ChE classroom

THREE TRENDS IN TEACHING AND LEARNING

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Great strides have been made in understanding learning, but few teachers have paid much attention to them. Teachers have continued to teach the way they were taught, namely, by using the lecture system. There is growing dissatisfaction, however, by both students and taxpayers about the quality of student learning. Learning has now become more and more the focus, and there have been a number of published research findings on how to improve it.[1-13]

HOW TO TEACH

A number of principles can be employed to improve learning. A teacher can change his or her approach to

- Show concern for the students as persons
- Demonstrate concern for the students' success
- Include activities that prepare students for the real world or for their profession, placing emphasis on what and how the students learn and not on how the teacher talks
- Empower students with parts of the learning process
- Publish clear goals and criteria for learning
- Make assessment processes consistent with the goals and criteria
- Include activities to help students create a useful knowledge structure
- Give prompt feedback
- Motivate the students

Students can also embrace change to improve their learning. They can

- Be active
- Work cooperatively
- Have a clear understanding of the task and the time allotted for the task, and apply themselves diligently to the task
- Be aware of their own learning preferences and know how to use them effectively
- Be aware of the need for knowledge structure and the importance of cues
- Have ownership of elements in the learning process

An interesting sidenote is that many of these principles for improving learning are also required in the second trend on "what to teach," featured in a later section of this paper.

So what can we, as teachers, do? The easiest, least expensive, and most effective change is a change in attitude, as outlined above. Identify ways to demonstrate your positive attitude to the students. (A questionnaire that gives you a chance to check your attitude is available from the author.)

If you currently lecture, try including some student activity in the lecture. One of the easiest methods to incorporate is "Turn to your neighbor..." When you see that glazed look in students' eyes, or when the twenty-minute boredom sets in, use this technique. The conditions determine the activity. I may use the comprehension-check activity described below several times in a single 50-minute period. I use it if I have just explained a difficult topic, if the students seem bored, if a student asks a question that might be representative of the whole class, or when I want to change from just me talking. In this activity, you might ask the students to

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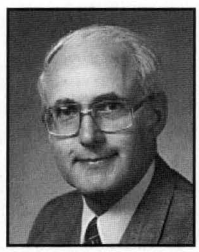

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- Talk about their understanding
- Explain the idea to each other
- Answer the question, "So what?"
- Perform a task that requires that they "know the subject," This could be a calculation, a simplified or complex problem, or a small section of the problem-solving process. *For this question, identify the pertinent knowledge you think they need to solve the problem and tell them to write out what they think they are asked to do.*

It is useful to obtain feedback on how well the teaching and learning is progressing by using "ombudspersons." Ombudspersons are volunteer members of a team from the class who provide you with feedback throughout the year. As teacher, on the first day of class you can greet your students with

> *Welcome to this course in chemical engineering. My role is to help you learn. I see learning as a two-way street, with you and me working together to help you get an A in the course. To help me in my role as teacher, I need periodic feedback from you. Here's what I suggest that we do: I would like three volunteers to be ombudspersons. Your role would be to relay to me, on behalf of the class, any comments, suggestions, or ideas on how I can help you the most. Any questions? Are there volunteers?*

Often there are no volunteers, especially if the idea is a new one to them. So, continue

> *No volunteers? It'll look good on your resume. In terms of time commitment, I have found it useful if I meet with the ombudspersons formally for about ten minutes twice a semester, at about week four and again during week seven. This is not a large time commitment, and look at the skills you will be developing—communication skills, political skills, succinct summarization of any frustration from your colleagues and expressing it so that I understand. Now, do I have volunteers?*

You will probably have more than enough volunteers at this point. I use about three for classes of fewer than 60 and about six for classes of 400. Try to select volunteers who represent a good cross-section of the class. Once they have been identified, ask them to stand so everyone in the class knows their names and can recognize them outside of class.

