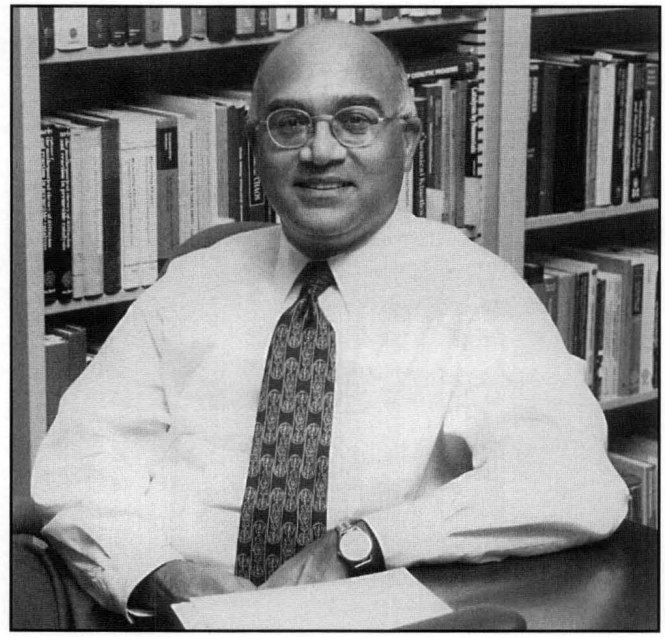
ChE *educator*

Arvind Varma

of Notre Dame



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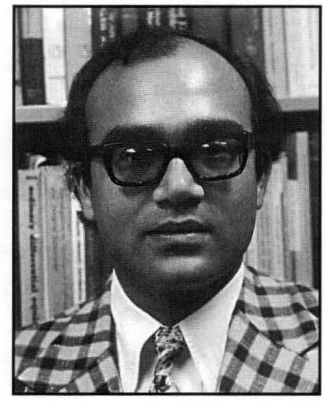
When Arvind Varma was awarded the University of Notre Dame's College of Engineering Outstanding Teacher of the Year Award for 1990-91, his students praised him as "an excellent teacher both in and out of the classroom," and said he showed a "great interest in his students" and was "willing to be a friend and a mentor." They cited his extensive availability, saying it was "a rare and valuable opportunity to work with a person with such great character and work ethic. He will be the professor whom we will vividly remember twenty years from now, and his influence will be matched by few in our lifetime."



The award and the citation that accompanied it were gratifying to Arvind, who believes that the most important thing a teacher can be is a good model for the students. "Whether you are in the classroom or doing research, you must always do things the right way," he says. "A teacher should not just impart information, but should also teach students how to think, how to live. You need to teach critical analysis, so that they are able to ask questions, to make decisions on their own. You can rely on people and other sources for information, but you should be able to analyze on your own to make decisions." That ability to analyze is what he hopes he has taught his students.

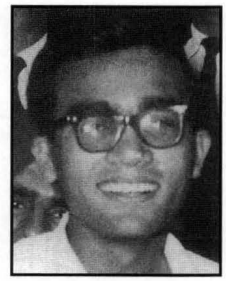
▲ As a young faculty member in the late 1970s,

and

◀ As a graduate student in the late 1960s,

and

◀ As an undergraduate student in the mid-1960s.



Carmo J. Pereira, a former student who is now a Principal Consultant at DuPont Engineering, believes he learned that ability as Varma's student. "When I first met Professor Varma, he had just arrived at Notre Dame after two years in industry. I am a practicing reaction engineer today in large part due to him. His love for reaction engineering, his great attention to detail, and his dedication to the profession

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are truly contagious! I have been greatly influenced by Professor Varma's desire to excel, and I have attempted to follow his example."

Another former student, Bala Subramaniam (now a chaired professor of chemical and petroleum engineering at the University of Kansas in Lawrence) says, "Professor Varma's research accomplishments are well known and recognized. What is probably not as well known is that Professor Varma is also a gifted teacher with exemplary dedication and excellence in educating his students." He adds, "His lectures are intellectually stimulating, characterized by careful preparation and energetic delivery. Professor Varma brought to his class the latest research developments from his program as well as others. This allows students to gain a better appreciation of creativity, which in turn inspires them to be creative. He is very accessible to his students, and whenever interacting with them either in or outside class, he creates an atmosphere that promotes the students' desire to learn and to excel. Personally, these experiences have helped shape my teaching philosophy and methods to a great extent."

