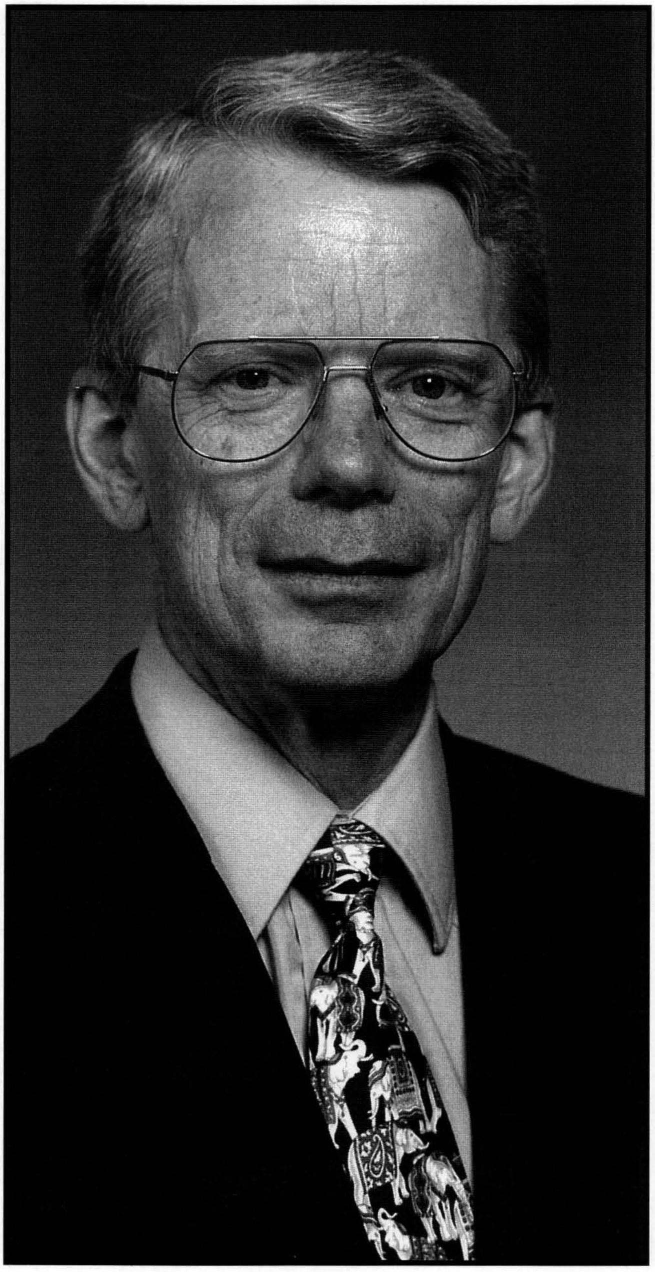
**ChE educator**

# Art Westerberg

## ... of Carnegie Mellon University



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It is refreshing to find a professor who, having had a profound impact in his field, is also a truly nice, honest individual, well liked and highly respected by all. It is also rare that a single person's career can be used as a measure in describing an entire research area. This is true in Arthur Westerberg's case. He has built a foundation that is used as a roadmap for process systems engineering, a dynamic and highly successful area of chemical engineering. Art approaches both life and research with a great sense of humor and optimism.

## BACKGROUND

Arthur W. Westerberg was born in St. Paul, Minnesota, in 1938, and spent his childhood in the farm country of that area. He inherited a practical bent as a problem solver from his father, who provided engineering services for farm equipment and construction. He also inherited a knack for applying general concepts and principles to a variety of different areas, and he later found that those interests were well suited to chemical engineering. He thus found himself in the young and dynamic atmosphere at the University of Minnesota in the late '50s in the company of such trendsetters as Amundson and Aris. After completing his BS degree in

