special feature

perspective on

how to skate on the edge of the paradigm . . . . . and keep from falling off

an interview with Nicholas J. Turro

"Long before it was popular, Turro brought together a team of faculty, graduate students and undergraduates to create interactive software tools that could teach students in new ways. What emerged was an animated infrared spectroscopy tutorial so far ahead of its time that a decade later IR Tutor still defines the field. It is used worldwide, can be found embedded in the digital supporting materials for the most widely used textbook of organic chemistry and is distributed by the world's leading scientific instrument maker with infrared spectrometers sold to industrial and academic users."

Professor Leonard W. Fine, Columbia University, from his nomination letter for the Pimentel Award

Courtesy of Nicholas J. Turro

During his summer break from graduate school at Caltech in 1959, the late Peter Leermakers dropped by the Connecticut State Water Laboratory at Wesleyan University to visit a friend. Leermakers had worked summers there while an undergraduate at Wesleyan, and became friends with a younger chemistry student, now about to begin his senior year at Wesleyan. "Caltech is the place to go for your Ph.D.," Leermakers advised. "You've got to work with George Hammond on photochemistry."

Young Nicholas J. Turro took the good advice, and launched a career as remarkable for its achievements outside the laboratory as in. In the lab, there has been pioneering research with the photon as a reagent for initiating reactions and as a product of the deactivation of excited molecules. But inspired by the excellent teachers and mentors he had at Wesleyan and Caltech, Turro developed a passion for teaching and learning and, over the past decade, has been at the forefront of efforts to integrate new information technology tools into chemical education and develop other new approaches to chemical education.

The American Chemical Society (ACS) recognized those efforts, selecting Nick Turro as recipient of its 2004 George C. Pimentel Award in Chemical Education.

"His plan was to use the 'hook' of the excitement over the newly emerging World Wide Web and personal computers as effective teaching and learning tools," the ACS said. In the early 1990s, working with colleague Leonard Fine, Turro provided the intellectual structure for the "IR Tutor," an interactive computer program for teaching or self-learning IR spectroscopy. IR instrument manufacturers have used the module as a tutorial for their instruments, as a supplement to organic chemistry textbooks, and as an aid for students to learn IR spectroscopy.

The success of IR Tutor and by extrapolation the power of computer tools encouraged Turro to introduce computer tools and the Internet in general in his educational activities. In 1994 he developed a Web-based resource center to help science faculty create information technology teaching tools. In 1999, Columbia expanded Turro's model to set up the university-wide Center for New Media for Teaching & Learning, which helps faculty create interactive learning programs to enhance both undergraduate and graduate education.

The National Science Foundation recognized those and related educational innovations in 2002 by selecting Turro as a recipient of a $300,000-NSF Director's Award for Distinguished Teaching Scholars.

Turro's first textbook on photochemistry appeared a year after he joined the Columbia University faculty in 1964. In 1978, came *Modern Molecular Photochemistry*, the field's current definitive text. He's working on a revision of the text (with V. Ramamurthy and J. C. Scaiano) that is scheduled to be in press by the end of 2004.

During the course of his career, Turro has mentored the Ph.D. theses of 70 graduate students and supervised the research of more than 160 postdoctoral associates and 100 undergraduates.

Far beyond that, however, a major element of Nick Turro's success is his genuine goodness and concern for others—his students, family, profession, and university. The world would be a better place, indeed, with more of Turro's ideals, enthusiasm, and energy.

In this conversation with *The Spectrum*, Turro discusses some of his concerns and aspirations for students, especially in regard to that ever-mushrooming mass of information called the chemical literature. He also shares 40 years of insights on managing a research group, goes out on a limb with predictions about photochemistry's future, and addresses a range of other topics.

Born in Middletown, Connecticut, Turro earned a B.A. in chemistry from Wesleyan University in 1960. After a 1963 Ph.D. from Caltech under Hammond (who won the Pimentel Award in 1974) and a postdoctoral year at Harvard University with P. D. Bartlett (Hammond's Ph.D. sponsor), Turro joined the faculty of Columbia University where he is the William. P. Schweitzer Professor of Chemistry.

His honors include membership in the National Academy of Sciences and the American Academy of Arts and Sciences and numerous awards for work in photochemistry, spectroscopy, and supramolecular chemistry.