Arvind was born in Ferozabad, U.P., India, the fourth of seven children. He had always been a good student and, due to double promotions, was only 15 years old when he graduated from high school in 1962. This made choosing a college difficult because most of the schools in India had age restrictions and required incoming freshmen to be at least 17 or 18 years old. The Indian Institutes of Technology were just starting then and were already prestigious, but they too had age restrictions.

Arvind had done well in chemistry and mathematics in high school and was looking at chemical engineering on the advice of his father, who was a civil engineer working in government service. When Arvind learned that Panjab University in Chandigarh (one of the schools without an age restriction) had recently started a chemical engineering program with American collaboration, he applied there and was accepted. It was a unique situation in that the engineering college affiliated with the school had the other engineering disciplines on its own campus, but the new chemical engineering department was autonomous and was housed on the main university campus.

The chairman of the department was Professor B. Ghosh. He was young, outstanding, and bright. Recently returned from Carnegie Tech (now Carnegie-Mellon), he was a thoughtful teacher, and through him, Arvind was exposed to a more American style of teaching. Professor Ghosh's classes were more open and discussion-based, and he didn't insist on such a strict student/teacher division. It was at this time that teaching as a profession began to appeal to Arvind.

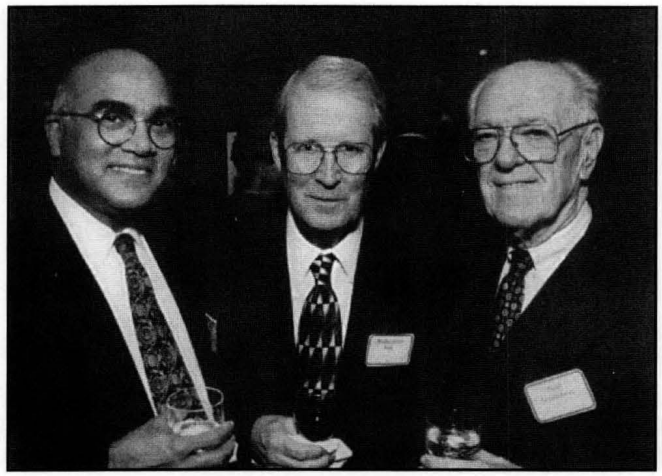
"The idea of standing up in front of class, explaining things, talking about what you knew, was very appealing to me," Arvind says. "I decided during my freshman year to be a college teacher."

When he finished his undergraduate work, Arvind was still only 19 years old and was anxious to come to North America for his graduate work. His parents weren't too keen on his leaving the country, but he was ready for new challenges. He applied to a few places in Canada and eventually chose the University of New Brunswick, where he would have the chance to work with Frank Steward in combustion of solid fuels.

At the University of New Brunswick he was exposed to even more of the Western style of teaching, further convincing him that he wanted to be an educator. But in his second year of graduate school, Frank Steward took a UNESCO appointment, and Arvind decided to change schools to pursue his doctorate. The University of Minnesota was rated very highly then, as it is now, and he was accepted and awarded an assistantship there.

During the late 1960s and 1970s, the University of Minnesota was an exciting place to be. A great deal of research was being done in the area of analysis of chemical engineering systems, particularly mathematical analysis. This effort was led by Professor Neal Amundson, who was department head and also Arvind's thesis advisor. Amundson had gathered together a top-notch faculty, many of whom had degrees in the sciences or math rather than in chemical engineering. At this same time, the Mining and Metallurgical Engineering Department was closing down and materials science was brought into chemical engineering. This mixture produced an emphasis on the fundamental scientific aspects of chemical engineering—the engineering science approach—in which there is an application of surface chemistry, biology, mathematics, and physics to chemical engineering problems. This mixture of disciplines is more common now, especially in research groups, but it was very unusual at that time.

