T6 #191   200 Years of Chemical Engineering Pedagogy

Pedagogy and some factors that influence how we facilitate student learning
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In this paper I'll share a personal overview of pedagogy in general. This will include a listing of my personal choices of the major events, from about 1950 onwards, that have had an impact on how I try to facilitate learning. The events occurred in Canada, the United States, UK and Australia. Some were publications; some were local, provincial/state and national initiatives; some were organizations; some were networking. I'll suggest the implications and usefulness of each.

I'll also overview idealized career paths of persons who a) neglected pedagogy and focused on subject-discipline research; b) implemented pedagogy and did subject-discipline research; c) implemented pedagogy; d) implemented pedagogy and did research in both pedagogy and subject-discipline research and e) implemented pedagogy and focused on pedagogy-based research.

From this personal overview of activities in different countries, the evolution of a rich set of pedagogical ideas and a brief look at career paths of persons using pedagogy in different ways, some suggestions are given about personal actions you might take.

How might we facilitate student learning?   In the 1960's when I joined academia, I thought I taught students via lectures with 50 minutes of teach talk. Yes, I tried to make the lectures interesting, entertaining and motivating. Then I joined ASEE and began to realize that many new approaches were being developed to improve student learning. In this paper I'll note the publications and major events that influenced me in my journey to improve student learning. Then I'll shift gears and give an overview of idealized career paths of persons who took different approaches to the teaching dimension of academia.   Finally, I'll offer suggestions about personal actions one might take based on these two perspectives of an overview of pedagogy and options people take in their career paths.

1. Pedagogy from a personal perspective

The documentation of this journey is personal. I may have missed major pedagogical events and I may highlight ones that others might find trivial.   Some of these may no longer have an impact but was pedagogy developed that provided, for me, important ideas at that time.   An * indicates what I consider to be a resource that should be read today or be on your bookshelf.

1. the publication of **Bloom's taxonomy** (1). This taxonomy is a structured list representing increasing level of difficulty in learning in the cognitive domain. This has been revised by Anderson et al. (2). Such a classification is extremely helpful in analyzing the degree of difficulty expected in a task. For example, on an exam students should be given a chance to demonstrate an ability to do tasks of varying levels, rather than assigning only tasks at Bloom's level 6. Similarly, students can use such a taxonomy to monitor their growth. For the affective domain, a similar taxonomy has been developed (Krathwohl et al., 3). *

2. **McKeachie's** book on **"Teaching Tips"** (4). McKeachie provided the basics for all new teachers (and continues to provide ideas for experienced teachers). The current edition continues to provide great insight on just about any topic.*

3. **Annual workshops on pedagogy at ASEE** meetings by such people as Lois Greenfield, Gus Root, Helen Plants and Jim Stice. In the 1960s, only a few sessions related to pedagogy were offered by the AIChE. Now that has changed. Indeed, if we want to interest those faculty whose major concern is research in chemical engineering, then having sessions at the AIChE conference is the way to introduce them to ideas about how to improve teaching. These research-oriented individuals are unlikely to attend ASEE. For those interested in improving student learning we can be inspired by the presentations at ASEE and AERA conferences.

4. In the late 1960s the major event was Ray Fahien's leadership with *Chemical Engineering Education*.   Ray turned this journal into a   major resource for those of us concerned about scholarship in teaching. Keep up-to-date by reading this important publication. *

In the 70s...

5. The McMaster Medical School's introduction of small group, self-directed, self-assessed, interdependent **PBL**, started in the late 60s with their first class of graduates in 1972. They

created their own Center for Teaching (called the Program for Educational Development) that ran frequent "Education Rounds", published in-house reports and gave in-house workshops. I was lucky that this occurred on campus, and I could learn details about their approach. But, it wasn't until 1980 when Howard Barrows and Robyn Tamblyn published "Problem-based Learning: an approach to Medical Education" (5) that others had better access to this approach. The cognitive and psychological basis is summarized by Henk Schmidt and by Norman and Schmidt (6). However, this was still limited because for McMaster's Medical School a) one admission criteria included performance in a PBL session (whereas students in most programs were admitted based on primarily on marks), b) students admitted to the medical school were usually graduates of other undergraduate programs (and were therefore three to four years more mature than our engineering students), c) the whole program was PBL so that one faculty tutor could be assigned to a group of five students (whereas in engineering one faculty member would have a class of about 30 to 100 students) and d) most of the material was developed in the context of health sciences. Hence, attractive as this pedagogical approach might be, major modifications were needed to make it effective in our engineering classrooms.   Today, there are many resources to help guide its implementation into different environments (7-9).