At about week three, suggest that it is time to get feedback from the ombudspersons. Check with them to see if it is more convenient for them to meet ten minutes before or after class, or perhaps to meet somewhere for coffee. The time needed to capture the ombudspersons' feedback varies. It has been my experience over the past twenty years that most ombudspersons come with a written list, and our time is spent clarifying my understanding of the feedback, usually about three or four minutes. At times the feedback is verbal, and in those cases ten minutes could be required. I prefer to take the feedback in front of the class to demonstrate to the students that I take it seriously.

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When meeting with the ombudspersons, make an accurate record of their comments, remembering that you are not responding to them but to the other students, and that your response will be to the class as a whole. At the beginning of the next class, read the ombudspersons' comments and make comments such as:

- "We think you wear lousy ties." *Thank you. I have a limited wardrobe, but I will try to select better ones in the future.*
- "We have to spend too much time doing the journal writing in this class—last week it was 15 hours. It takes too ____ much time!" *OK, here is why I have found journal writing to be vital. Without the reflection and elaboration needed in the journal writing, we find that the skills are not developed as well as we hoped for. An alumnus, Kyle Bouchard, said : "...writing those journals every week was a pain. But without that I don't think I ever would have learned the skill!" OK, that's why I think the writing is important. Now, about the time: fifteen hours is expecting way too much. Is three hours more reasonable? Five hours? Ok, let's try for two hours a week. Now, let's gather some ideas about how to actually do that. Please form small groups and brainstorm fifty ideas in five minutes about how we can gain the benefits from journal writing and yet take only two hours a week doing it. Then, from each group I want the top three ideas.*

To summarize, collect the information, then solve the problem together with the students. Bring them in on the solution. Ombudspersons—don't hold a class without them!

It is also useful to pose practical problems near the beginning of each new subject so students can see the application and learn the new knowledge within the context of a professional problem to be solved.

WHAT TO TEACH

Teaching students chemical engineering is not enough. Since the 1970s, a number of professors, departments, programs, and colleges have felt that graduates should know more than the subject knowledge—they should be able to

apply that knowledge to solve problems and should have a wide variety of process skills and attitudes needed in professional practice. The process skills include communication, teamwork, self-assessment, self-awareness, changing management, coping with change, leadership, and "professional attitude."

To achieve this goal, the skills and attitudes are described as valued abilities, competencies, or outcomes of courses or programs, and an effort is made to have specific activities within the programs to develop the skills. They then assess how well the students can display the skills. In the literature, these programs are called "outcome-based" programs. Some examples of early efforts in this direction are:

■ **Alverno College,** Milwaukee, Wisconsin (1972):[14-15] all graduates of every program must show at least four levels of competence in each of eight abilities: 1) communication, 2) analytical thinking (critical thinking), 3) problem solving, 4) making value judgments and independent decisions, 5) effective social interaction, 6) taking responsibility for the global environment, 7) effective citizenship, and 8) responding to and appreciating the arts and humanities. The college set up a separate assessment department, separate "departments" for each of the competencies, and then left it to the individual instructors of each course to identify and develop certain levels of skills. Their approach has attracted worldwide attention and numerous awards for their innovation. They run annual workshops on assessment.

■ **McMaster Medical School,** Hamilton, Canada (1969):[12,16] graduates of the medical program must display a variety of knowledge, skills, and professional attitudes. Table 1 illustrates these outcomes. The approach has attracted worldwide attention and has spread to many health science programs. In particular, variations on the approach are now used in medical schools at Maastricht in the Netherlands, Newcastle in Australia, and in many schools of nursing, occupational therapy, and physiotherapy, and more recently in pharmacy. The program runs annual workshops and uses a small group, self-directed, self-assessed problem-based format.

TABLE 1
What Outcomes are Valued in Your Program?

Knowledge	
laws, concepts	____
structure	____
cues	____
elaboration	____
Process Skills	
problem solving	____
team work	____
lifetime learning	____
time management	____
change management	____
communication (written/oral)	____
self-assessment	____
leadership	____
other	____
Attitudes	
accuracy	____
intellectual curiosity	____
persistence	____
cope with ambiguity	____
willing to risk	____
restrain impulsiveness	____
flexibility	____
monitoring	____
reflecting	____
systematic	____
manage distress	____
self-confidence	____
self-esteem	____
self-awareness	____
ethical	____
reliable	____
honest	____
trustworthy	____
meet deadlines	____
document activities	____
plan ahead	____
anticipate difficulties	____
other	____

■ **West Virginia University,** Morgantown, West Virginia (1972);[17-20] graduates of engineering programs are provided with communication, team, and problem-solving skills using a small-group, problem-based approach called "Guided Design."

