USE OF IBM's ADVANCED CONTROL SYSTEM IN UNDERGRADUATE PROCESS CONTROL EDUCATION

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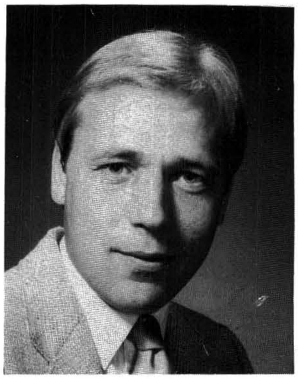

Lowell Koppel received his BSChE and PhD from Northwestern University and joined the chemical engineering faculty at Purdue University in 1961. He has been a frequent contributor to the literature and is co-author of a widely used introductory text on chemical process control. Recent awards include the 1982 Chemical Engineering Lectureship Award from ASEE and the 1984 "Innovations in Helping Students Learn" award from Purdue University. He has recently joined SETPOINT Inc. in Houston. **(L)**

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PROCESS CONTROL IS A difficult subject to teach because it ranges all the way from abstractions such as calcualtions in the complex frequency domain, to realities such as how a distillation tower will respond to a change in the reflux rate. Textbooks and lectures are not the best mechanisms for teaching students how to deal with real-time changes occurring over time spans of minutes, or even hours, in a real plant. Looking at a textbook graph of a previously generated plant response is a poor substitute for observing the real response. And, no textbook can provide a way for the student to test, tune, and revise a control strategy, which is a central thrust of professional practice.

These difficulties were highlighted in a recent trade article ("Putting College Back on Course," *Chemical Engineering*, Sept. 19, 1983, pp. 48-60), reporting a survey in which 4,759 engineers evaluated their undergraduate education. Process control courses were singled out with comments such as: "In college, process control is all Laplace transforms and transfer functions in the s-domain. In the real world, I need to . . . understand how control systems work." The article summarized its findings with this recommendation: "Courses in process control should have a practical orientation. Graduates are not using Laplace transforms and other control theory, but they do have a pressing need for information on how to design and operate practical control systems." As academicians, we can recognize this as a manifestation of the "never mind the theory, just teach me how to solve real-world problems" syndrome. Nevertheless, the perception regarding process control education is probably symptomatic of the problems mentioned above.

This article traces some of the history behind the IBM/academia arrangement, describes ACS and how it is currently integrated into the introductory undergraduate process control courses, discusses benefits to the students and instructors, and summarizes future plans.

A typical physically-based process control educational laboratory partially addresses these problems. However, the large numbers of students and the problems of maintaining equipment (particularly when used intermittently) make it difficult for universities to operate such facilities. Furthermore, laboratory processes are usually considerably smaller in scale

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*Present address: SETPOINT, Inc., Houston, TX than commercial facilities, thus negating some of the real-time feeling. Such laboratories usually have fixed control strategies which the students can test and tune, but not revise in favor of an improved strategy which they have synthesized.

The general-purpose computing facilities increasingly available in most universities can help overcome some of these difficulties. The physical process can be replaced with a simulation, and the standard control strategies can be pre-programmed. Maintenance problems are greatly reduced. However, interactive operation in real-time, over periods of minutes, is cumbersome and expensive on most computing facilities available for student use. In addition, programming the software needed to allow user-friendly implementation of alternative control strategies is a major effort, to say nothing of all the other software needed for effective student-to-computer interfacing.

One solution to this problem is the use of industrially developed software, on a computing installation devoted in major part to process control education. Purdue University and the University of Waterloo are now doing this. IBM's Advanced Control System (ACS) is a licensed program for implementing plant automation and is currently in use in refineries and plants around the world. Chemical engineering undergraduates at Waterloo and Purdue are using ACS, on color graphics terminals supported by an IBM 4341 mainframe, to study process control.

This article traces some of the history behind the IBM/academia arrangement, describes ACS and how it is currently integrated into the introductory undergraduate process control courses, discusses benefits to the students and instructors, and summarizes future plans.