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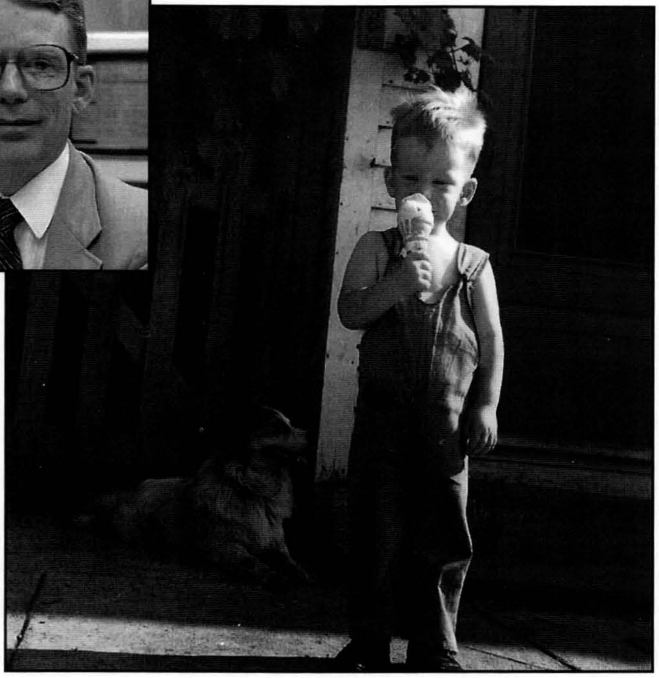


***Art Westerberg showed high proficiency in handling cool issues at an early stage.***

1960, Art was advised by Amundson to seek out the best graduate education he could find, and his choice was Britain's Imperial College.

American postgraduate students were unusual in Britain in 1960, especially since there were few mechanisms to provide funding for them. Consequently, Art pursued a master's degree at Princeton before accepting the position of Assistant Lecturer at Imperial to study for his PhD. He worked with Professor Roger Sargent, a young faculty member at Imperial who spearheaded the field of process systems engineering (PSE) and who spawned a legacy that includes virtually all PSE researchers. Working together on the development of SPEEDUP (a process simulator widely used today for steady state and dynamic modeling, analysis and optimization), they laid the foundation for computer-aided process analysis. For instance, the Sargent-Westerberg algorithm[1] for partitioning flowsheets and systems of equations is still widely used and quoted in the literature.

After receiving his PhD in 1964, Art joined Control Data Corporation in San Diego as a systems analyst, where he subsequently developed a number of novel codes for numerical analysis. In particular, his work on fast Fourier transforms led to efficient and powerful strategies for resolving chromatographic peaks and spurred the application of this separation technique in analytic chemistry.

The opportunity to teach and do research beckoned, however, and in 1967, Art went to the University of Florida and began his academic career in process systems engineering. PSE was in the embryonic stage in the late 60s, with only a handful of researchers and a host of unsolved and poorly defined problems in process design and analysis. Art's early research pioneered the equation-oriented approach to process flowsheeting. In particular, he focused on systematic methods for developing and solving process simulation problems and extending them so the processes could be optimized as well. In addition, Art, along with other young researchers, banded together to form the CACHE Corporation for education, and he also organized a number of symposia to discuss open research problems and to share experiences. Moreover, this emerging community forged important links to other engineering disciplines where design problems still required definition and solution strategies.

The efforts of the young engineering design community attracted quite a bit of attention in the 70s, especially at (the newly renamed) Carnegie Mellon University (CMU). At CMU, Dean Herbert Toor (with prudent advice from his neighbor, the Nobel laureate Herbert Simon) initiated a Design Research Center in 1975 and strongly influenced the hiring of a number of faculty in the computer-aided design area. They included Gary Powers in chemical engineering, Steven Fenves in civil engineering, and Stephen Director in electrical engineering. It was then only a matter of time before the fertile environment at CMU and Art's own research directions coincided. While Art was on sabbatical with Rudy Motard at the Computer Aided Design Centre in Cambridge, UK, the connection was made, and Art subsequently moved to Pittsburgh and to CMU.