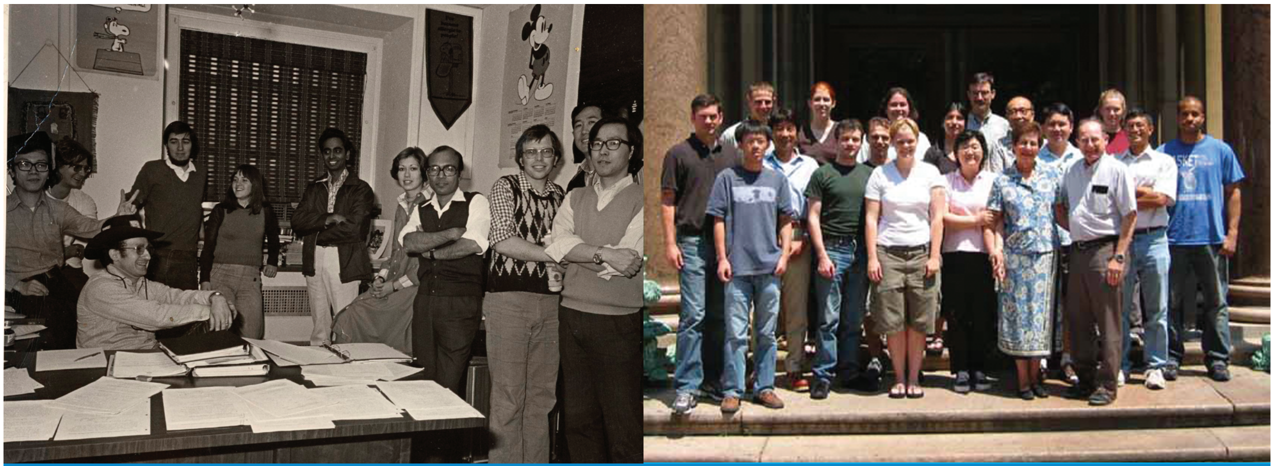
***The Spectrum:* Your students say that one of the most valuable lessons they've learned in the Turro Lab involves the importance of "mastering" the chemical literature. What's your definition of mastery?**

Turro: You can never totally master the literature. But there are certain levels of mastery that are essential and are straightforwardly achievable by all students. In fact, there is a certain attitude that students should take with respect to the literature. Most students don't fully appreciate the importance of this attitude until they discover that somebody knows something that they themselves should have known and could have known if they had studied the literature properly. The basic attitude required is that you should be familiar with enough of the literature so that you never unnecessarily repeat work published in the past and that you should be aware in broad strokes of what has been published in the past.

Students need to be aware that when a paper is submitted for publication, a lack of knowledge of the literature leaves them open to the professional embarrassment that occurs when some knowledgeable referee cites data published in the past that supports (pleasant surprise), or undermines (awful surprise), or duplicates (unpleasant surprise) what you've reported, and says, "You really should have known about this work." That's one level of mastery. The other level involves scholarship. Everyone should feel a certain level of duty and curiosity to dig into the literature and to finally reach the point where one is comfortable that they know essentially everything that's important about a subject.

I think that some students don't really get there for a variety of reasons. They may not understand the importance of the literature because they tend to think that you, as their mentor, already know this stuff and that it is your job to handle the scholarship part. Due to their dependence on the web, students don't seem to know how to use a library effectively any more. Rather than go to the library, they go to the web, and punch in a few key words. Something comes up or something doesn't come up. And to them, that's it. If it doesn't come up, it doesn't exist. After reading the literature for 45 years, I know it still may take a while to find a paper—especially that very important article that's right on the money and relevant to your project. It is really discouraging sometimes to know that students sometimes cannot find a very important article that you know exists. Even worse sometimes is to give a student the journal's and the author's name, and they'll still come up dry.

That's what I mean by mastery. Mastery means to reach a level of comfort and confidence with one's knowledge of a subject, not only from a scholarship standpoint but also from the ability to really mine the data and prosper in the literature of a field. When you know "it's been done," before, you know the kind of techniques that have been used, and the parameters. With mastery of the literature, you can move rapidly in your research because you know how to mine the existing data and find out the important information without having to waste time in the lab discovering how not to run an experiment or rediscovering artifacts, which every technique has hidden from the novice.