At the University of Minnesota, Arvind was influenced greatly by both Professor Neal Amundson and Professor Rutherford Aris. Besides being an innovative leader, Amundson was a brilliant teacher and researcher. He taught a two-hour course on mathematical methods in chemical engineering twice a week and did all his complex computations on the chalkboard without any notes. Aris was a great scholar and writer, very fluent with words and widely published. He was a soft-spoken, kind gentleman. Where Amundson was Arvind's model of an innovator and teacher, Aris was his model of a scholar.



Arvind with two people who shaped his academic development—Neal Amundson and Rutherford Aris—at Aris' retirement festivities in 1996

In 1971, Arvind married his wife Karen, then a senior majoring in biology at the University of Minnesota. A few days after getting married, they spent six weeks in India, meeting his family and seeing the country. Arvind received his PhD in 1972. His thesis on "Analysis of Tubular Reactor Multiple Steady States and Their Stability" generated a number of articles. After he was awarded his doctorate, Arvind stayed on at the University of Minnesota as a temporary assistant professor for one year, doing limited teaching while working on research. During this period he got to know Professors Amundson and Aris even better, as well as a number of other faculty members.

Arvind firmly believed that to be a good teacher, one needed industrial experience (as Amundson and Aris had), so when he was ready to leave the University of Minnesota he interviewed both in academia and in industry. After considering offers from a number of sources, he went to work as a senior research engineer for Linde Research of Union Carbide in Tarrytown, New York, where he did research in gas separations.

The research at Union Carbide was very different from that which Arvind had done for this thesis, but that was part of its appeal since it meant his experience would become even broader. He was hired as a part of the Process Research Group, a newly formed unit that was looking into novel methods of gas separation processes. Some of the projects that he worked on in their initial conceptual stages were a new process for breathing oxygen on aircraft, a new type of cryogenic insulation using thin evacuated glass microspheres, a zeolite slurry-based continuous gas separation process, and a parametric pumping system for an air separation process for producing oxygen for medical purposes. A number of these projects subsequently became commercial successes.

During this period, Karen and Arvind also became proud parents of their first child, Anita, born in 1974. Karen had worked as a laboratory assistant in microbiology since her graduation two years earlier, but now gave up her career to become a full-time mother.

In 1975, after two years at Union Carbide, Arvind received an offer from the University of Notre Dame. The chemical engineering department there was well known due to the work in catalytic reaction engineering done by James Carberry and Ernest Thiele (who was no longer at Notre Dame but who had added greatly to the stature of the department) as well as the work in thermodynamics and phase equilibria being done by James Kohn and Kraemer Luks. Also, the department's chairman, Julius Banchero, was a well-known educator who was supportive of young faculty. Arvind decided to make the change to academia and was further convinced that the decision was a good one when Roger Schmitz came from the University of Illinois in 1979 to take over as department chair upon Banchero's retirement. Arvind quickly progressed through the ranks, becoming a full professor in 1980, the same year that his younger daughter, Sophia, was born.

In 1982, Arvind became department chair himself when Roger Schmitz went on to become engineering dean. Although Arvind was young for the position, he had definite ideas he was eager to implement and, under his leadership, the department grew. During his tenure, Mark McCready (the current department chair), David Leighton, and Hsueh-Chia Chang (who served as chair after Arvind) all joined the faculty.

When he was chair, Arvind chose to teach the "Introduction to Chemical Engineering" course himself because he thought it was important for the chair to be visible to the new students in the department. He also brought team teaching to the undergraduate labs, with part of the faculty teaching the fall semester lab for seniors and another part teaching the spring lab for juniors. This had the dual effect of making it more interesting for the faculty to teach and encouraging camaraderie as they worked together. It was also good for students to have contact with a number of faculty members. The senior design course is also team taught, so every member of the faculty instructs in one of these three courses every year. All three courses have written and oral reports due at the end of the semester. By implementing his ideas, Arvind helped to create an atmosphere of high standards for

teaching and research.

Mark McCready, chair of the department, notes another aspect of Arvind's leadership. "While Arvind is well known for his mentoring of graduate students and his efforts to enhance these activities campus wide, he has also mentored a number of current faculty at Notre Dame. He provided a great deal of guidance to me during my first few years here. He helped with proposal and paper writing, encouraged my participation in departmental committees, and made sure that my views were heard. His efforts greatly enhanced my development as a junior faculty member."