## ART'S CONTRIBUTIONS TO PROCESS SYSTEMS ENGINEERING

The following summary does little justice to Art's research contributions. His trailblazing research has strongly influenced the current practice of process simulation, process modeling environments, process optimization strategies, synthesis of chemical processes, and the modeling of engineering activities.

Art's early work on process simulation concentrated on exploiting the structure of process equations. This led to efficient strategies for partitioning equation sets into subsets, tearing strategies for process equations and streams to ensure faster convergence, and selection of decision variables to avoid structural singularities. This work led to the evolution of equation-based strategies for process simulation that employ rapidly converging techniques for simultaneous convergence, which was also enhanced by Art and his colleagues. Developed in the early- to mid-70s, these tools were almost two decades ahead of their time and are now regarded as the basic elements for large-scale modeling and optimization of chemical processes.

With this background, Art's work evolved to handle larger-scale problems and to consider dynamic simulation. Coupled with this task is the importance of handling differential-algebraic equations (and the treatment of high-index systems, where simulations are doomed to failure in a novice's hands) and the extension to structuring calculations for partial differential equations. The thread running through all of these novel contributions was that the simultaneous equation-based paradigm allowed tremendous generality in dealing with a large set of simulation problems in process engineering. This principle was especially powerful when extended to the optimization of these systems. As a result of the simultaneous approach, optimization tasks were raised from a set of tedious case studies to an efficiently integrated part of the simulation platform. The approaches developed by Art and his coworkers paved the way for modern real-time optimization of petrochemical plants and refineries, which has now become the industrial standard.

**TABLE 1**

**Art Westerberg's PhD Students**

◆

F.C. Edie
J.A. de Souza Neto
R.L. McGalliard
C.J. De Brosse
J. R. Cunningham
S. Nayak
G. Stephanopoulos
G.L. Allen
J.V. Shah
T.J. Berna
S. Kuru
J. Cerda
M.H. Locke
M.H. Chao
P.A. Clark
M.J. Andercovich
J.B. Hillerbrand, Jr.
S.S. Kim
A.N. Hrymak
J. Vaselenak
R. Banares-Alcantara
N.A. Carlberg
F.D. Carvallo
P.C. Piela
A.K. Modi
O.J. Smith, IV
Y. Chung
R.S. Huss
O.M. Wahnschafft
M.E. Thomas
K.A. Abbott
B. Safrit
Joseph J. Zaher
D. Cunningham
B.A. Allan
V. Rico-Raminez

Coupled with his advances in simulation, Art recognized the importance of developing modeling systems that capture the physical phenomena and topology of processing systems. Here, the challenge is also to embed within modeling systems efficient simulation tools that are easy to use, helpful with diagnostics, and extendable to building very large-scale models. The vehicle for these ideas is the environment that evolved into ASCEND (Advanced System for Computation in Engineering Design). Moreover, development of ASCEND spawned a complementary research effort into the creation of modeling strategies and languages that, like the simulation tools, were concise and efficient and would support the construction of extremely large models. ASCEND has evolved over four generations and continues to be used by a variety of researchers for modeling, simulation, and optimization of steady state and dynamic processes.

Art did not stop with the modeling of processing systems, however. With the use of ASCEND and other design tools in engineering project teams, Art recognized the importance of managing project information among design teams and in developing platforms that support the entire design process. Heading a diverse team of researchers (engineers, computer scientists, and even artists), Art has spent the last decade molding these ideas into the n-dim system in order to support the 'design' of the design process for a project team. Offshoots of this project include products like the LIving REpository (LIRE') that supports a life cycle of information (authoring, searching, editing, publishing, etc.) for a design team.