6. In the late 60's and early 70s William Perry published his groundbreaking analysis of "Forms of Intellectual and Ethical Development in the College Years"(10).   However, it took about 10 years for the impact of this research to take effect. First, the initial approach to helping students understand their "**Perry level**" required trained professional analysis of essays. It wasn't until the 80s when people like Bill Moore established the Perry Network, Dick Culver gave workshops and Bill Moore, Peggy Fitch and Joanne Gainen created easy-to-use diagnostic tests (8) that the classroom use of the Perry inventory became used more extensively.   This inventory helps students (and faculty) identify the attitudes the students hold related to the teaching and learning process. For example, students with a Perry level of 2, when placed in a PBL environment react by saying "the professor isn't doing his/her job; they are not *teaching* me." An inventory more related to developing reflective judgment and critical thinking has been developed by King and Kitchener (11).   See also Rich Felder's article "Meet Your Students: 7. Dave, Martha, and Roberto." *Chem. Engr. Education, 31*(2), 106-107 (Spring 1997). Three students at different levels of Perry's Model of Intellectual Development. This can be downloaded from Rich's website (38).

7. the Ontario University Program for Instructional Development in the 1970s provided **financial support** for pedagogical projects; they had annual retreats and had external evaluation. In Canada at that time this was a very rare event. The OUPID program was described by Elrick (12). At that time, we were interested in developing *process skills* (sometimes called soft, generic, procedural or higher-order thinking skills) and our research was to learn how best to teach such skills as communication, problems solving and team work. The results from our research were published (13). In terms of process skills, one of the most challenging pedagogical issue is how best to develop confidence and skill (because lecturing was ineffective) in this domain.   Conger's publications in the late 60s and early 70s for the Saskatchewan Newstart Program were an excellent resource (14).

8. A major key for learning is to have well-written, published **learning goals**. Mager (15), Kibler et al. (16)   and Johnson and Johnson (17) provided excellent guidelines as to how to write learning objectives. These guidelines were the basis for developing the Keller plan for Personalized System of Instruction, PSI, or "Individualized Instructional Material". As an aside, we used their ideas in creating our workshop to develop student's skill in creating learning objectives as part of self-assessment. This is part of the McMaster Problem Solving program (13). Well-written learning objectives are still a critical part of any learning activity. Johnson and Johnson (17), Kibler et al (16) or Mager (15)   remain my best resources.*

9. **Alverno College's program for the eight abilities** (18). In the mid 1970's Alverno College, Milwaukee, WI, published a list of the eight abilities as outcomes for all their programs.   These abilities were effective communication, analytical capability, problem solving ability, facility in forming value judgments, effective social interaction, understanding of individual/environmental relationships, understanding the contemporary world and educated responsiveness to the arts and humanities. For each ability they published six goals/learning objectives. They trained students in self-assessment and created a separate assessment office where students could demonstrate their abilities. This revolutionary approach was, and remains, unique. I was lucky enough to be hosted by Dean Austin Doherty who graciously shared materials and helped me see how I could apply some of their approaches at McMaster. Alverno created a separate program evaluation unit to evaluate the effectiveness of their approach (19). I would encourage everyone to learn as much about their program as they can by attending their workshops and reading their publications. Their work on self-assessment is superb.*

10. In the 1970s, Keller's **personalized system of instruction**/ self-directed learning was a new approach. This prompted workshops, such as Lee Harrisberger's workshops on   Individualized Learning Management or Self Paced Instruction (eg in Ontario such a workshop was held at the University of Guelph 1974) (20). Background about this approach, and variations on it continue to be used, and the principles can assist the development of distance learning modules.