In order to devote full time to teaching and research, Arvind decided to leave the department chair position in 1988. Within a few months of this decision, he was named the first occupant of the Arthur J. Schmitt endowed chair professorship, a position he still holds.

All of Arvind's research involves undergraduate, graduate, and post-doctoral students, true to his vision of an educator. When he was awarded the 1997 Burns Graduate School Award from the University of Notre Dame this past May, the citation noted, in part, that he is "a quintessential professor who excels in all phases of academic life and for whom there is no boundary between teaching and research."

In his twenty-three years at Notre Dame, twenty-seven students have completed their doctoral dissertations under his direction, and several more are currently in progress. Every dissertation has resulted in coauthored publications in leading journals and typically in one or more paper presentations at technical meetings. One of his students, Jean-Pascal Lebrat received the 1993 Graduate School Award in Engineering in recognition of the quality of his dissertation research. Furthermore, largely through Arvind's efforts in counseling and mentoring, his former students have been very successful professionally in both industry and academia. Of his former PhD and post-doctoral students, eighteen are in academic positions at institutions around the world.

"As a mentor, Professor Varma led and taught by example. His enthusiasm for his research program was infectious and evident during the weekly research group meetings," Bala Subramaniam says.

Arvind's early research involved various topics in chemical and catalytic reaction engineering, including diffusion-reaction in catalyst pellets, reactor modeling and optimization, gas-liquid reactors, and three-way catalysis for automotive exhausts. Beginning in the early 1980s, his focus was mainly in two areas. One area was the optimal distribution of catalyst in pellets, in which the problem addressed is "How should a fixed amount of catalyst be distributed in a pellet to optimize some specified performance index?" This problem is common to *all* reactions that use supported catalysts. In systematic and innovative theoretical and experimental work, Arvind and his students have shown that the optimal distribution is a Dirac-delta function, *i.e.,* the catalyst should be deposited at a specific radial position within the pellet. He has also developed experimental methods for preparing such catalysts. This work has direct implications for rational catalyst design and manufacture.

The other area of Arvind's research during this period was parametric sensitivity and runaway in chemical reactors. In certain regions of operating conditions, chemical reactors exhibit parametric sensitivity whereby small changes in input parameters lead to large changes in output variables. This behavior is common to *all* exothermic reaction systems. Determining these regions is of substantial interest because such behavior leads to deleterious reactor performance. By original and penetrating analysis, confirmed by experiments, Arvind and his research group have provided rigorous and easily applicable criteria for identifying the regions of parametric sensitivity and runaway for a variety of reacting systems.

For the last six to eight years, Arvind's research has been in the area of materials, specifically the combustion synthesis of materials. This is a large research program for mechanistic studies of combustion synthesis: What is the mechanism by which advanced materials such as ceramics, intermetallics, and composites are synthesized by the novel technique called combustion synthesis? How does the reaction occur? How is the product material formed? How can the microstructure of the material be controlled as it is being synthesized? Because the microstructure affects the properties of the material, by understanding the mechanism of the reaction and how the microstructure is formed, Arvind hopes to gain an understanding of the control over what the properties of the material are going to be. His funding for this research is from NSF and NASA.

In the NASA program, Arvind is looking at effects of gravity on combustion synthesis of materials. Both the NSF and NASA programs have produced some unique results and new research techniques. One such technique, producing promising results, is the high-speed microvideo recording of the combustion wave front.

"We are able to expand the wave front through magnification, using a long focus microscope attached to a high-speed video camera," Arvind says. "We can increase the spatial resolution up to 800 times and can record up to 10,000 frames per second."

Arvind and his students can watch just how the reaction is occurring and can see many of the details of combustion wave propagation, leading to a better understanding of how the wave front propagates in heterogeneous reaction mixtures that are used for synthesizing advanced materials. They have the only facility in the world for doing this and are at the forefront of developing new techniques for understanding how such reactions occur. Using this novel technique, Arvind and his research group have identified new modes of

propagation that have never been witnessed before—they call it a scintillating reaction wave. In recent work, they have shown that in many instances, the reaction initiates ahead of the wave front and sparks appear. They are the first precursor of the main reaction that occurs a few milliseconds later.