■ **McMaster Chemical Engineering,** Hamilton, Canada (1978);[21] graduates are required to show skill in communication, team, problem solving, self-assessment, change management, and self-directed, lifetime learning.

On the one hand, these approaches have increased in popularity because of the positive student response to the programs, the positive response from alumni, and the extremely positive response from employers and those in private professional practice. On the other hand, emphasizing the development of these "process skills" and attitudes is not easy. The traditional methods of teaching do not seem to be effective in developing the skills. For example, asking students to solve problems, asking teachers to demonstrate how they solve problems, asking students to work in groups, asking students to solve open-ended problems, asking students to demonstrate how they solve problems, rarely develop the students' skill or confidence. We should select explicit programs that have been proven to be effective in the past.

The trend is linked to research on improving learning, as discussed earlier. Figure 1 illustrates the links. Ideas to improve learning lead to actions in the classroom and provide at least three specific ideas that are needed to develop process skills: the need for explicit goals, the importance of using active workshops (instead of lectures), and the need for self-assessment (to develop student's confidence in the process skills). One learning environment (problem-based learning) implements most of the ideas to improve learning: active, student ownership, self-assessment, cooperation, and knowledge structure development complete with cues and prompt feedback. The effective use of problem-based learning, however, requires that both the students and the tutor possess process skills. Problem-based learning requires and develops student's ability to generate learning issues, to teach each other new

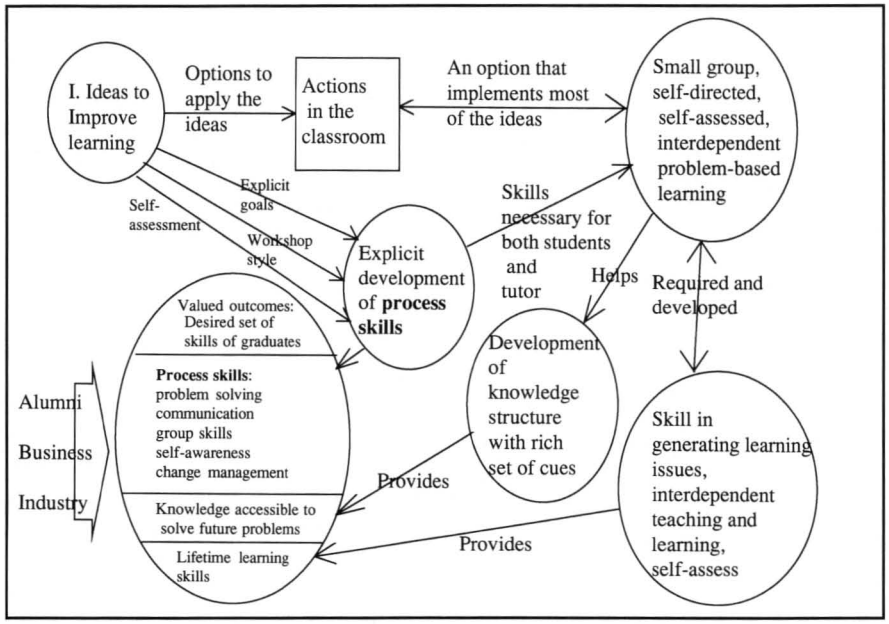

Figure 1. *Linking ideas to improve learning to the development of process skills and to the* creation of knowledge structure with cues.

TABLE 2
Contact Time for Developing Skills and Attitudes

References and subject context	Conventional programs or courses	Small group, self-directed, self-assessed problem-based learning that requires process skills
Albanese/Mitchell[22] medical schools	100% knowledge	80% knowledge because 20% is spent applying and using process skills
Winslade[23] pharmacy		82% for chemical engineering courses with 18% spent explicitly developing process skills
MPS program[21] engineering		

knowledge, and to self-assess.

