didn't understand thermodynamics; if possible, my students understood even less about it; and even when I did understand it, I didn't know how to explain it."

Ken concluded that there had to be a better way to teach thermodynamics, but he didn't start pursuing it because he had added electronics and instrumentation courses to his academic repertoire. A flair for instruments and circuits, discovered in graduate school, led him to associate with chemist Howard Malmstadt who had been presenting "Electronics for Scientists" courses at Illinois since the late 1950s. Ken went back to Illinois for several summers to teach with Malmstadt and also taught his own NSF summer electronics courses at Brooklyn Poly while writing a series on the subject for *Chemical Engineering.*

Ken also contributed a session on "Harmonic Oscillators" at Brooklyn Poly's annual Executive Technical Development Program. His after-dinner session, scheduled near the end of three weeks of intense continuing education courses on statistics, math, and semiconductors, sounded oppressive to the executives in the program. They were relieved, however, to discover that the oscillators were vibraharp bars, the harmonies were jazz "changes," and the lecture was on the history of jazz. "I didn't even mention Fourier," Ken says.

During his New York years, Ken also played the "wedding-Bar Mitzvah-Scandinavian circuit." At one memorable dinner-dance in New Jersey, many of the guests came with bodyguards, and at another job Ken was playing in the Grand Ballroom of the Waldorf Astoria while Robert Goulet sang in the room next door.





Ken, equally hard at work preparing a demonstration of the Joule-Thomson process (shown above with Ron Cotterman, John Prausnitz's grad student) or manipulating the mallets (right) for his own and others' enjoyment.

But then he left the Big Apple for Iowa State University. "I was getting serious about teaching thermodynamics by this time," he says. "I didn't think we needed another textbook, but we *did* need better ways to explain fundamentally difficult concepts. We could demonstrate fluid flow in a pipe and do experiments showing heat and mass transfer, for example, but we couldn't demonstrate enthalpy or buy an entropy meter." For him the better way was visual: "I was convinced that many of the thermodynamic subtleties that usually bewilder students could be represented graphically, and that the phase diagram was the basic structure for doing this. I may not have been very sophisticated in thermodynamics," Ken recalls, "but I had discovered that textbook authors liked to draw pictures of thermodynamic surfaces."

"Gibbs postulated these connections more than a century before machines were invented to visualize them," [Ken] marvels. "It's a stroke of fortune that we now have the ideal scientific visualization tool—computer graphics."

In the early 1970s, Ken saw a thesis that used a 3-D plotting program to locate the minimum points of a function showing the economics of power-plant design, and the connection to using the computer for thermodynamic drawings became obvious to him. "I wanted to try 3-D pictures, and the PVT diagram was the simplest I could think of," he says. Over the next five years he and three students wrote computer programs to draw phase diagrams for pure fluids, using the geometrical operations associated with projecting 3-D images onto a 2-D plane. With steam-table data they drew a variety of thermodynamic functions and published several papers. They also tackled mixtures. Kenneth Starling at Oklahoma provided a program that generated mixture data, and two more students joined Ken to do the graphics.

Ken's drawings were more than just cosmetic; they were quantitative, and they were helpful in teaching. But they were still just "a picture of this, and a picture of that," he says. No conceptual links existed among the drawings until he discovered *Thermodynamics and Its Applications,* by Modell and Reid. The textbook changed the way he thought about and taught thermodynamics.

Modell and Reid described "a fundamental equation that sits at the top of the thermodynamic hierarchy and contains all the information about the variables," Ken explains. The Legendre transform connects the various fundamental forms, and the applied functions, such as PVT, heat capacity, and refrigeration diagrams, are derived from them." To learn more about this connectivity, he went on leave in 1981 to work with John Prausnitz at Berkeley.

Meanwhile, Ken hadn't neglected his aural art. During his early years in Ames he played for Sonny and Cher and for Helen Reddy, as well as numerous area events. He played in shows such as *Pippin* and *The Fantastiks,* directed the orchestra for the musicals *Hair* and *Jesus Christ Superstar,* and occasionally played percussion with the Des Moines Symphony. At Berkeley he played a Noon Concert in Hertz Hall with two Bay area musicians.

