ChE educator

Duncan Fraser

of the University of Cape Town, South Africa

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As a young Ph.D. student in chemical engineering at the University of Cape Town (UCT), Duncan Fraser was asked on a number of occasions to cover courses for lecturers who were on sabbatical. This was maybe not the most ideal arrangement with regard to completion of the thesis (he says it took "forever") but the teaching bug bit him well and truly, and this experience was the start of a long career devoted to all aspects of the teaching of chemical engineering. Duncan has taught nearly every course in the curriculum, has introduced numerous innovations in the classroom, has overseen major curriculum change, has researched the learning of students, and has worked at institutional, national, and international levels to improve the quality of undergraduate education. On top of this he has pursued technical research in process synthesis that has recently been awarded with an impressive "B-rating"* from the National Research Foundation in South Africa.

Duncan with his youngest student, grandson James.

Richard Felder, Hoechst Celanese Professor Emeritus of Chemical Engineering at North Carolina State University, has the following recollections: "I first encountered Duncan several decades ago at an AIChE conference education session, where he spoke about some work he was doing with black students from educationally disadvantaged backgrounds. I was struck by several things as I listened. First, the work he described was remarkably innovative and clever—as good as any educational work I knew about going on anywhere in the world. In addition, he was doing it in South Africa and

* *B-rated researchers are those who "enjoy considerable international recognition by their peers for the high quality and impact of their recent research outputs." <www.nrf.ac.za>*

in the era of apartheid, which spoke volumes to me about both his principles and his courage. I introduced myself to him afterwards and that began a lasting friendship." High praise indeed from one of the legends in chemical engineering education.

GETTING GOING

How did the uncertain Ph.D. stand-in lecturer develop into the internationally renowned engineering educator? Duncan identifies two early experiences that took his innate enthusiasm for teaching to a new level. First, he attended a series of teaching workshops run by the UCT Medical School in the early '80s. "To go away for two whole days and just to think about your teaching—that was a rare experience," he says. The second key experience was a sabbatical at Imperial College in London during 1984/85. Here he was delighted to work with kindred spirits in the innovative group of Stephen Richardson (now head of the Department of Chemical Engineering), Geoff Maitland (now chair of Energy Engineering), and John Perkins (now vice president and dean at the University of Manchester). He particularly remembers the manner in which they always gave detailed constructive feedback to students, and how he took this practice back home into his teaching at UCT.

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The mid-1980s in South Africa was a difficult time. The struggle against apartheid was in full swing and black schools were very troubled places. At this time, the government began to relax the racial restrictions on higher education institutions and the first black African students entered chemical engineering at UCT. (Under the apartheid system UCT had in 1959 been designated a "whites-only" university, and only small numbers of other racial groups had been permitted to study engineering there, but no black African students). These students were coming from schooling backgrounds that were very poorly resourced and often quite dysfunctional, being at the heart of the struggle and subject to boycotts and protests.

From his early student days Duncan had a passion for a nonracial society emanating from his church involvement, and he was keen that these students should succeed despite their poor school backgrounds. Cyril O'Connor, then head of the department and now dean of the Faculty of Engineering and the Built Environment at UCT, picks up the story: "Duncan recognized these challenges sooner than most and vigorously and enthusiastically began developing new approaches to teaching chemical engineering to these students." Duncan first tried a system of extra sessions, but found that this further added to the high workload and had no impact on student success. He also tried increasing the number of postgraduate teaching assistants for the course, but this had equally little impact. He then came across the literature on Minority Engineering Programs in the United States and found out about collaborative study groups. Duncan says that he thought to himself, "I've got to try this!" He had never spoken to anyone else about this idea, and started out with considerable fear and trepidation. He was going to be doing something rather different in the classroom and negotiated with the class for the go-ahead. They said they were happy to give it a try. Duncan now says that the first collaborative learning session was "one of the most exciting things I have ever done." Students worked the whole afternoon without a break, and Duncan noted a real "buzz" in the class. He then continued with this innovation through the remainder of the course and was delighted to note a marked effect on success rates. He notes that the innovation seemed to improve the success rates of all students, but that of black African students the most.

Cyril O'Connor notes: "There were two remarkable outcomes to Duncan's research. First, it soon became clear that the methods he was promoting also represented a far better way to teach engineering to all students irrespective of their educational background. Secondly, it also became clear that the unique circumstances in which we found ourselves at UCT with such a diverse student population provided an opportunity for us to develop new approaches that would have a universal appeal, as has happened with Duncan's research."