HISTORY

In February, 1982, chemical engineering academicians from several institutions attended an IBM seminar on ACS, held in Houston. The purpose was to expose the academicians to the capabilities of ACS and to explore the possibilities for using it in chemical engineering education. Considerable enthusiasm was expressed, and in September, 1982, one of the authors (LBK) met again with IBM officials in Houston, this time to formulate a concrete arrangement for (1) installing the hardware and software at Purdue, (2) developing study guides for students to use ACS in an educational framework, and (3) making the facility available to students at other institutions. Final agreements between IBM and Purdue University were completed early in 1983, and the hardware and software were delivered, installed, and operating by July, 1983.

As stated by IBM, the ACS package is a licensed program providing a framework for implementing plantwide process control in medium- to large-scale plants.

At Waterloo, the ACS system was first installed in March, 1982, as part of a contract with IBM to develop a two-week intensive engineer's user course for ACS. At that time, only the ACS software was delivered in order to allow course development. The ACS system shared hardware resources with 350 other university users on a network of three IBM 4341 computers. Obviously, response was less than desirable. In May, 1983, as a result of a partnership agreement with IBM Canada Ltd., and the University of Waterloo, a dedicated IBM 4341 was installed solely for ACS and computer-aided design activities in the chemical engineering department. This, along with an IBM Series I Interface computer, has allowed real-time application of ACS for control on some of the pilot plants (*e.g.*, cyclic feed reactor, single cell protein plant).

In the fall semester of 1983, 168 chemical engineering students at Purdue and 75 at Waterloo used ACS as part of their introductory process control course. Currently, intermediate process control elective courses are being taught at Purdue (with over 50 students) and at Waterloo (with over 40 students), all using ACS. The remainder of this paper will be concerned with the development and delivery of the introductory process control course.

GENERAL DESCRIPTION OF ACS

As stated by IBM, the ACS package is a licensed program providing a framework for implementing plantwide process control in medium- to large-scale plants. It uses IBM general purpose and sensor-based computers for execution of control strategies and for single-source storage of information for plant and operating management.

As seen by plant operating personnel (and students), ACS is (among other information management functions) a user-friendly, menu-driven software package for implementation of computer process control. The operator sits before a console, typically made up of two or more color-graphic terminals, and can call up a variety of vivid and easy-to-use "live" displays from which to monitor and control the plant. Among the most frequently used of these are

- **Process schematics (Figs. 1,2). These can show the process flow and the control strategy. They are operating**

displays with real time update and change capability.

- **Faceplate displays (Fig. 3). These mimic the faceplates of older board-mounted controllers.**
- **Multitag plot displays (Fig. 4). These display short-term trend plots of up to four single tags, and can be converted to historical trend plots at the press of a button.**

Control strategies for ACS are defined on-screen by fill-in-the-blanks forms. Built-in control algorithms are supplied for P-I-D, lag/lead, ratio, multi-level bumpless-transfer cascades, high-low (constraint) control, interactive decoupling, and nonlinear or error-squared control. In addition, a General Algorithm facility enables straightforward programming of custom strategies, such as energy balance control.

EDUCATIONAL USE OF ACS

A key aspect of the educational use of ACS is that the manufacturing process itself can be simulated and simultaneously controlled on the host computer. A variety of process simulations are already available, including the furnace shown in Fig. 1. These can be constructed either within an ACS General Algorithm (as is the furnace), in the User Fortran Interface (a slave partition provided with the ACS system), or in dynamic simulation languages such as SPEED-UP. The simulations give a real-time feeling by having time constants on the order of minutes. The students, when operating the simulated process from the ACS displays, experience virtually the same events that would confront operators of the real process, with the exception of drastic events such as equipment failure.

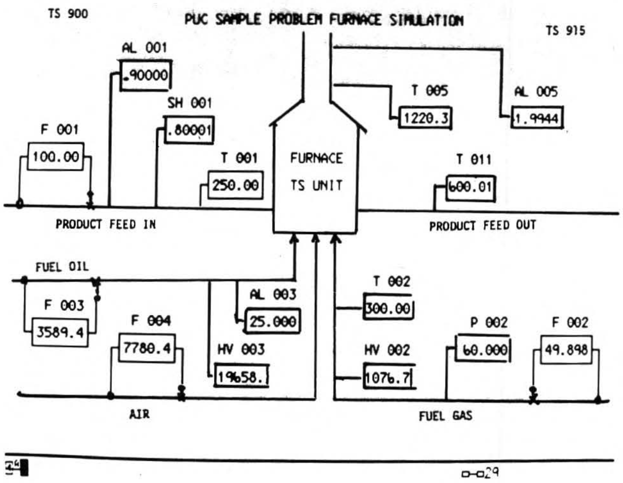


FIGURE 1. Overall schematic for furnace process. The black-and-white reproduction belies the vividness and easy comprehensibility of this and the other color ACS displays presented in this paper.