The Turro Group in 1976 (left) and in 2003 (right). Courtesy of Nicholas J. Turro

The Spectrum: **In a talk a few years ago, you quoted a student who summarized the Turro Corollary on mastering the chemical literature in one sentence: "Three months in the laboratory can save a couple of hours in the library."**

Turro: That's a great, great, quote. I attribute it to Matt Zimmt, one of my very best students (now a Professor at Brown University) who taught me an awful lot about areas in which I was a novice at the time. I think Matt's point was that many students love to do lab work, but do not like searching the literature as much. However, some students possess a different attitude: "I don't need the literature, I can figure things out for myself." Or, "Literature is for wimps." I don't understand those attitudes about not going to the literature and looking something up. Oh, sure, I can accept that a starting student who gets into a new area, wants to get into the laboratory and splash around a little. But only up to a certain point, especially when the results are not working out. You know somebody made it work out in the past, then you've got to get into the literature and dig. Yet in some cases the student still doesn't stop and check the literature. It is fundamentally inexcusable and there is no way to condone such an attitude. It's what I will call fundamentally unprofessional behavior.

Here's a typical situation. Give the student a reprint of a former student's work, and they repeat the procedure, but "it doesn't work." They keep trying. Time goes by. Then I'll ask, "Well, did you go to the lab notebook?" And they look astonished, and ask, "Go to the notebook?" Yeh, we've got the notebook. They'll go to the notebook, and realize that their predecessor used column chromatography to purify that compound and not the technique they were trying. There's your three months in the lab right there. As a professor, you assume that the student did the minimal stuff and looked it up, but unfortunately many times they didn't.

This brings up another issue. You cannot be subtle with respect to the literature. In my experience, you have to be explicit to many students in terms of what they've got to do in terms of handling the literature. So here's how we've been dealing with it. We have identified a set of topics that are important to our group, and collected reprints and PDFs of all the relevant articles and organized them in a way that will be useful. For each topic, there is review and primary literature, both are listed chronologically. When you start delving into a topic, you start with the most recent reviews or primary literature and work your way backwards. The group has created areas of "core competence" over the decades and there is a literature that will reveal the history of these areas to novices who are entering the fields. It is now clearly expected and required that a student entering a new area will check out the literature that is on our list.

The Spectrum: **And with the Web, you can be pretty confident that this in-house database is comprehensive?**

Turro: The web and literature search engines are great and very useful. However, we need greater awareness about the limitations of web searches. A literature search on the web is a nice, quick way to get started. But you've got to use other resources, including the library, local experts, and experts anywhere you can get hold of them. There are lots and lots of reviews in the literature on various subjects that are buried away. Somebody spends an enormous amount of time writing a review or a book and sometimes their great reviews are not cited because nobody knows they exist. The only way you know it's there is to spend hours in the library looking though, say, *Advances in Photochemistry* or *Organic Photochemistry* and seeing what articles are there. We've gone to the web and found out there are all kinds of reasons why you can't find some of these articles. There are typographical errors, for instance, or SciFinder just doesn't categorize materials in certain books or review journals. Monographs like *Annual Reviews of Physical Chemistry* fall somewhere between a journal article and a book. There are great articles in these books on various subjects and you could totally miss them unless you physically go to a well-stocked library and look and search by hand. An approach like this has a richness and robustness to it. I haven't figured out any other way than to literally go down and start thumbing through the volumes, and start thumbing through the tables of contents. We also photocopy journals' tables of contents, and we keep them accessible to the students as part of the organization program described above.

The Spectrum: **Do you get involved at all in this winnowing process?**

Turro: Oh, yes. Every Saturday, if I can, I go down to the library and go through about 40-50 journals by hand. I use a spreadsheet in a lab notebook to keep track of any article that I think is, or might be, of future interest, and I make brief notations about each article. My wife, Sandy, photocopies the articles, or gets PDFs, and puts them into 3-ring binders for the students to use. Come to the lab sometime and you'll see them right next to my office. Sandy also enters them into EndNote file for the students. These are all in an EndNote file that is on the web for my students to use.

The Spectrum: **You make it easy for them.**

Turro: Ha! I really do try to make it easy because I feel it is so important. However, sometimes I have to tell them to go to that EndNote file and look it up, and only then do they do it. There's something about students. At first, they really don't like to get into the literature unless you basically say, "You've got to do it." Then they go crazy when they see all this great stuff in there. Only then, after experiencing the rush of finding excellent material that is relevant to their research or which is neat chemistry that has been out there, do they begin to build up the proper habits and respect for the literature.