Duncan was soon called on to advise on the design of all engineering programs at UCT, and he played a key role in a wholesale curriculum overhaul in the early 1990s. This involved the introduction of an engineering course to the first year of the program, which had previously had the traditional format of a purely science-based introduction. Duncan found it challenging to develop an engineering course at first-year level, and after the first lecture he found he had to throw his meticulous plans out of the window and rethink ways of reaching students at their level. He devised an innovative series of experiments to introduce students to the fundamentals of the discipline. His philosophy here involved taking students from the known to the unknown. They therefore studied heat transfer using coffee cups as well as sophisticated digital thermometers. Reaction kinetics was approached by boiling potatoes and measuring the reaction progress using vernier calipers then modeling the results using simple DEs and spreadsheets. Mass transfer was seen in the dissolution of lollipops in a stirred beaker of water. Duncan had seen an

Duncan (back row left) with members of the Chemical Engineering Department hiking group he led. His colleague (and "biographer"), Jenni Case, is in the front row with her son.

article about a mass transfer experiment in *Chemical Engineering Education*, but it involved loose candies that needed to be dried and weighed, and he was looking for something simpler to measure and also to model. He was out shopping with his young daughters one day and they had asked him to buy some lollipops, at which point he realized this was exactly the thing he needed. Much to their dismay he took one of the lollipops to try out how long it would take to dissolve in water, and he found that it suited his purpose perfectly.

Duncan played an important role in mentoring new academic staff members in the Department of Chemical Engineering at UCT. Professor Sue Harrison, former head of the department, remembers the early days: "As a young novice lecturer, directly out of a Ph.D. degree, I was extremely fortunate to share my first teaching assignment in material and energy balances with Duncan Fraser. He educated me from day one in pacing and varying my lecture speed and complexity, on the importance of learning 92 first and family names of culturally diverse students within the first two afternoons of term, and on the elements of the students' baptism by fire in problem solving. I could not have had a better teacher, or educator of the educator!" Later on, Sue only agreed to take on the head of department position with the support of Duncan as Director of Undergraduate Studies. She says, "Not only is he the member of staff with the most extensive knowledge of the curriculum, the learning process, the student body, and the academic administration, he is also one of the most dedicated. I have had the pleasure of working with him in both the introduction of the revised design-based curriculum and in ensuring a robust outcomes-based curriculum—both rigorously tackled. Probably the greatest compliment to him as an educator is that, in a department where every academic is a serious researcher, these developments were achieved through his championing with the buy-in of the entire staff. This inspiration to continue to marry research and teaching enthusiasm in the same academic group is key to the achievements of our department."

Duncan's reading of the education literature also sparked an interest in conducting educational research to address the challenges faced in improving chemical engineering education at UCT. The Chemical Engineering Department, with its strong research profile and its tradition of dedication to undergraduate education, plus solid industrial support, was the perfect place for launching this new enterprise involving research on education. A major donation from Caltex (now Chevron) in 1993 allowed Duncan and colleagues to establish a lectureship in the department to focus specifically on these issues. I met Duncan when I came into this post in 1996 and we have worked collaboratively on many projects since then. A major highlight came in 2002 when a paper we had jointly published in *Chemical Engineering Education* was awarded the Corcoran Award for best paper of the year.

Another key initiative that helped build an engineering education community at UCT was the establishment in 1996 of the Centre for Research in Engineering Education (CREE), which Duncan spearheaded together with Jeff Jawitz. It is now a full decade down the line and CREE has evolved into an active network of tertiary science and engineering education researchers in the Western Cape province (see <www.cree.uct.ac.za> for more details). A recent UCT review of CREE commended it highly for the quality of research output and the presence of a national and international profile for the field. There is an exhaustive list of events that Duncan has helped coordinate to raise the profile of engineering education, including seminars, workshops, conferences, and the like. A particularly

Above left, Duncan and his wife, Jenny, on the Cam. Above, Duncan with Richard Felder at Cape Point in 1996. Left, colleagues Jenni Case and Duncan Fraser with 2003 final-year students Rosanna Martin and Bryan Maytham, exhibiting a poster on their education research project.

memorable series of workshops has been run by Richard Felder together with Rebecca Brent, and these have made a huge impression, particularly on young engineering academics in South Africa.