TABLE 1
Study Guides for ACS Process Control Units

UNIT	PURPOSE
I	Basic mechanics of ACS, such as display callup and entering changes.
II	Introduction to the furnace process. More basics of ACS. How to operate furnace through manual changes in fuel oil and air flow rates.
III	Manual operation and representation by single-variable block diagrams.
IV	Manual operation and representation by multivariable block diagrams.
V	Disturbances and their effects. How to overcome by rational manual operation. Limitations of manual operation for multivariable processes. Motivation for atuomation.
VI	Introduction to feedback control. Study of single-loop proportional control and its implementation to regulate the furnace. Effect of changing gain.
VII	Study of integral feedback. Implementation to regulate the furnace by single-loop proportional-integral control. Effects of changing integral time. Advantages and disadvantages of integral feedback.
VIII	Study of derivative feedback. Implementation of single-loop proportional-derivative and proportional-integral-derivative control to regulate the furnace. Effect of changing derivative time. Advantages and disadvantages of derivative feedback.
IX	Tuning control loops by process reaction curve method and by closed-loop cycling method. Tuning of loops dominated by delay time. Use of the furnace regulatory loops to practice and evaluate these tuning methods.
X	A study of the effects of interation between control loops. Effects of reversing loop pairings to alter the furnace control strategy.
XI	Open-loop frequency response. Students apply sine waves to fuel oil valve, observe temperature response, and prepare Bode diagram. Comparison of results with point obtained by loop tuning in Unit IX.
XII	Closed-loop frequency response. Students apply sine wave distribution in furnace throughput, observe temperature response, prepare Bode diagram of ratio of responses with feedback loop closed and open. Verify that loop is vulnerable near the resonant frequency.
XIII	Feedforward energy balance control. Use of a general algorithm to compute correct fuel oil flow from measured disturbance and feedforward to the correction through a lag/lead compensator. Tuning of the lag and lead time constants. Advantages and disadvantages over feedback.
XIV	Cascade control. Purposes and implementation. Bumpless transfer and coupling. Implementation of combined feedforward and feedback. Tuning of the controllers in these combined circumstances, compared with tuning when operated singly. Grand control strategy for furnace, using all previous concepts plus ratio and material balance. Comparison of results to show advantages of rational strategy based on process knowledge vs. "black box" feedback strategies.

A good analogy is a flight training simulator. This addresses many of the difficulties of process control education mentioned in the introduction. Students can quickly perform and see the immediate impact of open loop response tests, control strategy design, and changes in loop tuning parameters.

We have chosen a series of self-study guides as the vehicle with which to use ACS to introduce students to the practice of process control. These guides were written at Purdue as a series of Units, and were tested both at Purdue University and the University of Waterloo during the 1983 fall semester. The units are designed to form a complete support package for a traditional introductory undergraduate course in process control. Titles and brief descriptions of the introductory units are shown in Table 1. The units are now fully integrated into the Purdue and Waterloo programs.