The Spectrum: **Instrumentation drives research in photochemistry, as it does in other fields. Are there areas of photochemistry that ground to a screeching halt in the past because the right instrument wasn't there, research that could be dusted off and resumed today?**

Turro: If anyone wants to get ideas on research projects, I'd say just go and read *JACS* between 1950 and 1960. You will find incredibly bright people doing interesting things in physical organic chemistry, in photochemistry, who at the time lacked the techniques we have now. There is a tremendous amount of new information to be obtained using modern instrumental methods. The real issue is finding interesting systems to which that information can be applied. I'm always stunned when I go back and read some papers from the 1960s when NMR was just emerging, time resolved flash methods, too, and direct spectroscopic kinetic measurement of transients. Everything then was basically product oriented. And then flash photolysis came along, fluorescence, etc., in the 1970s and l980s. Today's instrumentation is so good that it can do things impossible when the first models became available. One example: timed-resolved IR and time-resolved EPR. Go back and look for systems in which there's a specie believed to be an intermediate, with a very specific IR band or EPR signal, and you've got a nice research problem.

The Spectrum: **What instrumentation needs are hindering research in photochemistry today?**

Turro: I think photochemists need new, but affordable and convenient lasers beyond the YAG and Excimer. I'm talking about lasers that an old-fashioned organic chemist or physical organic chemist could use, lasers that don't need a lot of attention. Those currently available are mainly still nanosecond lasers with a few picosecond types out there. There aren't that many wave lengths available in that range. You can get very fancy with certain parametric oscillators. But they are very tricky to handle, and might not be of much long-term use to students in an organic lab. I also think it would be interesting to take some of the work that people are doing with femtosecond lasers and show it can be done with a nanosecond laser. I don't mean time-resolution work, but two-photon effects, multiphoton-effects, and interesting non-linear phenomena.

The Spectrum: **What problems would they address?**

Turro: To me, two of the interesting challenges in photochemistry are figuring out how to combine photons and how to split photons apart. How can I take a blue photon and split it into 50 red photons? You're not violating any fundamental laws; it's just tricky to do. That's the sort of challenge that the chemical physicists deal with on some levels. Chemists can come in with ideas that many folks reject out of hand because their theories say they're "impossible" and they're embarrassed to try them. This is a great area for people to play with photoreactions where the product is the proof of the pudding. In the end, if you've got the product, it will prove you can do something with a laser that theory says is impossible. You have a product, so there must be a mechanism to get it, even though the mechanism still has to be worked out.

The Spectrum: **What turns you on, and off, when a prospective faculty member presents an interview lecture or departmental colloquium?**

Turro: They probably shouldn't do what I did when I interviewed at Columbia in 1963. I came in and told a horrible joke to break the ice. The story about why Alexander the Great was the first photochemist. It's too long to get into; anyone who wants to hear it can buy me lunch.

The most important thing in any interview, lecture or colloquium is to understand the paradigm of the audience. What does the audience believe in? What do they think is important? What literature are they likely to know? Here is where mastery of the literature can be either devastating or a big boost. Suppose you know something that's unusual and will immediately make the audience say, "You can't do that, its impossible." But you know it's been done. Then you've got the edge. You can yank that audience's interests all over the place, entertain them, yet inform them of new things that they will remember, and you'll made a big impression.

***The Spectrum*: For Example?**

Turro: Well, let's take the simplest stable molecule, molecular hydrogen, H_2. Most chemists think they probably know everything important there is to know about H_2. Suppose I say that I've got two different stable forms of molecular hydrogen each in two separate bottles. I claim that one sample has an NMR spectrum and the other has no NMR spectrum! The audience thinks it's a trick question. But these are real gases. Turns out there are two forms of hydrogen, which differ with respect to nuclear spin. The one with no NMR spectrum has spins that are up and down. It's a singlet with pair electron and nuclear spins, diamagnetic, no NMR, period. In the other one, the electron spins are paired but the nuclear spins point in the same direction. The two forms of H_2 interconvert very slowly in the absence of a paramagnetic catalyst. You can actually separate them. The physicists have known about this phenomenon for over 50 years. The typical organic chemists don't know anything about these two forms of H_2. So you can get talking about this and they think you're nuts, but in the end when they look it up, they are startled to find out that it is true.

***The Spectrum*: You're a big fan of supramolecular photochemistry's prospects for the future. What contributions do you foresee from this field in the years ahead?**

Turro: Chemists started mastering atoms, and then learned to master molecules. The next level is interaction between molecules and a science that is no different from looking at the atoms on the Periodic Table or thinking about making covalent bonds. Remember that 70 years ago, many chemists didn't think you could synthesize fancy molecules. Nature knew how to do it, but we couldn't do it. Right now I don't think anyone believes that intermolecular bonds can be manipulated in the same way that we can handle covalent bonds. Twenty or 30 years from now, they're probably going to look back and say, "What was the problem back then?" Every new level of structure has its induction period. Conformational analysis is a great example because it is relatively recent. In 1950, many organic chemists didn't believe there were rotations around bonds or conformation.