In tandem with modeling, simulation, and optimization lie Art's contributions to the design of processing systems and the synthesis of chemical processes. Adopting a systems approach to discover and apply underlying concepts for putting processes together, Art attacked a wide variety of problems in process synthesis from a wide variety of approaches. His perspective and grasp of the synthesis problem were envisioned in 1980 in a beautifully written review paper.[2]

Art's contributions in process synthesis can be organized in threads along process lines, starting with the design of heat-recovery networks and evolving to a broad set of separa-

*The Westerbergs: Art, Barbara, Ken, and Karl.*

tion systems that include distillation, heat-integrated column systems, multi-effect evaporation, and most recently, synthesis of nonideal, azeotropic distillation. In all of these areas, Art and his coworkers sought underlying guiding principles that exploit the nature of the problem and provide an understanding of 'why' the best design had its essential characteristics. Art's approaches to synthesis have been novel and diverse; they include strategies at the cutting edge of development, evolutionary and heuristic strategies, optimization, and the use of artificial intelligence and expert systems. In all of these cases, Art was careful to choose the 'right tool' for the right problem and to develop a synergy between both, in order to develop a deep understanding of the designed system.

It goes without saying that Art's efforts have been recognized by the chemical engineering community through numerous honors and awards. They include membership in the National Academy of Engineering, early recognition in the CAST Computing Award, the AIChE Walker and Founder's Awards, and the E. V. Murphree Award from ACS. At Carnegie Mellon, he received the Swearingen Chair in 1982 and was named University Professor in 1992.

## ART'S INFLUENCE ON THE DEPARTMENT

The list of Art's many research contributions does not begin to present a complete picture of his contributions to the Chemical Engineering Department at CMU. Shortly after arriving, Art assumed the position of Director of the Design Research Center (DRC) and proceeded to build up interaction among departments across the campus. Under his leadership, the DRC provided a forum for like-minded faculty to collaborate and learn about design problems and solution strategies in other fields. Tangible results were the creation of a seminar series as well as a widely distributed technical-report series. Art's influence also led to the hiring of several design faculty on campus, including Ignacio Grossmann in Chemical Engineering.

As department head, from 1980-83, Art faced some turbulent times due to transitions in research funding and the departure of several CMU faculty. During his term, Art spearheaded rebuilding the department by hiring almost half of its faculty, including Myung Jhon, Larry Biegler, Mike Domach, Gary Blau (now at Purdue), and Greg McRae (now at MIT). Art enjoyed a brief sabbatical rest in 1983-4 as the Hougen Visiting Professor at the University of Wisconsin. His return to CMU led to a number of important achievements.

From 1985 to 1986, Art led the competition for a new NSF Engineering Research Center in the area of interdisciplinary engineering design. The resulting Engineering Design Research Center (EDRC) was founded on the concept that basic principles and tools for the design process could be generalized across all engineering disciplines, which in turn would lead to a more fundamental understanding of how to improve the cost, quality, and time for developing designs.

Art served as the first EDRC director from 1986-1989, and his leadership fostered a culture of interdisciplinary research and showed how design research cuts across domains.

Art's presence in the EDRC (and its successor, the Institute for Complex Engineered Systems (ICES)) remains strong through his guidance of the n-dim group and his advice and service on the ICES board. Within the chemical engineering department, many of us look to Art for his advice, wise counsel, and leadership. In the process-systems area, he has further contributed to its growth by influencing the hiring of Erik Ydstie and Steinar Hauan. Moreover, the department continues to remain young and active largely through Art's example and leadership.

## ART'S INFLUENCE IN EDUCATION

Art has creatively integrated the discovery of design concepts, modeling strategies, and process synthesis approaches into both undergraduate and graduate teaching. His approach has been to motivate and to teach through concrete examples. This presents a clear need for new methods and exposes the important features of the problem as well as open research questions that need to be addressed. Art's teaching incorporates fundamental concepts for design and synthesis, with less emphasis on specific computer tools than on a general understanding of what needs to be done. Nevertheless, novel modeling features of his research (including prototypes of ASCEND) have been incorporated into both undergraduate and graduate courses.