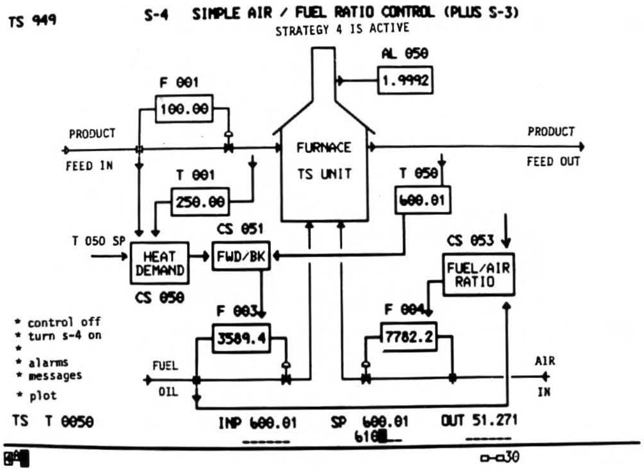
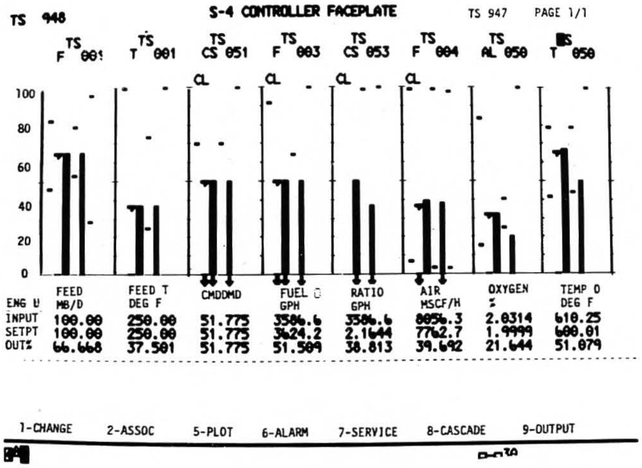


FIGURE 2. Schematic of a control scheme for furnace process. Note setpoint change being entered at bottom of display.



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        FEED     FEED T              FUEL      RATIO     AIR       OXYGEN    TEMP O
ENG U   MB/D     DEG F     CMDDMD    GPH       GPH       MSCF/H    %         DEG F
INPUT   100.00   250.00    51.775    3586.6    3586.6    8056.3    2.0314    610.25
SETPT   100.00   250.00    51.775    3624.2    2.1644    7762.7    1.9999    600.01
OUT%    66.668   37.501    51.775    51.509    38.813    39.692    21.644    51.079
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FIGURE 3. Faceplate display. Displays a user-defined group of variables.

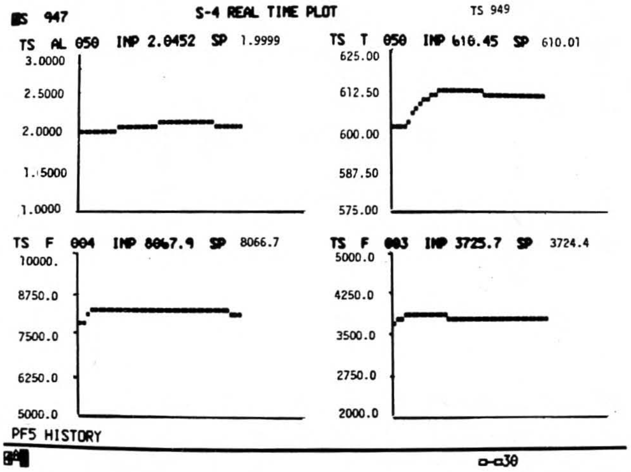

FIGURE 4. Multitag plot display. Short-term trend plots of a user-defined group of up to four variables. Pressing programmed-function key converts it to an historical trend plot.

Additional units dealing with other simulated processes, and with more advanced control strategies, are either available or being developed. In these advanced units, students are allowed to develop, implement, tune, and test their own control strategies, for a variety of processes. These units are designed for students interested in learning more about process control than is covered in a typical introductory course, presumably in the framework of an elective follow-up course.

Figures 5 through 8 illustrate some of the hard-copy responses the students obtain while performing the tests in the study guides, and offer some insight into the material covered. On all response plots, adjacent points are 8 seconds apart; the entire time axis covers approximately 7.5 minutes of real time.

COURSE FORMATS

At Purdue, the introductory process control course is required for all chemical engineering students. To incorporate ACS, the three-credit hour class has been structured into two formal lecture sessions, given to the entire class, and one recitation session, given to the class in six groups of approximately twenty-eight students each.

The lectures cover a traditional process control

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CONTROL SYSTEM

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outline, using the Coughanowr and Koppel text. A few of the recitations are orientation and preparation sessions, instructing the students in how to use the ACS system. Although the units are self guiding and can be used without this preliminary instruction, students can accomplish more study of process control after the preparation sessions. Other recitations use the ACS system in the demonstration mode to illustrate and reinforce particular course concepts. In either type of recitation, a video projector is used to put the instructor's CRT on a large screen for class viewing.