***The Spectrum*: There was a particular mindset then?**

Turro: One that is easy to understand. You can go back to the literature to find out. What sort of research did chemists do before 1950? Well, they didn't mess with mixtures of compounds because they were too complex to study. How did they stay away from mixtures? They crystallized things. What do you crystallize? It has to be pretty big molecules like steroids. Once you start playing with steroids, which are inherently rigid structures, your paradigm is going to be there's no such thing as a flip-flop of cyclohexane. Then somebody begins to find data that doesn't jive with that. People gradually understand that steroids are the exception to the rule. It took Derek Barton (Nobel Prize for discovering conformational analysis) and other people who had enough knowledge of the literature to understand. There's another interesting aspect to scholarship. There's a fair amount of information in the literature that is wrong. People would do things with steroids and other molecules, would run an experiment that didn't show conformational mobility. So, therefore, they concluded that the molecule must be rigid. Later, people went back and found out that those experiments or the interpretation were just incorrect. So you have somebody giving lectures that favored rigidity using bad data. This is something you have to understand in deciding how much credibility to give to experiments. There are bad experiments that can kill good ideas and bad ideas that can inhibit the execution of certain experiments.

***The Spectrum*: That brings us to your ideas on extraordinary science and pathological science. In a few sentences, give us the danger signs, the red flags that may suggest research has become pathological.**

Turro: We talked about a couple of things already. One of the important ways of avoiding pathological science is knowing the literature. Knowing the literature keeps you away from traps. The real issue with pathological science breaks up into two domains. One is using statistically marginal data to make conclusions that are well beyond what the data justify. That's part of human nature. The cure is simple. When a result looks extraordinary, you've got to try your best to kill it. If it's true, you can't kill it. And if it's not true, you want to be the one to kill it before it gets out the lab door. We used that approach with our data on magnetic effects and dioxetanes. In the thermal decomposition of dioxetanes it appeared that we were getting the triplet directly without going to the singlet. And we decided it was so extraordinary, and it would be great if it were true, but it could not possibly be correct so we needed to prove it wasn't so. We tried three independent methods to kill the interpretation, and only then did I say, "All right, we can publish now." Magnetic effects was the same way. I was expecting a 1% effect. With the original dibenzyl ketone we got a 50% effect and I said, "Come on, now, this can't be right.

We're making a mistake somewhere." We did mass spec and then an NMR. It came out the same. Then we went to IR. Only then was I finally convinced. Every time you get a crazy result, you have to watch it and try to kill it. So it's a dicey situation when you're dealing with very marginal data. You'd better watch it! On the other hand, marginal data have won Nobel Prizes. The first buckyball paper reported about 150 mass spec peaks from graphite. You could see one at corresponding to C60 that was about 20% higher than the rest. The researchers interpreted it as special stability for C60. At that time, many people thought it was ridiculous. Nevertheless, Smalley proved it was true. There's an interesting situation when two conflicting paradigms clash and you have a crisis in science. The advocates and the opponents break up into roughly 50-50 each. It's unbelievable. It was that way with cold fusion, polywater, buckyballs, and superconductivity. The results sometimes appear to point in two completely opposite directions. One goes to Nobel Prizes and one to IgNobel Prizes. Just before that happens you'll find advocates on both sides.

***The Spectrum:* What's on the horizon in terms of commercial, medical, and industrial applications of photochemistry?**

Turro: One obvious target is the holy grail of capturing solar energy efficiently and making it competitive with fossil fuels. Along with direct fuel cells, it would have all kinds of applications ranging from cell phones to laptop computers to fueling cars and heating and cooling buildings. In medicine, one of the holy grails is finding drugs that will absorb light in the red. Red light will go through the body. Try a simple experiment to see what I mean. Point a green laser and a red laser at different figures. The red one will light up the tip of your finger like Rudolph's nose. The green won't penetrate. That's a very dramatic demonstration of why red light sources are critical in photomedicine. Another possibility involves getting light deep into the body linking it with magnetic resonance imaging (MRI). Absorbed light could increase the speed of MRI if, somehow, the light causes relaxation in certain organs that get imaged much faster. I'm just throwing out that idea. Suppose we produce singlet oxygen in a certain part of the body as a result of using red light, which excites some natural chromophore in the system. That singlet oxygen deactivates to triplet oxygen which is paramagnetic and can relax nearby water molecules. So you might have a potentially specific imaging device that has a combination of light, photosensitizer, and production of singlet oxygen. In the commercial area, the high cost of photons will always limit us to high-value products—chips and that sort of material—unless we can figure out how to harvest photons more economically.