11. A variation of the Personalized System of Instruction was Charlie Wales and Bob Stager's publications and workshops on **Guided Design** (21).   They produced a facilitated form of problem-based learning for large groups where autonomous groups of students are given written/guided tasks to do. They have created several great resources: two books for Freshman engineering courses (including an instructor's guide) and a guide for new faculty on how to facilitate student learning via Guided Design. The book is written as a guided design format. They build their learning process around an 11-step decision-making process. I was fortunate enough to participate in several of Charlie's workshops, and the published material can be used to help craft PBL activities.

12. Craig Hogan introduced me to his research on **Jungian Typology** (22). This inventory provided students with a rich understanding of individual uniqueness and their particular style in learning, deciding and interacting. This inventory is similar to the Myers Briggs Typological Inventory, MBTI, and the Kearsey Bates inventory (23). We included this as part of the MPS

units on Personal Uniqueness and on Learning Skills (13). I recommend that this be included in all programs as the first step, following Bandura's model for self-efficacy (24), in helping students develop self confidence*.

13. Robert **Karplus** (25) created workshops including activities to develop reasoning. The activities available are in the subject domains of general science, physics, biology and chemistry. Again the pedagogical underpinnings illustrate the use of active learning.

14. Jack **Lochhead conferences** (26). In the mid 1970s Jack organized a conference on teaching reasoning, problem solving and critical thinking. He brought together key psychologists and researchers in the area of cognitive thinking (including Dorothea Simon, Jill Larkin, Alan Schoenfeld, Fred Reif, Art Whimbey, John Clement and Moshe Rubinstein). Fortunately, I was included. This was a very steep learning curve for me because these researchers were using terminology and concepts that were new. It also was a great networking opportunity. I came away with reprints and ideas that provided a strong pedagogical basis for developing problem solving skills. Additional conferences were held. A recommendation is to interact with colleagues in the cognitive and behavioural sciences and base your in-class interventions on pedagogically-sound principles (and not gut feelings).

15. The creation of *Centers for Teaching* and the gradual introduction of internal grants to support this activity at various Universities. Some, like the one at the University of Michigan, were established very early. At McMaster University Drs Alan Blizzard and Dale Roy, of the Instructional Development Centre, helped me immensely by TV taping my class and providing *gentle* feedback, bringing excellent workshop leaders to campus and alerting me to new developments. Frequent your Center for Teaching. *

16. Various **Newsletters** were published on developing problem solving skills and teaching (the Franklin Institute Press "Problem Solving" newsletter; McMaster University "PS News", and the HERDSA newsletter).

17. The **Pfeiffer** collection of practical workshops to develop soft skills (27). This is an excellent guide for active workshops on a wide variety of topics. I consult this resource often.

18. The publications of and workshops given by David Boud, Graham Gibbs, Alan Jenkins that brought a **European and Australian perspective**. In Canada with the Commonwealth connection, we were fortunate to have visiting educators from the UK and Australia who presented workshops (28).

19. Engineering Practice Introductory Course Sequence, **EPICS**, program at Colorado School of Mines.

20. AIChE's subcommittee on **Education Projects** and the increasing number of sessions from Group 4a at the annual meetings. Jud King's leadership; Ed Eisen's annual surveys of "how to teach subject...", the practice schools. These activities may not have had much emphasis on pedagogy but they provided very useful resources.

21. The creation of the *Annals in Engineering Education* as a split off from Engineering Education to focus on scholarship.

For the 1980s

22. The Jossey-Bass series **"New Directions for Teaching and Learning**" (29). This excellent series is in most Centers for Teaching and provides easy access to the fundamental research in cognition and behavior upon which to base our efforts.*

23. The creation of the Canadian **3M teaching fellowship** program (1984 onwards) had an immense impact in Canada. Ten awards are given annually from among 33,000 faculty across Canada in all disciplines.   The criteria are effective in-class teaching and scholarship in teaching.