A letter Ken received at Berkeley changed his approach to his visualization work. "When two minds separated by many years . . . arrive independently at the same conclusion (concerning the usefulness of graphical methods)," wrote North Carolina State chemistry professor Henry Bent, "perhaps . . . there is something compelling to that conclusion. Indeed, the time is probably ripe for someone with the proper gifts and interests and experience to go back over that ground covered by Gibbs, from the standpoint of the capabilities of modern computers. You may be precisely the right person for that project."

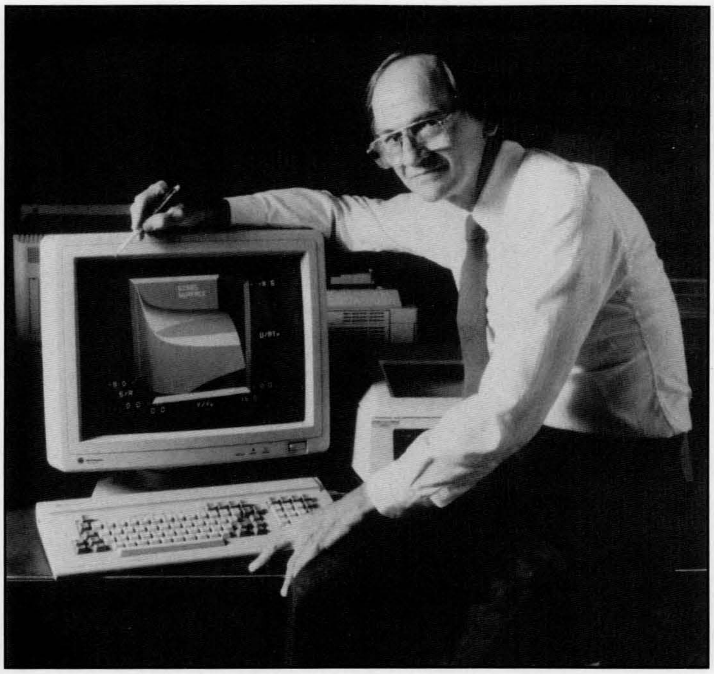
That message sent Ken to the library for J. Willard Gibbs' original accounts of his geometry-based formulation of thermodynamics. Gibbs' elaborate descriptions of lines, planes, and contours described intriguing rationales for the state of a system and for the tendency—through consideration of thermodynamic stability—for those states to change. For the first time, Ken says, someone had proposed a geometric art form to show the structure and logic of thermodynamics.

"Although Gibbs used very few drawings, he had an exact geometrical analogy for phase transitions," Ken says. "It was based on the energy-entropy-volume surface with its changing curvatures, and it used a plane rolling over the surface to reveal not only the property values but also the phase transitions associated with those changes. If you have the fundamental equation model for a particular system and the right kind of geometrical tools, you can roll that plane and determine precisely all the thermodynamic properties one normally tabulates. I found that idea fascinating and learned that other people found it fascinating, too, and had tried to model it." But their efforts, all done by hand, were imprecise—and as one-of-a-kind models, gave no hint of the connectivity Gibbs had described.

Ken was convinced that the Gibbsian approach could explain how thermodynamic functions are related and thus remove some of the abstraction that makes it such a difficult subject. "Gibbs postulated these connections more than a century before machines were invented to visualize them," he marvels. "It's a stroke of fortune that we now have the ideal scientific visualization tool—computer graphics."

After returning to Iowa State, Ken discovered that Keith Gubbins at Cornell shared some of his interests in graphics, so he spent a semester there teaching thermodynamics and working on the visualization processes. But he found that the facilities, good as they were, could not accomplish what he wanted to do.

By the time he returned to ISU, he was quite comfortable with the Modell and Reid approach to thermodynamics and the concept of using fundamental equations to reveal the various levels of stability and provide a logical flow of information for developing practical tools. Still, interest in using the geometric approach for teaching was limited. "I couldn't understand it," Ken says. "All the complicated things we talked about we could now see—all the interesting thermodynamic effects we deal with we could now visualize."