It has not always been easy going. At times Duncan struggled to get recognition for his work and felt discouraged. He says that it is his faith in God that has kept him going. He is also sympathetic to the challenges that young academics face in following their passions and building a scholarly focus to their teaching.

Close to retirement now, Duncan shows no signs of slowing down. In 2006 he was centrally involved in setting up a new initiative that took second-year chemical engineering students on an extended industrial field trip involving active engagement in the plant environment. This event was particularly well received by students, and was only made possible by a donation from Xstrata, a mining company, who also facilitated the appointment of a second lecturer to focus on education development. The incumbent of this post, Linda Kotta, a young chemical engineer with industrial experience and a master's degree in education, has been the latest excellent addition to the team. Duncan has also recently been appointed to the position of assistant dean in the Faculty of Engineering and the Built Environment at UCT, tasked with addressing the throughput of quality engineers across all the programs in the faculty.

FAMILIES AND FUN

Duncan was born in Cape Town in 1946, but most unusual for a Capetonian, he spent his childhood and youth in a range of places across the Southern African continent. This was because his father was a Methodist minister, and these early experiences established in Duncan a love of wide open spaces, a fascination with birds and wildlife, a passion for the country, and an enjoyment of traveling long distances on dirt roads (which fortunately his children also got used to in many family holidays on the road!). Duncan also built on this initial immersion in a spiritually focused home to become a committed Christian, and throughout his life he has been an active leader in his church and other Christian organizations. Growing up in a church manse he got used to having a very open and hospitable home, and together with his wife, Jenny, he has now replicated a sense of that in their own home in Cape Town, which has a constant stream of visitors and lodgers.

While at junior high school in a relatively rural backwater of South Africa, he came across a pamphlet on industrial chemistry, and decided that it sounded like a career choice that he would like. As it turned out the pamphlet was possibly quite dated as the industrial chemistry course at UCT had already changed into the discipline of chemical engineering. Fortunately, however, by the end of senior school his teachers had also become aware of this development, and so he arrived at UCT in 1964 to study chemical engineering. Although he had always been the top student at his school he failed some of his first class tests in that first year, and

The Fraser clan on sabbatical in the UK in 1985. . .

this experience is still with him today when he encourages first-year students, many of whom have similar experiences. Soon, however, he found that he loved the discipline, feeling that "It was me!" He graduated in the regular four years with first-class honors, a rare achievement.

As noted earlier, the Ph.D. was something else—a thesis focusing on turbulent air flow, analyzing velocity fluctuations in three dimensions and building the circuitry to sample data, something that Duncan wryly notes would be trivial with today's technology. One very important development during his Ph.D. studies was an acquaintance with a young doctor named Jenny Hurley. They met while playing mixed doubles squash at a Student Christian Association conference. Prior to this point he had come to the sad conclusion that women and Ph.D. studies were a poor combination, but meeting Jenny quickly changed his mind. Six months after that first meeting they were married. The wedding took place on Jenny's parent's farm in Zimbabwe, at a turbulent time in that country's history, happening as it did exactly a week after the start of the guerilla war that occupied most of the '70s. Duncan and Jenny have retained a strong emotional commitment to Zimbabwe during the changing fortunes of that country's political and economic situation.

Jenny finished her final year of medical studies during their first year of marriage, and when she started working the following year she had to support Duncan, as he had run out of funds with his lengthy Ph.D. pursuit. Jenny became pregnant with their first child, Debbie, while working around 108 hours per week in cardiology. Duncan remembers 1976 as the year when he started his first job, they had a small baby, and he was writing up his dissertation after hours. He says "I wouldn't want to live through that year again!" He is also reminded of the joy of being a new parent, however, and still remembers his utter disappointment and surprise when Debbie didn't win the "baby of the year" competition for which he had enthusiastically entered one of her baby photos.

He was delighted when, after three years in industry, UCT invited him to apply for a lecturing position. Jenny says that the day Duncan started working at UCT he was a different person. Duncan knows that it is the stimulation and the academic freedom that has kept him in the same job for nearly 30 years. He also values the three years he spent in industry, however, and continually draws on this experience in his academic work.