24. Marshall Lih and the **NSF programs** to financially support educational activities. Again, regrettably Canada does not have such a program.

25.   Edward **deBono**'s book on the *Mechanism of the Mind* provided good background material for the MPS creativity workshop (13). His *Thinking Course* and his workshops were a great resource on how to teach thinking   (30).

26. **Chickering and Gamson** (31) summarized cognitive research and suggested that we can improve student learning by applying seven basics: use cooperation not competition, expect student success, have clear time on task, account for your student's different learning styles, provide prompt feedback, use active instead of passive environments, and have extensive teacher-student interaction. *

27.   Felder and Silverman's **learning style inventory** (32).   Rich's articles "Meet your students..." illustrate the implications (38).*

28. The **ASEE Summer Schools** initially had negligible contributions to pedagogy but recently have included more, for example Rich Felder's contributions to the Denver Summer School. Throughout the years they have been an excellent source of how to teach different topics.

29. Noel Entwistle and Paul Ramsden's work on **deep, surface and strategic learning** (33) and their development of the **Course Perceptions Questionnaire** and the **Approaches to Studying Questionnaire** *. Dr Chris Knapper, Instructional Development at the University of Waterloo and later at Queen's University, alerted me to this research and revised the inventories to North American terminology (34). Rich Felder's article "Meet Your Students: 3. Michelle, Rob, and Art." *Chem. Engr. Education, 24*(3), 130-131 (Summer 1990) describe three different approaches to learning (deep, surface, and strategic), and the conditions that induce students to take a deep approach. This can be downloaded from Rich's website (38)   A new version of the Course Experience Questionnaire has been developed to include process skills. (33) *

In the 1990s

30. **Karl Smith's** workshops and publications provide the basics for the use of various types of cooperative groups (35). *

31. **Wankat and Oreovicz** published an excellent text *Teaching Engineering.* This text can be downloaded free. Consult it often (36). *

32. **Davidson and Ambrose's** book in 1994 for young faculty (37).

33. John Prados and Stan Proctor's initiative with **ABET 2000 criteria**. Sadly the Canadian Accreditation is still bean counting.

34. **Websites**: Rich Felder has an excellent website from which you can download a rich set of resources (38). *   Another excellent web source is the Society for Teaching and Learning in Higher Education (Canada) **STLHE** electronic mail **forum**. Use this forum to pose questions, follow discussions and keep up-to-date (39).*

 35. In Physics, Hestenes, Wells and Swackhamer (40) developed an inventory to test a student's understanding of the concept of "force". Steif and Dantzler (41) created a concept inventory for statics. **Ron Miller**, of Colorado School of Mines, has developed three excellent concept inventories related to thermodynamics, heat transfer and fluid mechanics (42) *.   Such inventories can be used to evaluate the effectiveness of various learning environments as done, for example, by Hake (43).

36. At McMaster University several ways are used to recognize an emphasis on improving student learning. These include *The McMaster Student Union annual awards* for teaching and for lifetime achievement; the **President's Awards** for educational leadership, for resource preparation and for in-class teaching, and the Teaching Wall of Fame display. The University of Guelph took the initiative in 2000 to give an **honourary DSc** for scholarly contributions in teaching and learning. They also have a Visiting Teaching Fellow program. What options does your university offer to celebrate excellence in teaching? *

37. John **Heywood's book** is a monumental summary of "Research and Development in Curriculum and Instruction in Engineering Education" (44). * Heywood surveys and critiques papers that have been published in engineering education. Keep this reference book handy for good ideas.*

38. The series of five papers on *The Future of Chemical Engineering Education* published in Chemical Engineering Education (45).*   Papers 2 and 3 in this series are a convenient summary of ways to improve student learning.

39. The National Survey of Student Engagement, **NSSE** (46). This North American survey provides data about a) the level of academic challenge (based on mainly Bloom's taxonomy plus

length of assignment); b) active and collaborative learning, c) student-faculty interaction (includes elements of talking to faculty outside of class, receiving prompt feedback, working on committees with faculty), d) enriching educational experience and e) supportive educational experiences. Data are given for freshman and for seniors. The 95th and 5th median data are published on the web for DRU research intensity universities at three different categories (very high activity, high and doctoral). Data are also given directly to the participating institutions. The questions can be downloaded so that you could use the same questions to gather data at the course, department and faculty levels. Extensive norm data are available. *

So what?