***Heading a diverse team of researchers (engineers, computer scientists, and even artists), Art has spent the last decade molding these ideas into the n-dim system in order to support the 'design' of the design process for a project team.***

Moreover, Art's teaching legacy is evidenced in two texts: the widely distributed work on process simulation (Westerberg, A.W., H.P. Hutchison, R.L. Motard and P. Winter, *Process Flowsheeting*, Cambridge University Press, Cambridge, England, 1979) and the recent design text (Biegler, L.T., I.E. Grossmann, and A.W. Westerberg, *Systematic Methods of Chemical Process Design,* Prentice-Hall, Englewood Cliffs, NJ, 1997)

Finally, Art's legacy as a graduate mentor can be seen in the education of thirty-seven PhD students; six of them have pursued academic careers (see Table 1). Needless to say, he has strong links with all of his former students and they view him as an example of outstanding scholarship.

## ART'S INFLUENCE IN THE PROFESSION

Aside from being an intellectual leader of process systems engineering and contributing to research and education, Art has been influential in the chemical engineering profession itself. He has been active in the AIChE, serving on a number of committees (*e.g.* CAST Division, Awards) and teaching short courses. He was one of the founders of CACHE, and he co-chaired the second conference on Foundations of Computer-Aided Process Design, a meeting that now takes place every five years. He was also a member of the National Research Council Committee on Chemical Engineering Frontiers, heading the panel on Process and Control Engineering.

Art has given a large number of seminars in chemical engineering departments, many of them named lectureships. He also serves as member of the editorial board on several journals (*I&EC Research, Computers and Chem.Eng., Chem.Eng. Reviews, AI-Edam, Research in Engineering Design, JOTA*) as well as on the visiting committees at Florida, Princeton, and Wisconsin. His interactions with industry have also been extensive, both in consulting and research projects.

## ART AT HOME

Art's pioneering efforts in research and education have not left him isolated from the finer things of life. He and his wife of thirty-five years, Barbara, share a love of music and are frequent visitors to the Pittsburgh Symphony. Moreover, Barbara, an accomplished oboist and pianist (trained at Oberlin College and the University of Florida) organizes annual musical soirees that have enlivened and enriched the lives of many of their colleagues at CMU.

Art and Barbara's sons, Ken and Karl, are continuing in Art's footsteps, with a PhD in chemical engineering (University of Washington) for Ken and a PhD in Physics (Princeton) for Karl. Both maintain strong connections to chemical engineering and are pursuing careers in mathematical modeling and design.

Art remains active in athletics. He is an avid skier and a competitive racketball player. Moreover, his interest in personal electronic devices is legendary among his friends. This can be traced back to his mastery of sophisticated, multiscale slide rules as a teenager, as well as to the purchase of a mechanical calculator for his fraternity house when he was an undergraduate. More recently, Art has awed his colleagues with his expertise on palmtop computers as well as software and sophisticated operating systems for truly individualized computing.