***The Spectrum:* People in George Hammond's group at Caltech in the 1960s remember it as an almost magical experience in terms of new ways of approaching problems and results. What was so special about George's approach?**

Turro: The "chemistry" of putting an extremely successful research group together is interesting. You need a special combination of good people, plus a mentor, plus a problem, plus a special place to do science, plus a whole series of exciting things going on in the field. The conglomeration of all those forces is what made it so special at Caltech. All of those elements came together. George was absolutely essential. Caltech was, as well. We had people like Wilse Robinson right down the hall talking about integrating photochemistry and spectroscopy, people like Jack Roberts thinking about mechanisms. Just having good people that were close together was very special. There wasn't very much in terms of equipment at that point. We just had lamps, GCs, and after I left there, the first fluorescent spectrometer came along. Later, they had their first flash set up. By that time the field was becoming mature, in the late 1960s. George had a very special situation. But at the same time in the U.S. alone Howie Zimmerman had a group that was thriving, Orville Chapman had a group that was thriving, Bill Dauben had a group that was thriving. That would indicate there was something about the field that was driving the ability for people to get together and churn out a lot of good ideas and results. Getting back to this paradigm idea. We were developing in George's group an attitude about mechanistic photochemistry that turned out to be pretty darn good. As a result, we could come in on weekends and talk about these experiments and by Monday have them going. We were on the right track. Everybody was focusing on taking this information and doing things with different systems—with stilbene, with benzophenol, with dienes, etc. But to a certain extent within the paradigm that was developing, they were all the same idea. Triple sensitization was an idea. So you sensitized azomethane, you sensitized 1,3-pentadiene, you sensitized that. And you had something that could be published. So if you want to say something special about George's approach, whether it was

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implicit or explicit, he understood how to take good ideas and get them very quickly into the lab in experiments that gave relatively immediate answers.

***The Spectrum:* You've managed an enormously successful research group for 40 years. How has your management style changed? Was there any one glaring mistake that you've made and learned from making?**

Turro: One of the things I've learned over time is to recognize my limiting resource, and understand not to push it any harder. So if I was idea-limited and had three times as many people in the lab as I had ideas, I was wasting a huge amount of effort. Your resources also are limited in terms of being able to mentor and take care of your people. At one time, I didn't think one could have too large a group. I now know you can have too large a group. Everybody's got to decide where that turnaround point is. For me I decided it's probably somewhere closer to 10 than 20. If I expand to 15 I start feeling stressed out and have too many people to worry about. Then I really can't concentrate on ideas and results. The numbers obviously change with the quality of the people.

I remember in the early 1990s when I had several Russians in the lab. We had an army of these guys, and they were basically faculty members. All you did was to provide them with a few initial ideas and some equipment and they'd take off. But if you're dealing with starting graduate students and a mix of postdocs that's different. I now think very carefully about who I'm going to take into the group. I've come up with an interesting philosophy. I will not take anybody into the group who does not come up with a second sponsor. All my graduate students are co-sponsored; all my postdocs are co-sponsored. The reason? I have to be forced to learn things, too. So if we have a graduate student co-sponsored by someone in applied physics who is currently working with nanoparticles—as we currently are—I'm going to learn about nanoparticles. This guy knows and he can teach me. This strategy works for both of us. It allows me to expand the group without actually doing it at all levels.

There also is the matter of funding. Whenever I get into one of these arrangements I get a funding share without having to go out and apply for still another grant. I find many benefits for the students. The key is finding somebody you can work with. There are huge issues of personality, ego—all that. When you find somebody with whom you can collaborate, that is a gold mine. You can really take off and do a lot.

***The Spectrum:* Any tips for incoming members of a group on how to work most effectively, and keep the boss happy?**

Turro: Of course the best way is to get great results. We get back to this literature thing. I really value students who understand the effort required to go into the literature and get the information they need. Students I like are those who really like to dig and take the extra effort to move forward.

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