1. Your pedagogical journey will be different from mine. However, some common elements will probably include: #1 Blooms taxonomy; #6 Perry's inventory; #8 how to create learning objectives or goals; #12 and #27, learning style inventories; #15 draw on the expertise of the professionals in your *Center for Teaching*; #26 Chickering and Gamson's seven principles and #38 the *Future of Engineering Education* series of papers.

2. Base what you do on the cognitive fundamentals. I was lucky to have been invited to Lochhead's conferences. Otherwise it would have been very difficult for me. Not all of us may be this lucky. So, ideally, attend the AERA conference. Second best is to borrow the Jossey-Bass series from your *Center for Teaching*. Next, at the AIChE conference we might annually sponsor a session on "State of the Art for Learning" to which we would invite three noted researchers from cognitive or behavioral sciences to present one-hour overviews.

3. I've noted some resources that you might want to add to your bookshelf. I also think the dual perspective of US-based innovations and Canadian-based innovations is useful. Some are similar but some are not. For example, the 3M and the hon DSc are, I think, mainly Canadian   stuff (that would be nice to see in the US), and we also have a rich set of workshops (either at our universities or our national STLHE conferences) that draw from the UK and Australian connections.   On the other hand ABET, NSF funding, AIChE and ASEE are really strong US elements that I wish we had in Canada.

Consider now some possible career paths.

2. Possible Careers Paths

From my experience as a consultant, as a member of the Promotions and Tenure Committee, as Departmental and Program Chair, as expert witness in a law case and as reference for candidates seeking promotion at a wide variety of universities, I offer five imaginary career paths of individuals. These faculty place different emphasis on pedagogy.   Although these are imaginary, they are relatively realistic snapshot of life for research-intensive universities around 2008. Michelle, Hector, Janice, David and Frances are from different Chemical Engineering Departments.

2.1 Michelle

Michelle focused on Chemical Engineering research. She tried to be a good supervisor and teacher but her emphasis was on her research. She published about 10 papers/ annum and received the most external grants of any of her colleagues. Her research papers won awards. For in-class teaching, her student course ratings were below the average but not disastrous. She never attended any workshops to improve teaching. She was described as "a good solid lecturer". She had trouble writing a Teaching Dossier but, with the help of her mentor, her Dossier was satisfactory.
Michelle was promoted to Full Professor two years in advance.

2.2 Hector

Hector's research in reaction kinetics was going well. He received good grants and some industrial sponsorship. He produced about two refereed publications per year. Hector likes to teach and is rated as one of his Department's better teachers. Active learning is something he uses in all his classes and the students respond very positively. He attends most student events throughout the year. Occasionally visiting faculty from other Universities come to talk to Hector about his teaching. Hector attends many of the seminars given by the Center for Teaching.

Hector was promoted to Full Professor on time.

2.3 Janice

Janice loved to teach; she really wants her students to learn. As soon as she was granted tenure, she ceased applying for research grants in her specialty process control and phased out her graduate students. Yes, she continued to be a member of supervisory committees and tried to keep up-to-date with developments in process control. But her focus was on being an outstanding teacher.. and outstanding she was. Her students raved about her courses, visitors came to sit in on her classes; she won numerous student teaching awards for her in-class teaching. Her skill seemed to come naturally; she rarely consulted with colleagues in the Center for Teaching nor did she attend conferences or read educational journals.

Janice remained an Associate Professor for all her career. Indeed, she was encouraged to assume a heavy teaching load because "the students love her".

2.4 David

David was a terrific performer in class. "Spell binding", "fun", "tops in entertainment and you learned too" - these are some of the student accolades. He annually won the top awards from the students. David frequents the Center for Teaching and gives many popular workshops. He publishes papers describing teaching tips, approaches he uses in the classroom and how to interest students in any topic. The paper are published in refereed journals.