The remainder of the Fraser brood arrived in relatively quick succession, and Duncan has played a very important role in the lives of all four of these interesting young people. He particularly enjoyed watching them as students and recalling his own happy memories of varsity life. The children all studied at UCT, are now all married (the last wedding in the family took place in April 2007) and busy producing the next generation of Frasers. Although Duncan didn't manage to convince any of them to study chemical engineering, their careers reflect the same interesting mix of people and technology that Duncan has made his speciality. Daughter Debbie works in developing small businesses, son David is a systems analyst developing software for the process industries, son Andrew is a mechatronic engineer and daughter Anni is an occupational therapist working in a psychiatric hospital in Johannesburg. Duncan says that he is grateful for what has been such a "rich" family life, including many holidays to game reserves and at the seaside, even if he has maybe not amassed riches in the conventional financial sense.

Duncan still remembers going on sabbatical with four children aged between one and eight years old. They arrived at Heathrow airport with more than 20 pieces of luggage between them and a kindly porter took charge and put Duncan on the escalator first with, piece by piece, the luggage and the children following!

INTELLECTUAL INSPIRATION

Duncan's technical research is in process synthesis, and the amazing thing is that the stimulation to go in this direction also came from his very formative sabbatical at Imperial College.

. . . and on the occasion of his eldest daughter Debbie's wedding in 2004.

Initially this research was aimed at improving energy recovery in chemical processes. In 1988 he produced a pinch analysis study of the Caltex refinery where he had cut his teeth as a graduate engineer 10 years earlier. To this day this publication remains the only refinery-wide study in the literature. In 1989 Duncan developed the concept of a minimum flux to replace the minimum approach temperature that was traditionally used as a design parameter for heat exchanger networks. This enables one to replace a set of stream-dependent minimum approach temperatures with a single minimum flux, which reduces the optimization of such systems from a multivariable one to a single-variable one.

Some of Duncan's most exciting technical work arose from his work with a particularly gifted Ph.D. student, Nick Hallale. Building on the work that had been done over 20 years in the development of heat exchanger networks, they were able in two years to develop a parallel approach for mass exchanger networks. This has made it possible to optimize the design of mass exchange networks ahead of detailed design, as well as to design systems that meet the optima established. This means that design alternatives can be compared without having to do detailed design. Duncan and Nick also demonstrated that their approach leads to designs that are better than or equal to those generated by mathematical programming techniques, for less effort. Currently Duncan is working on developing approaches to the analysis and design of joint heat and mass exchange systems—work of crucial importance in developing more sustainable chemical process systems.

At a deep philosophical level there are interesting links between Duncan's technical research and his engineering education work. Process synthesis involves getting the structure of processes right before optimizing individual pieces of equipment. In education, Duncan has found that you get limited returns if you only make changes in one course; you need to work on the whole structure in order to move forward.

Duncan is a very happy occupier of the cramped quarters that one is subjected to in economy-class air travel, and has clocked up impressive mileage around the globe in building academic contacts in both chemical engineering and engineering education. Over the last few years Duncan has found himself "out of town" for approximately two months each year, and despite the jet lag, lost luggage, missed flights, and general exhaustion he still seems to have an appetite for more! I have had the lucky opportunity of accompanying Duncan on a few trips to education conferences, and have discovered what impels Duncan to cross time zones again and again: Travel is for Duncan a precious time away from undergraduate students, postgraduate students, small children, big children, and the remainder of the huge community that all depend on him for help. Duncan himself says that he likes the stimulation of meeting new people on his travels, and that he also likes to take himself out of his comfort zone, something that the legendary Scott Fogler says is essential to enhancing your creative abilities. It also helps not having to keep the proverbial 10 balls in the air, but rather being able to focus on one thing at a time. Walking the Yorkshire moors or strolling along a beach in Rio are the times when Duncan's mind crosses all the boundaries that restrict it during normal life. He comes up with all sorts of inspiring ideas, and I have found it to be quite a treat to be dragged along on a walk by Duncan at the end of a conference day.

On the technical front, he had a fruitful formal collaboration over a number of years with the late Professor Zsolt Fonyo from the Technical University of Budapest, who passed away in 2005. On one such trip I happened to accompany Duncan following an engineering education conference we had just attended in Poland. In the few minutes we had available before catching a train from Krakow, I headed off to buy food, while Duncan headed in another direction to draw money. We had arranged to meet on the advertised train platform, but a subtle complication entered when the Polish train authorities decided

at the last minute to change the platform. I happened to notice the advertised correction, but Duncan's mind was presumably solving a difficult equation or planning a cross-continental curriculum reform, and so he settled down nicely at the old platform. As the train pulled out of the station I realized that Duncan was not on the train with me, and also that I had both train tickets while he had all our money! I would also need to somehow make myself known to Zsolt, who was meeting us in Budapest on the other end, as he was expecting to see Duncan. I therefore arrived with a handwritten note stating that I was "Duncan Fraser's colleague" and fortunately Zsolt found me, but when he asked me 'Where is Duncan?' I had to reply that I didn't know—hopefully somewhere making his way across Eastern Europe to Budapest! Zsolt knew Duncan to be famously eccentric but this news had him in stitches. Fortunately Duncan managed to find another train heading to Budapest and we were all reunited much later that evening, but it took Duncan a while to live down this incident.