Gibbs postulated geometric analogies in thermodynamics more than a century before machines, like the one above demonstrated by Ken, were invented to visualize them.

"Thermodynamic diagrams show many relationships that otherwise require verbal, numerical, 'left-brain' processing," Ken says. "I am utterly convinced, and enough others who understand thermodynamics agree, that this is the way, maybe the best way, to solve the long-standing teaching problem in this difficult subject." As physicist Herbert Callen wrote to Ken, "your elegant pictures" mean students will "have a more concrete view of a subject which has always been hampered by its abstract nature."

Of course, visualization skills are not distributed equally throughout the population. "I didn't realize when I started that people learn in different ways," Ken says. "Learning through visualization was natural for me, and twenty years ago I assumed it was natural for everyone else, too. Even though it isn't ideal for everyone, visual learning does work well for many people. But the pedagogical methods we use in engineering tend to ignore them."

In 1984, a computer engineering student, John Ries, added an interactive shell to one of Ken's PVT programs, allowing users to input data more easily. Computer equipment had also improved by this time, and color was available. Another undergraduate student, Dan Coy, created a PC version of the program, and these changes liberated the process of making the drawings and changing them to fit specific situations. Ken named the program "Equations of State," added tutorials and documentation, and began taking it to conferences and writing about it. Although some viewers didn't "get it," others thought it was marvelous, and thermodynamics teachers around the world (nearly fifty of them to date) bought it for use in their classes.

"I knew what was hard about thermodynamics, and I knew what would make the course better and help students learn," Ken reflects. "In this case, I needed the power of the computer, and I molded the tool to fit the subject. I think too often it happens the other way around: the computer looks like a neat tool and someone contrives a way to plug it into a course. Unfortunately, it may not add anything of substance; it may not be a genuine improvement in the course or in the way it's taught. The judicious use of technology to do something substantive in teaching can enhance a good textbook and even a good teacher," he adds. "Too often the computer is much ado about not very much. Students rave about 'Equations of State' because they can do things with the computer that they can't do any other way." As Imre Zwiebel at Arizona State puts it, Ken's program "makes students think before they plunge into a problem."

Students also rave about another program Ken developed. When he began teaching the separations course at ISU, he realized he couldn't assign some of the most interesting problems because the computations were too hard. "But with process simulators like FLOWTRAN or ASPEN to do the calculations, students could work on these more realistic examples in absorption, distillation, and extraction," he notes. Since those solutions almost always end up in graphical form as stagewise operating diagrams, it seemed obvious to Ken that he could use computer graphics for the drawings. One of his graduate students, Deepak Lumba, wrote a program to extract the numerical results from FLOWTRAN and produce the stagewise displays; another student, Michelle Nelson, wrote a program to let students run the simulator interactively. The combination produced "Simulation Graphics."

"I think it's an enormous advance in teaching separations processes," Ken says. "You can do complicated separations quickly, repetitively, and in different modes and then see the results graphically." Students agreed, and Dick Seagrave, Ken's department head during most of that development period, told him "Simulation Graphics" was the best thing he had produced.

And through it all was the music. Ken played at after-

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EDUCATOR: Ken Jolls

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concert dinners for three major orchestras (Philadelphia, Baltimore, Leningrad). He has played "Jazz in July" concerts in Des Moines each summer, a public TV special with a Des Moines personality, and numerous club dates. He hosted a reception for jazz vibes player Gary Burton, hosted a visit by pianist and radio personality Marian McPartland, conducted honors courses on jazz and improvisation, and presented pre-concert programs about the Modern Jazz Quartet and Marian McPartland.

And he kept thinking about Gibbs and his geometrical formulation of thermodynamics, but those drawings were harder to do. They needed more sophisticated equipment, for one thing, and in 1986 Ken got it: an NSF grant provided a Silicon Graphics IRIS 3030—the first advanced graphics workstation at ISU. On it, graduate student Michael Schmitz generated the first Gibbs surface—the Helmholtz energy function for a pure fluid—using Movie.BYU software.