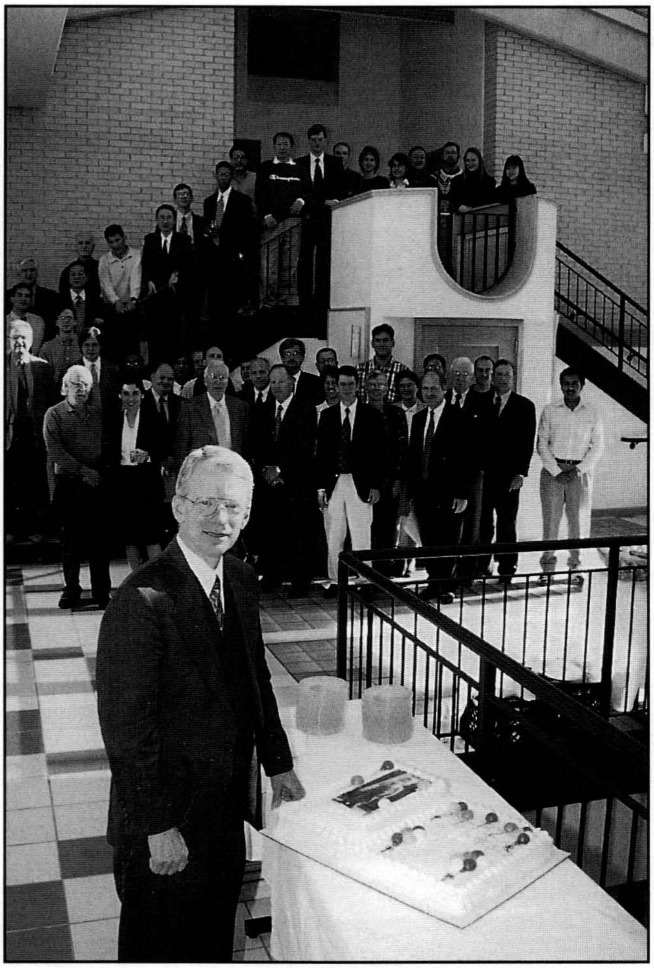
## CONCLUSIONS AND A NEW BEGINNING

When Art turned sixty last fall, it dawned on many of his colleagues that the birthday marked a milestone not only in Art's career but also in the evolution of process systems engineering as a major research area in chemical engineer-

**TABLE 2**

**Mini-Symposium Program**
**Art Westerberg's 60th Birthday**
**Carnegie Mellon, November 24, 1998**

| | |
|---|---|
| **9:00 AM** | *An Overview of Art Westerberg's Contributions*<br>George Stephanopoulos, MIT |
| **9:40 AM** | *A Further Contribution from Art Westerberg*<br>Karl Westerberg, Princeton |
| **9:55 AM** | *Art Westerberg's Work in Process Flowsheeting*<br>Rodolphe L. Motard, Washington University |
| **10:15 AM** | *Art's Contributions in DRC and EDRC*<br>Steven Fenves, Carnegie Mellon University |
| **10:35 AM** | BREAK |
| **10:55 AM** | *ASCEND*<br>Benjamin Allan, Sandia National Lab |
| **11:15 AM** | *SPLIT*<br>Oliver Wahnschafft, ASPEN Technology |
| **11:35 AM** | *n-dim*<br>Eswaran Subrahmanian, Carnegie Mellon University |
| **12:00 PM** | LUNCH |
| **1:00 PM** | *Polymer Flow*<br>Andrew N. Hrymak, McMaster University |
| **1:30 PM** | *Remarks from a Former Colleague*<br>Fritz Prinz, Stanford University |
| **1:45 PM** | *Remarks from Former Dean*<br>Herbert Toor, Carnegie Mellon University |
| **2:00 PM** | *Closing Remarks*<br>Ignacio E. Grossmann, John L. Anderson |



***Colleagues, friends, and former students who joined Art for his surprise 60th birthday celebration and symposium at Carnegie Mellon.***

ing. The event was marked with a memorable celebration at CMU—a complete surprise to Art. Along with a gathering of his colleagues, friends, and former students from far and wide, the event included a symposium sponsored by the Chemical Engineering Department. As shown in Table 2, participants included former students, collaborating authors, and researchers as well as colleagues at CMU.

This milestone represents not only Art's legacy but also a continuation of an exciting research area. Our hope is that Art will actively participate in the continued evolution of the area for many years to come. Therefore for all of Art's contributions in

- Defining the core of process systems engineering
- Testing the boundaries of the definition
- Enriching our approaches
- Expanding the scope with a multi-disciplinary context,

and in serving as a

- Profound Analyst
- Creative Synthesist
- Teacher par Excellence
- Challenging and Inspiring Advisor and Mentor
- Innovative Founder
- Excitable Hacker
- And Valued Colleague

we acknowledge a debt of gratitude. For those that have come know him, Process Systems Engineering will always be at the state of the Art.

## REFERENCES


1. Sargent, R.W.H., and A.W. Westerberg, "'SPEED-UP' in Chemical Engineering Design," Trans. Instn. Chem. Engrs, Vol 42, T190-T197 (1964).
2. Nishida, N., G. Stephanopoulos, and A.W. Westerberg, "A Review of Process Synthesis," AIChE J (Journal Review), 27(3), 321-351 (1981) ❐