For the "hands-on" use of the ACS system, students divide into groups of three. Each group has reserved for it a weekly three-hour time period in which to perform the units. During this period, they have exclusive use of an ACS console, made up of two intercommunicating color graphics terminals, and exclusive control over a simulated process. Within this time frame, students are able to proceed at a nominal pace of one unit per week with little, if any, supervision.

At Waterloo, the first undergraduate course in process control is given at the 3B level (second half of third year). The course text is Coughanowr and Koppel. Originally, the course consisted of three hours per week of lectures for a term consisting of thirteen weeks. The first undergraduate course using ACS was given starting in September, 1983. With ACS, the course structure was altered to two hours per week of lecture with three hours per week in the computing lab using the coursework modules. The computing lab setup and hardware is essentially identical to that at Purdue. Over the course of the term, ACS unit modules I-XII were covered during the lab sessions.

STUDENT EVALUATION AND COMMENTS

Near the end of the courses at Purdue and Waterloo, students were invited to comment on the educational value of ACS. At both locations, approximately 70% of the respondents rated the use of ACS as "effec-

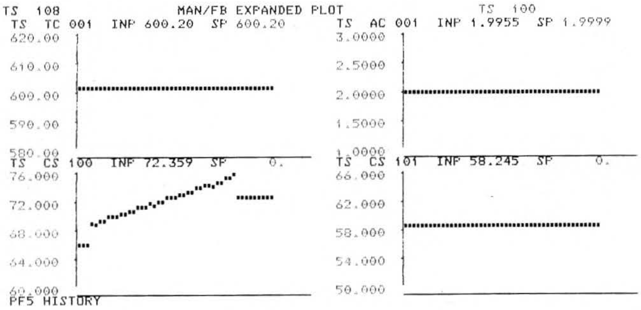

FIGURE 5. Controller output response to set-change in error. Students check validity of controller action by measuring slope of ramp and height of step.

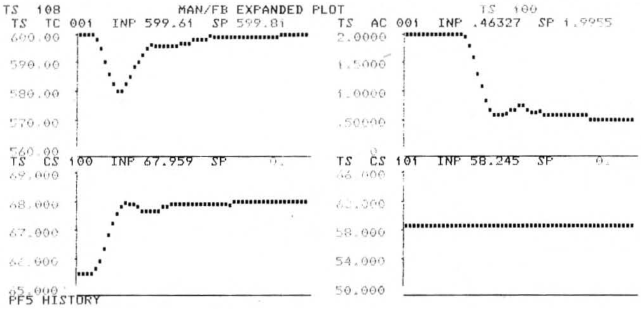

FIGURE 6. Response of furnace feedback control to step change in load. Students tune controller to obtain desirable response and to note effects elsewhere in process.

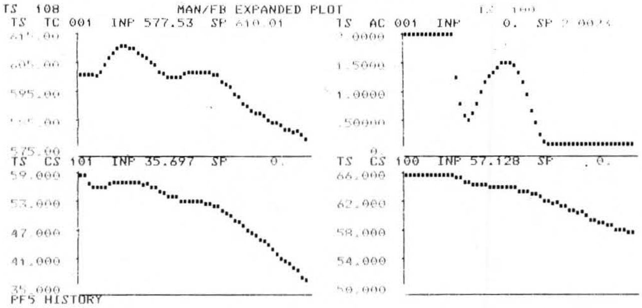

FIGURE 7. Response of control scheme using two single-loop feedback controllers. Students verify relative gain array prediction that no controller tuning can stabilize this control scheme.

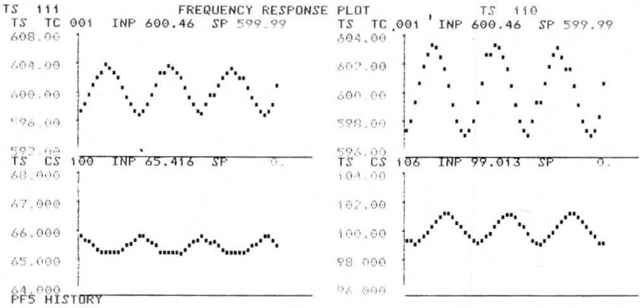

FIGURE 8. Closed-loop frequency response plot. Students verify vulnerability of feedback control schemes to disturbances near the process resonant frequency.