Later, graduate student Day Coy produced the complete set of four pure-fluid images based on the Peng-Robinson equation for ethylene. "Those first Gibbs images represented a fixed amount of mass, but that isn't necessary in thermodynamics," Ken says. "The mathematical description of a thermodynamic system can be scaled in a variety of ways, depending on the ultimate use of the results. Dan later worked out schemes so that drawings could be made according to all scalings possible. To some people they seem almost like a circular set of representations of the same thing through the power of the Legendre transform. But these are necessary redundancies that give us more useful forms.

"Dan was able to generalize both the thermodynamics and the graphics schemes for producing the surfaces. He was able to comprehend the three major aspects of the project: the thermodynamic connectivity, the computer programming, and the visualization. His dissertation is a masterful piece of work," Ken says. "This is the first time these drawings have been presented in any connected, quantitative, knowing—even artistic—way. We thought about color, lighting, perspective—what we needed to make the contours convincing." Ken calls the drawings "the art of thermodynamics."

"If you take the time, you can look at every function in Modell and Reid and see that 'this comes from that and with good reason,'" Ken says. "Sometimes those reasons are pretty subtle, but they're all rooted in the structure of classical thermodynamics and in stability theory. That's what makes it all work. If it weren't for thermodynamic stability, the world would be a single-phase blah," he adds. "Stability theory says that we have preferred states—things boil, condense, freeze, form crystals. Dan's dissertation has drawings that show those ideas."

But it hasn't always been easy. "Funds are hard to get," Ken notes, "and funds for teaching improvements—especially for teaching improvements that don't involve laboratories—are even harder to come by." Ken has had NSF funding and grants from the Dreyfus Foundation and Union Carbide. "I was warned against doing this work," he recalls, "and I wouldn't advise a new faculty member trying to get tenure to do it either. To do this stuff right takes a lot of time. And you can't work in a vacuum; you need support from the department and the department head, plus release time. It doesn't work very well as an add-on."

Academic software needs to be documented, it needs to be used, and it needs to be reviewed, just like other scholarly efforts, Ken says. If the work is done right, the intellectual effort to develop teaching software is no different than the intellectual effort to do research. "That's not a popular opinion," he adds, "but it's the truth."

Jazz requires intellectual effort, too. "I learned chords when I started playing the guitar," Ken says. "And because I have a mind that tends to organize things mathematically, I figured out what the link was to other musical forms, and I saw ultimately how jazz fits into general music theory.

"I also have a good ear. A friend in music school once said I could 'hear around corners,'" Ken recalls. "That basic ability to detect harmonies is crucial. I was born with the nerve endings that create a good ear and a mathematical mind," he adds. "Seeing those traits reproduced in my son removes any doubt about the genetics," Michael Jolls works as a programmer analyst in St. Louis, plays guitar and piano, and does magic.

"I call it a quantitative ear," Ken explains. "I hear harmonies, realize exactly what creates them, and can reproduce them; I can connect what I hear—or even just what I think about—to the way to play it. Because of my formal training in theory, I can also talk about it, and often do—but it's still easier just to play it."

Jazz on the vibraharp is geometrical, too. "There's no magic," Ken says. "You just spread the two, four, or five mallets and turn them so as to connect pairs of points with straight lines." One of the things that keeps him playing is that he can. Even though he doesn't practice very much, he can shift into music mode very quickly. "Sometimes I feel like I won't be able to find middle C," he groans, "but once I get the mechanical thing going, I can do about 80% of the rest off the top of my head."

In jazz, a composer writes chord structures to fit a melody, and an improviser plays a line of notes that fits those chords but is different from the melody. That requires a willingness to take risks, to deviate from the formula, to step out of the mold and try something new, Ken says. Of course, that's what he's done in thermodynamics with his quantitative eye—with his work to express scientific ideas visually. "There must be a connection," Ken says, "or a very strange coincidence." Well, truth is often more novel than fiction. ❐