Another direction of Arvind's current research is inorganic membranes. With funding from the National Science Foundation and from industry (primarily Union Carbide), he is studying various types of inorganic membranes—both metal composite membranes in which a thin (a few microns thick), dense, metal film is deposited on a porous support, as well as ceramic membranes with controlled pore size and catalytic activity distributions. He and his students have developed some novel techniques, such as the use of osmosis in conjunction with electroless plating. Using this idea, they have synthesized high-flux thin metal composite membranes for both high temperature reaction and separation processes.

In his current research, Arvind is applying the principles of chemical engineering and novel experimental techniques. His approach of combining theory and experiments, and of determining the influence of processing variables on the resulting microstructure and the reaction mechanism and extent, is having a strong impact on the materials synthesis field. He is frequently the only, or one of only a few, chemical engineers invited to speak at conferences related to the reaction synthesis of advanced materials. Examples include the TMS Annual Meeting in 1991 and all four International Symposia on Self-Propagating High Temperature Synthesis held in the former USSR (1991), Honolulu (1993), China (1995), and Spain (1997). His plenary lecture on the "Combustion Synthesis of Advanced Materials" at the 1992 International Symposium of Chemical Reaction Engineering has received considerable acclaim and attention as a landmark summary of research in this area. His forthcoming monograph will update this work and has been praised already as "the seminal review on combustion synthesis."

Arvind has published extensively in collaboration with Massimo Morbidelli, now a chaired professor at ETH in Zurich, Switzerland. Massimo came to Notre Dame in 1979 on a fellowship from Italy. He stayed only six months, but wrote four papers while he was here and made a lasting impression on Arvind, who felt that he had great potential and encouraged him to get his advanced degree.

His influence made a difference to Morbidelli. "I decided to come back for my PhD," Massimo recalls, "But since I was a researcher at Politecnico de Milano, I could not do it on a full-time basis. It was Dr. Varma who arranged (with the help of the department chairman at that time, Dr. Roger Schmitz) a semi-non-resident PhD program for me at Notre Dame."

Since then, Massimo and Arvind have written some forty articles and two books together, making their collaboration one of the longer standing ones in academia. Their textbook *Mathematical Methods in Chemical Engineering* (Oxford University Press) was published earlier this year, and *Parametric Sensitivity in Chemical Systems* (Cambridge University Press), written jointly with research associate Hua Wu, was completed this past August and will be published early next year as part of the Cambridge Series in Chemical Engineering, of which Arvind is the founding editor.

"I have continued my collaboration with Dr. Varma for almost twenty years now," Massimo says, "And I find it always more exciting, although we have now evolved in different research areas. But even recently, when after long hours together, one in front of the other at the same table, reviewing our math book when we finished it, I felt the same sense of accomplishment as when we finished our first paper in 1979. I really felt I did something to my best, without saving energies. This was in fact the program that Dr. Varma stated many years ago when starting the 'book adventure.' He'd told me, '. . . and at the end we will sit together, read each page of the book, and leave there each word only if we like it.' And it has been done. This is really a great teaching for how to proceed in science, and I have seen this teaching penetrating all my students who later came to work for longer or shorter periods of time with Dr. Varma from Italy: Alberto Servida, Roberto Baratti, Giacomo Cao, Hua Wu, Marco Apostolo, and others.

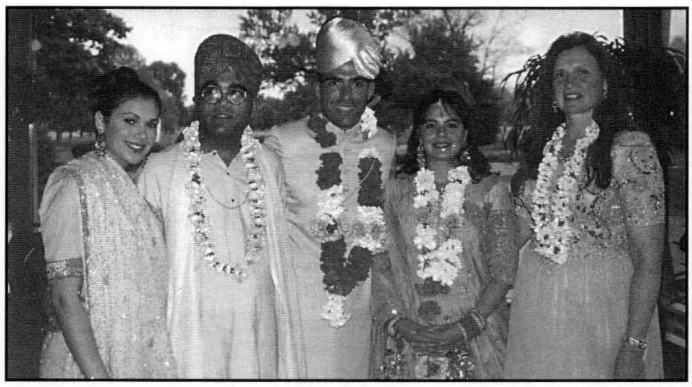
"Professor Varma has made significant contributions to reaction engineering," Carmo Pereira says. "His work on optimizing catalyst intraparticle profiles and on high temperature synthesis is seminal, and he has received many honors for his work, including AIChE's prestigious Wilhelm Award."