In addition, David has a research group in nanotechnology. He receives good funding and usually has one Masters and one PhD student.

When David was considered, "on time", for promotion to Full Professor the committee turned down his promotion because "we normally expect ten refereed publications. David has five refereed in nanotechnology. He also has five papers in education, but in neither field - nano or education - does David has ten".

2.5 Frances

Francis loves to teach and wants to measure the effectiveness of her classroom interventions. She also is a skilled researcher and decided to apply her research skills to teaching. She selected cooperative learning and self-assessment as her two areas of specialization.

After she attended Karl Smith's workshops at an ASEE meeting, she returned to campus and immediately introduced cooperative learning into both her undergraduate and graduate courses. Her student evaluations plummeted. In consultation with the Center for Teaching she realized that, when introducing new approached, she needed to rationalize the choice to the students, and use class ombudspersons to continually monitor the quality of the teaching-learning team. Subsequently her student ratings increased dramatically. Frances is rated one of the better teachers in the Department. To evaluate the effectiveness of her methods she gathered pre and post data using Miller's concept inventories and compared her results with the performance of students in conventional lecture classes. She also gathered data from the Course Perceptions Questionnaire and from NSSE. Frances publishes about three refereed papers/annum about her research-in-teaching. She receives grants from NSF to support her educational research. Her scholarly papers have won awards, and she is frequently asked to give seminars about cooperative learning or about self-assessment.

Frances's case for promotion to Full Professorship has been delayed for two years. In discussing this with the provost the provost admitted that the P&T committee has difficulty assessing the quality of the refereeing system used by the educational journals in which she published. "We know about *Chemical Engineering Science* and about the *AIChE Journal* but how rigorous are journals like *Assessment and Evaluation in Higher Education*? The committee will reconsider your case next year.

2.6 So What?
In summary from these cases, most institutions are research orientated and know how to measure effectiveness in Chemical Engineering research. P&T committees, and administrators tend to be learning about, but remain unconvinced and uncertain about, research-in-teaching. We need to demonstrate that refereed journals, such as "Assessment and Evaluation in Higher Education" are equivalent in reviewing standards to Chemical Engineering Science, for example.

Faculty are learning that research-in-teaching requires well-designed evaluation of pedagogical interventions. In the past we have incorrectly tended to use "they liked it" and "I liked it"

evaluation. We tended to "diddle around" trying different things in the classroom without evaluating their effectiveness. We published refereed papers describing what we did in the classroom, as David did, instead of measuring the effectiveness. We should apply our well-developed research skills to evaluate our approaches to teaching.

3. Summary

From this view of activities in different countries, the evolution of a rich set of pedagogical ideas and a brief look at career paths of persons placing different emphasis on pedagogy, here are my top three recommendations.

1. Personal, starts with you. **You** can have a major impact.
2. Look beyond US, beyond AIChE, ASEE and learn from what others have done. Arrange three day visit with educators in your area of specialization. Visit your Center for Teaching often.
3. Have a realistic understanding of your local P& T system; if you don't get tenure you can't teach.

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Rationals and Artisans. Keirsey includes four Jungian types in each of his four categories. These differ in name between the web results and the book. For example, the "Guardian" includes ESTJ, ISFJ, ISTJ and ESFJ. To obtain more details about the type from the web version requires payment. *Comment:* the seventy questions offer either yes or no answers whereas Hogan's version allows you to distribute a numeral from 0 and 5 between the two options (as long as the total is 5). Thus, in question 1 from Keirsey, "at a party do you (a) interact with many, including strangers or (b) interact with a few, known to you." Keirsey expects an either-or answer. I might prefer (a) 3 and (b) 2, meaning that I usually prefer meeting new people but I certainly enjoy visiting with known friends.   Furthermore, Hogan's version provides a numerical value between 0 and 40. Thus a score of 20 on the NS scale would suggest that I am either N or S; whereas a 30 N, 10 S would suggest I am rather strongly N. I prefer the Hogan version.

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