From another viewpoint, alumni, business, and industry have identified a range of skills they hope graduates possess: process skills, subject knowledge that can be readily used to solve unique problems, and lifetime learning skills. One effective learning environment to develop the latter skills is problem-based learning. Connecting both the valued outcomes and problem-based learning is the explicit development of the process skills. The next section elaborates on the development of knowledge structure.

We can develop process skills in several ways:

- Determining the valued outcomes or skills you want graduates to possess. Table 1 list some possible outcomes.
- For each course in the program, identify both the outcomes and where in the program the skills are developed and practiced. Developing process skills effectively takes time, however. Table 2 summarizes published evidence that suggests that the skill development needs about 20% of the available time. This means that educators who want to move in this direction have to expand the semester, increase the number of semesters in the program, or reduce the amount of subject knowledge in the current curriculum by at least 20%. We chose the last. We retained a core of fundamentals and streamlined the number of courses.[21]
- Select proven methods to develop the students' confidence and skill. Options that have proved to be effective are to give students clear objectives and examples of examinations to test such skills,[24] to give students a chance to try the skill and to receive immediate feedback, and to provide students with

target skills and opportunities to practice, practice, practice. Bandura[25] offers explicit suggestions about how we can develop students' confidence by carefully structuring activities to help them succeed. Sternberg[26] and Beyer[27] offer general criteria for selecting programs. The option we used is based on the research of Sternberg, Beyer, and Bandura.

HOW WE LEARN KNOWLEDGE AFFECTS HOW WE RETRIEVE IT!

Effective problem solvers initially need to have both generic problem-solving skills and subject knowledge. The subject knowledge should be readily accessible for the contexts in which it is needed to solve problems. How we learn knowledge affects our ability to use it in the future.

There is some interesting research to support this contention. Godden and Baddeley required some underwater divers to memorize lists of words on land and others to memorize lists while under water. Later, they were asked to recall the list of memorized words. Recall was hampered if it was done in the opposite environment, that is water instead of land and vice versa.[28]

Zhu, et al.[29] and Zhu and Simon[30] worked with high school students who were learning to factor quadratic equations and to solve problems about buoyancy. Three different approaches were taken: 1) the conventional teacher-talk about the fundamentals and sample applications, 2) students worked individually with carefully structured and sequenced examples in the form of "if-then" rules ("if" the equation has this form, "then" take this action), and 3) students were given problems and answers to the problems. They found that students who learned by working examples focused on acquiring the "conditions" to identify when to apply the knowledge. The students noticed cues about when conditions were satisfied and when to apply a given set of knowledge. They spent time elaborating on what they found to be effective in solving the problems. From each success, they created checklists of the relevant conditions; they learned to ignore the irrelevancies. The researchers concluded that how students learn knowledge affects their future ability to apply it.

Eylon and Reif[31] showed that teaching or helping students learn the material using deductive methods helped them perform better on future deductive tasks (compared with a control group). Those who learn or were taught knowledge following a historical or developmental organization performed better on future historical tasks. They also concluded that how students learn the knowledge affects their future ability to apply it.

Schmidt[3,4] provides more details of other research and relates it to problem-based learning. He emphasized the importance of giving students a chance to elaborate on the knowledge as they learn it.

Some of the techniques we might use to good advantage are:

- Consider using problem-based learning in which the problem is posed to drive the learning. In other words, students learn knowledge because they need it to solve a problem.
- Include activities such as "Turn to your neighbor and..." to have students reflect and elaborate on the ideas just presented in class.
- Ask students to create concept maps of the knowledge; emphasize the importance of "cues." Figure 1 is an example of a concept map. Each bubble is meant to be a key issue, and the bubbles are joined by lines with arrows that show the relationship between concepts. Words should be added to each line to explicitly show the connection. Details about concept maps and how to assess them are given by Woods[12,24] and Novak and Gowin.[32]
- Require that the students complete checklists, such as those developed by Larkin[33] describing the terms in the equations, limitations, conditions, and cues as to when to use them.
- Provide "knowledge structure" charts. Examples of such charts are given by Woods and Sawchuck,[34] Felder,[35] Bird,[36] Fogler,[37] and O'Connell.[38]
- Use the didactic model suggested by Bagno and Eylon[39] with an added emphasis on the addition of cues.