Arvind has also found time to serve the University of Notre Dame as well as many professional organizations. In 1992, he was awarded a Special Presidential Award by the University for his "indefatigable energy in research, writing, and all activities that engage his sharp mind and for serving simultaneously on a large number of university, college, and departmental committees." He was a member of the University's Executive Committee of the Academic Council for three years, served on the Academic and Faculty Affairs Committe of the Board of Trustees for three years, and was chairman of the Task Force on Research Systems, as well as other committees. He is a founding director of the Catalysis and Reaction Engineering Division of AIChE, serving a three-year term; a current member of the AIChE Awards Committee, serving a five-year term; and has organized and chaired numerous technical sessions at national and international conferences.

"Professor Varma's well-balanced contributions in teaching, research, and service are truly remarkable and make him the consummate professional and excellent role model that he is," Bala Subramaniam says. "The fact that several of his students have gone on to assume successful careers in aca-

Arvind and Karen, along with his research group and their terrier Frankie, at a recent get-together at their home. ►

A family photograph in traditional Indian dress on the occasion of older daughter Anita's marriage to Ken (also a chemical engineer) in May of 1997. On the left is younger daughter Sophia, currently a high school senior. ▼



demia and in major companies is a testament to his excellent training and positive influence on his students."

Roger Schmitz, Keating-Crawford Professor of Chemical Engineering at Notre Dame, has worked with Arvind for eighteen years and says, "I find it difficult to identify Arvind's strongest points because he excels in virtually every respect in his professional and personal life. Few individuals can match the combination of traits—dedication to academic work, motivation to excel, adherence to high standards of quality, selflessness in service to the university and the profession, boundless energy and capacity for work—that make him a valuable member of our faculty and of our profession.

Massimo Morbidelli finds it hard to pick just one outstanding attribute from the many things that he has learned from Arvind. "The one that I am not sure I have learned, but one that I certainly admire, is his honesty in science. By this I mean not only of a moral but also of an intellectual nature. In particular, stating and writing a concept only after he has tried by all means to clarify and to penetrate it. I do not recall a single time when he said, 'Well, it doesn't matter....' He always wanted to go as deep as possible in all aspects of a problem and in all details, which was not always easy for grad students. Another aspect was his profound knowledge of the literature and his capability of always giving appropriate credit to all other researchers."

"Above everything else, Professor Varma is an outstanding individual who treats his students with courtesy and fairness," Subramaniam adds. "Among the many memories that I cherish from my graduate students days at Notre Dame are the cookouts and get-togethers at his house. Professor Varma and his wife, Karen, are extremely gracious hosts and treated students to a variety of culinary dishes, including, of course, spicy Indian food! The friendships and associations forged there have been long-lasting. At the AIChE annual meetings, Professor Varma makes it a point to organize a dinner-outing with his former students. These outings have become a pleasant forum for developing new friendships as well as reminiscing about old times."

Arvind's commitment to his students extends beyond just the schooling years. He has truly lived his belief of being a model for them all.

In spite of the intense agenda of work and professional activities to which he holds himself, Arvind has managed to balance his time and interests between professional and family obligations. He is quick to express pride in the accomplishments of Karen and his daughters, and he considers his family to be the most important element in his life. Anita is a 1996 Notre Dame graduate in political science. She worked for one year as a volunteer in the Americorps Vista project and is currently a first-year law student in Washington, DC. Earlier this year, she married Ken Motolenich, a Notre Dame chemical engineering graduate with a master's degree in environmental engineering from MIT. Their wedding included both church and traditional Hindu ceremonies. Sophia is currently a senior in high school, busy with college applications, and has strong interests in drama and musical theatre. Anticipating more free time in the future, Karen has been preparing for the last several years for a teacher's certificate in high school science and expects to start her teaching career next fall. She is also an accomplished opera singer. ❐