Another productive collaboration took him to India to work with Professor Uday Shenoy from the Indian Institute of Technology, Bombay. Together they developed a novel approach to sizing mass exchange units that avoids the discontinuity of the conventional method. One of the bizarre features of modern air travel struck him on returning from one of his trips to India—having dinner in Mumbai one evening, and being back in Cape Town for breakfast the next morning!

Duncan is great at crossing borders, not only in a geographical sense, but also academically. Although he identifies fervently with the chemical engineering discipline, he has developed enormously fruitful collaborations with academics in other disciplines. And with Duncan being Duncan, these collaborators have often ended up as close friends. One lifelong friend was the late Professor Brian Hahn, a mathematics professor. Brian and Duncan met as postgraduate students when they started a Christian newspaper on the UCT campus. Many years later they developed an innovative course to introduce first-year students to chemical engineering, with Brian contributing his amazing expertise in the teaching of mathematical modeling. Many of these innovations were worked out on the slopes of Table Mountain, with Brian and Duncan using their shared love of running to get some free space to think and discuss ideas together. Students would be somewhat surprised to see their lecturer running past the cafeteria in jogging shorts over lunchtime but soon got used to it.

Another generative friendship-cum-academic collaboration has been with Professor Cedric Linder, who holds professorships at Uppsala University in Sweden and the University of the Western Cape in Cape Town. Duncan and Cedric met while walking their dogs in a local Cape Town park, and discovered that there was considerable synergy between Duncan's educational approach and that which Cedric was trialing with his physics students. Cedric later introduced Duncan to the arcane mysteries of phenomenography, an approach to studying student learning that they have both put to good use in researching their courses. Their research collaboration was facilitated by a grant from the Swedish-South African Intergovernmental S&T Co-operation Programme.

Duncan's greatest inspiration comes from working with students. He says that at least half the students in the class are brighter than him, but he at least has the advantage of experience. He enjoys being challenged and stretched by these young people. On a lighter note, their sense of humor also keeps him on his toes. One day while running a design project where he did what he thought was a superb role play of a difficult and demanding boss, he was somewhat tickled when halfway through the afternoon one of the students requested "Can we have Professor Fraser back please?"

WIDENING THE NETWORK

Duncan feels that South Africa, with its unique mix of first-world and third-world contexts, has a particular role to play in encouraging the development of engineering education in Africa. He has built up an impressive network of engineering educators across the continent, partly built from his contacts as an external examiner in Tanzania, Kenya, Ghana, and Zambia, and also through his active participation in engineering education conferences in South Africa, Nigeria, and Cameroon. He has been centrally involved in efforts to formalize these networks into an association, and has been recently selected as secretary general of the new African Engineering Education Association.

Dr. Russel Jones, chair of the World Federation of Engineering Organization's Committee on Capacity Building, explains Duncan's modus operandi: "In his quiet but effective way, Duncan has led reform of engineering education both at his home institution and well beyond throughout sub-Saharan Africa. He works by providing a role model for faculty colleagues, and by demonstrating what can be done by a dedicated and talented individual faculty member." Cedric Linder says the following of Duncan: "At a personal level he is strong-willed, but with a gentle open-minded manner that has been particularly useful in helping open doors to pursue new directions in higher education transformation." This is the key aspect of Duncan's work. Although he networks across the globe, his work is solidly rooted in his own classroom experience. Right now if you pop into Duncan's famously cluttered office on the second floor of the Chemical Engineering Building at UCT, you will see him hard at work preparing a holiday class for students who are having a second shot at mastering the chemical engineering basics. Come a bit later and you will see a stream of students outside his door asking for advice on anything from solving mass balances to obtaining a bursary for their studies to coping with a death in the family. Russel Jones describes him as an "educator's educator," someone who has built a career out of a passion—a rare privilege indeed. ❐