SUMMARY

This paper reviews three recent trends in education. The first trend is that much of the research on the learning process provides teachers with a rich resource of proven ideas to improve student learning. Research has shown us about a dozen ideas on how to improve student learning. Teachers should focus on facilitating learning rather than on teaching. A teacher's task is to help students succeed. Seven ideas on the roles of students in the learning process were given. Four specific suggestions for teachers are to conduct an "attitude check," to bring activity into the classroom by telling the students to "Turn to your neighbor and...," to solicit feedback about the quality of the learning by using ombudspersons, and to introduce new topics by posing practical problems.

A second trend is that alumni and employers want graduates to have more than just a sound grounding in the fundamentals of the subject discipline. They should also be skilled in problem solving, in communication, in teamwork, and in a host of generic skills called "process skills." This paper describes four programs that produce graduates with this combination of knowledge and process skills. The programs are at Alverno College, McMaster University Medical School,

and at the chemical engineering programs at West Virginia University and McMaster University. The difficulties in developing these process skills are reviewed, example effective interventions are outlined, and suggestions are given as to their implementation.

A third realization is that the context in which students learn new knowledge affects future retrieval and use of that knowledge. In other words, the structure of knowledge in memory is important. That structure is affected by the context in which the knowledge is learned. For example, if students learn new knowledge in a problem-based context, the knowledge is learned in the context of having to learn knowledge to solve a problem. Cues relate the knowledge to the problems. Suggestions are given to help students acquire some of that structure when they learn in the more traditional lecture- or subject-based format.

These three trends are connected. Problem-based learning is suggested as an integrating vehicle.