tive" or "very effective" in teaching process control. The bulk of the remaining responses rated it "OK." Virtually all students agreed that the sacrifice of lecture time for the use of ACS was well worthwhile. We are confident that their responses would differ from those of the engineers who participated in the *Chemical Engineering* magazine survey. At both Purdue and Waterloo, other indicators of positive student reaction were

- **Students worked at a faster pace than anticipated by the instructor. Only ten units were originally planned for the introductory course; the last four had to be added to keep up with the students.**
- **Students arrived as much as half an hour early, even for sessions scheduled at 7:30 AM, explaining that they wanted the additional time to experiment in greater depth.**
- **The original enrollment limit for the follow-up elective course was set at 38 students. Due to demand, this had to be increased, and even the larger figure was quickly oversubscribed. This is particularly unusual for process control, which is regarded as one of the most difficult subjects in the curriculum.**
- **The ACS facility was visited by over a score of industrial recruiters, on a "drop in" basis. They indicated their interest was spurred by the comments of their student interviewees, who almost invariably listed it as one of their favorite educational experiences.**

SUMMARY AND FUTURE WORK

We are enthusiastic and excited over the use of ACS in the undergraduate process control course. Our future plans are focused on the development of a wider base of process simulations for additional senior process control courses, and making the coursework modules available to any other universities desiring them.

Plans are already being implemented to make ACS and the study guides available to the chemical engineering department at Northwestern University and to the pulp and paper technology department at the University of Wisconsin-Stevens Point, both by remote dial-up to the Purdue facility. Other ACS sites now include Louisiana State University, Imperial College (England) and Queensland University (Australia).

The authors are grateful to the many people at IBM and IBM Canada Ltd. whose steadfast and enthusiastic support has made this valuable tool available to the chemical engineering academic community. Specific acknowledgment is given to Ross M. Aiken at Purdue as well as to Jerry van de Hoef and Blair Thompson at Waterloo for their dedicated system and tutorial support. ☐

ACCREDITATION

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ticipate only by invitation. Some university administrators would be delighted to see accreditation disappear. Who needs those interlopers putting more heat on for scarce resources for their favorite discipline? Who cares whether someone else likes the curriculum? I suppose the answer is that our profession is collectively interested in knowing what type of graduate is being produced beyond a potluck process.

This brings me back to my initial comments—those of us involved in the accreditation system represent AICHE and the chemical engineering profession, a profession involving educators and practitioners in industry and government. I conclude by confessing that participating in the camaraderie of the Exxon suite sure beats grinding through a mountain of accreditation reports and sitting through literally days of meetings. Anyone wish to trade places? ☐

BRIDGING THE GAP

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institutions. It is suggested that an integrated approach is more realistic and meaningful to study and to bridging the gap between academic curriculum and industry's needs. Specifically, we recommend that curriculum-related data and job-related data be analyzed simultaneously. The authors feel that this approach should give us better insight to the much reported 'gap' between theory and practice.

REFERENCES

1. Giauque, William C. and R. E. D. Woolsey, "A Totally New Direction For Management Education: A Modest Proposal," *Interface* (August 1981): 30-34.
2. Landis, Fred, "Employers Responsible for Education, Too" *ASME NEWS* (April 1984): 3.
3. Lipowicz, Mark A., "Putting College Back on Course," *Chemical Engineering* (September 1983): 48-60.
4. McClenahen, John S., "New Marching Orders for MBA's," *Industry Week* (August 1983): 49-51.
5. Newell, R. B., P. L. Lee, I. S. Leung, "A Resource-Based Approach to ChE Education," *Chemical Engineering Education*, Winter, 1985, 36-50.
6. Pollock, John A., Jon R. Bartol, Bruce C. Sherony, George R. Carnahan, "Executives' Perceptions of Future MBA Programs," *Collegiate News and Views*, Spring 1983, 22-25.
7. Prentice, Marjorie G., "An Empirical Search for a Relevant Management Curriculum," *Collegiate News and Views*, Winter 1983-84, 25-29.
8. Richman, Louis S., "B-School Students' Favorite Profs," *Fortune* (January 1982): 72-79,
9. Windsor, Duane and Francis D. Tuggle, "Redesigning the MBA Curriculum," *Interfaces* (August 1982): 72-77, ☐