REFERENCES

1. Chickering, A.W., and Z.F. Gamson, "Seven Principles for Good Practice in Undergraduate Education," *AAHE Bulletin*, March 3-7 (1987)
2. Chickering, A.W., and Z.F. Gamson, "Applying the Seven Principles for Good Practice in Undergraduate Education," *New Directions for Teaching and Learning,* **47**, Jossey-Bass, San Francisco, CA (1991)
3. Schmidt, H., "Problem-Based Learning: Rationale and Description," *Med. Ed.,* **17**, 11 (1983)
4. Schmidt, H., "Foundations of Problem-Based Learning: Some Explanatory Notes," *Med. Ed.,* **27**, 422 (1993)
5. Wankat, P.C., "Learning Principles: A Quick Guide to What Works," *Chem. Eng. Ed.,* **27**(2), 120 (1993)
6. Wankat, P.C., and Frank S. Oreovicz, *Teaching Engineering,* McGraw-Hill, New York, NY (1993)
7. McKeachie, W.J., et al., *Teaching Tips,* 9th ed., D.C. Heath and Co., Lexington, MA (1994)
8. Felder, R.M., "Things I Wish They Had Told Me," *Chem. Eng. Ed.,* **28**(2), 108 (1994)
9. Ramsden, P., "How Academic Departments Influence Student Learning," *HERDSA News,* **4**, 3 (1985)
10. Ramsden, P., and N.J. Entwistle, "Effects of Academic Departments on Student's Approaches to Studying," *Brit. J. of Ed. Psychol.,* **51**, 368 (1981)
11. Stone, H.L., "Data Gathering Instruments for Evaluating Educational Programs and Teaching Effectiveness in the Center for Health Sciences," University of Wisconsin-Madison, WI (1991)
12. Woods, D.R., *Problem-Based Learning: How to Gain the Most from PBL,* Woods, Waterdown ON, distributed by McMaster University Bookstore, Hamilton, Ontario, Canada (1994)
13. Woods, D.R., "PS Corner," *J. College Science Teaching,* **19**, 109, Dale's cone of learning (1989)
14. Mentkowski, M., and A. Doherty, "Abilities that Last a Lifetime: Outcomes of the Alverno Experience," *AAHE Bulletin,* **36**(6), 5 (1984)
15. Edgerton, R., "Abilities that Last a Lifetime: Alverno in Perspective," *AAHE Bulletin,* **36**(6), 3 (1984)
16. Barrows, H.S., and R. Tamblyn, *Problem-Based Learning,* Springer, New York, NY (1980)
17. Wales, C.E., and R.A. Stager, "Educational Systems Design," West Virginia University, Morgantown, WV (1973)
18. Wales, C.E., and R.A. Stager, "Teaching Decision-Making: Guided Design," West Virginia University, Morgantown, WV (1977)
19. Wales, C.E., "Does How We Teach Make a Difference?" *Eng. Ed.,* **69,** 394 (1979)
20. Bailie, R.C., J.A. Shaeiwitz, and W.B. Whiting, "An Integrated Design Sequence: Sophomore and Junior Years," *Chem. Eng. Ed.,* **28**(1), 52 (1994)
21. Woods, D.R., et al., "Developing Problem Solving Skills: The McMaster Problem-Solving Program," *J. Eng. Ed.,* **86**(2), 75 (1997)
22. Albanese, M.A., and S. Mitchell, "Problem-Based Learning: A Review of Literature on Its Outcomes and Implementation Issues," *Academic Med.,* **68**, 52 (1993)
23. Winslade, N., "Large Group PBL: A Revision from Traditional to Pharmaceutical Care-Based Therapeutics," *Am. J. of Pharma. Ed.,* **58**, 64 (1994)
24. Woods, D.R., "Problem-Solving Objectives," in "Problem-Based Learning: Resources to Gain the Most from PBL," available on the WWW at http://chemeng.mcmaster.ca under Innovations: Problem-Based Learning (1997)
25. Bandura, A., "Self-Efficacy Mechanism in Human Agency," *Am. Psychologist,* **37**, 122 (1986)
26. Sternberg, R.J., "Criteria for Intellectual Skills Training," *Ed. Researcher,* p. 6 Feb (1983)
27. Beyer, B.K., *Developing a Thinking Skills Program,* Allyn Bacon, Boston, MA (1988)
28. Godden, D.R., and A.D. Baddeley, "Context-Dependent Memory in Two Natural Environments: On Land and Under Water," *Brit. J. of Psychology,* **66**, 325 (1975)
29. Zhu, X., Y. Lee, H.A. Simon, and D. Zhu, "Cue Recognition and Cue Elaboration in Learning from Examples," *Proc. Natl. Acad. Sci. USA,* **93**, 1346 (1996)
30. Zhu, X., and H.A. Simon, "Learning Mathematics from Example and by Doing," *Cognition and Instruction,* **4**(3), 137 (1987)
31. Eylon, B.-S., and F. Reif, "Effects of Knowledge Organization on Task Performance," *Cognition and Instruction,* **1**, 5 (1984)
32. Novak, J.D., and D.B. Gowin, *Learning How to Learn,* Cambridge University Press, Cambridge, UK (1984)
33. Woods, D.R., "PS Corner," Larkin's Checklist, *J. College Sci. Teach.,* **13**, 467 (1984)
34. Woods, D.R., and R.J. Sawchuk, "Fundamentals of Chemical Engineering," *Chem. Eng. Ed.,* **27**(2), 80 (1993)
35. Felder, R.M., "Knowledge Structure of the Stoichiometry Course," *Chem. Eng. Ed.,* **27**(2), 92 (1993)
36. Bird, R.B., "The Basic Concepts in Transport Phenomena," *Chem. Eng. Ed.,* **27**(2), 102 (1993)
37. Fogler, H.S., "An Appetizing Structure of Chemical Reaction Engineering for Undergraduates," *Chem. Eng. Ed.,* **27**(2), 110 (1993)
38. O'Connell, J.P., "Thermodynamics," *Chem. Eng. Ed.,* **27**(2), 96 (1993)
39. Bagno, E., and B.-S. Eylon, "From Problem Solving to a Knowledge Structure: An Example from the Domain of Electromagnetism," *Am. Assoc. of Physics Teachers,* **65,** 726 (1997) ❐