LEARNING AND TEACHING STYLES IN ENGINEERING EDUCATION

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Author's Preface — June 2002
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When Linda Silverman and I wrote this paper in 1987, our goal was to offer some insights about teaching and learning based on Dr. Silverman's expertise in educational psychology and my experience in engineering education that would be helpful to some of my fellow engineering professors. When the paper was published early in 1988, the response was astonishing. Almost immediately, reprint requests flooded in from all over the world. The paper started to be cited in the engineering education literature, then in the general science education literature; it was the first article cited in the premier issue of ERIC's National Teaching and Learning Forum; and it was the most frequently cited paper in articles published in the *Journal of Engineering Education* over a 10-year period. A self-scoring web-based instrument called the *Index of Learning Styles* that assesses preferences on four scales of the learning style model developed in the paper currently gets about 100,000 hits a year and has been translated into half a dozen languages that I know about and probably more that I don't, even though it has not yet been validated. The 1988 paper is still cited more than any other paper I have written, including more recent papers on learning styles.

A problem is that in recent years I have found reasons to make two significant changes in the model: dropping the inductive/deductive dimension, and changing the visual/auditory category to visual/verbal. (I will shortly explain both modifications.) When I set up my web site, I deliberately left the 1988 paper out of it, preferring that readers consult more recent articles on the subject that better reflected my current thinking. Since the paper seems to have acquired a life of its own, however, I decided to add it to the web site with this preface included to explain the changes. The paper is reproduced following the preface, unmodified from the original version except for changes in layout I made for reasons that would be known to anyone who has ever tried to scan a 3-column article with inserts and convert it into a Microsoft Word document.

Deletion of the inductive/deductive dimension

I have come to believe that while induction and deduction are indeed different learning preferences and different teaching approaches, the "best" method of teaching—at least below the graduate school level—is induction, whether it be called problem-based learning, discovery learning, inquiry learning, or some variation on those themes. On the other hand, the traditional college teaching method is deduction, starting with "fundamentals" and proceeding to applications.

The problem with inductive presentation is that it isn't concise and prescriptive—you have to take a thorny problem or a collection of observations or data and try to make sense of it. Many or most students would say that they prefer deductive presentation—"Just tell me exactly what I need to know for the test, not one word more or less." (My speculation in the paper that more students would prefer induction was refuted by additional sampling.) I don't want instructors to be able to determine somehow that their students prefer deductive presentation and use that result to justify continuing to use the traditional but less effective lecture paradigm in their courses and curricula. I have therefore omitted this dimension from the model.

Change of the visual/auditory dimension to the visual/verbal dimension

"Visual" information clearly includes pictures, diagrams, charts, plots, animations, etc., and "auditory" information clearly includes spoken words and other sounds. The one medium of information transmission that is not clear is written prose. It is perceived visually and so obviously cannot be categorized as auditory, but it is also a mistake to lump it into the visual category as though it were equivalent to a picture in transmitting information. Cognitive scientists have established that our brains generally convert written words into their spoken equivalents and process them in the same way that they process spoken words. Written words are therefore not equivalent to real visual information: to a visual learner, a picture is truly worth a thousand words, whether they are spoken or written. Making the learning style pair *visual* and *verbal* solves this problem by permitting spoken and written words to be included in the same category (verbal). For more details about the cognition studies that led to this conclusion, see

R.M. Felder and E.R. Henriques, "Learning and Teaching Styles in Foreign and Second Language Education," *Foreign Language Annals, 28* (1), 21–31 (1995). <*http://www.ncsu.edu/felder-public/Papers/FLAnnals.pdf*>.

The Index of Learning Styles

The *Index of Learning Styles* (ILS) is a self-scoring web-based instrument that assesses preferences on the Sensing/Intuiting, Visual/Verbal, Active/Reflective, and Sequential/Global dimensions. It is available free to individuals and instructors who wish to use it for teaching and research on their own classes, and it is licensed to companies and individuals who plan to use it for broader research studies or services to customers or clients. To access the ILS and information about it, go to <*http://www.ncsu.edu/felder-public/ILSpage.html*>.

And now, the paper.

"Professors confronted by low test grades, unresponsive or hostile classes, poor attendance and dropouts, know that something is wrong." The authors explain what has happened and how to make it right.

Learning and Teaching Styles
In Engineering Education

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Students learn in many ways— by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorizing and visualizing and drawing analogies and building mathematical models; steadily and in fits and starts. Teaching methods also vary. Some instructors lecture, others demonstrate or discuss; some focus on principles and others on applications; some emphasize memory and others understanding. How much a given student learns in a class is governed in part by that student's native ability and prior preparation but also by the compatibility of his or her learning style and the instructor's teaching style.

Mismatches exist between common learning styles of engineering students and traditional teaching styles of engineering professors. In consequence, students become bored and inattentive in class, do poorly on tests, get discouraged about the courses, the curriculum, and themselves, and in some cases change to other curricula or drop out of school. Professors, confronted by low test grades, unresponsive or hostile classes, poor attendance and dropouts, know something is not working; they may become overly critical of their students (making things even worse) or begin to wonder if they are in the right profession. Most seriously, society loses potentially excellent engineers.

In discussing this situation, we will explore:

1) Which aspects of learning style are particularly significant in engineering education?

2) Which learning styles are preferred by most students and which are favored by the teaching styles of most professors?

3) What can be done to reach students whose learning styles are not addressed by standard methods of engineering education?

Dimensions of Learning Style

Learning in a structured educational setting may be thought of as a two-step process involving the reception and processing of information. In the reception step, external information (observable through the senses) and internal information (arising introspectively) become available to students, who select the material they will process and ignore the rest. The processing step may involve simple memorization or inductive or deductive reasoning, reflection or action, and introspection or interaction with others. The outcome is that the material is either "learned" in one sense or another or not learned.

A *learning-style model* classifies students according to where they fit on a number of scales pertaining to the ways they receive and process information. A model intended to be particularly applicable to engineering education is proposed below. Also proposed is a parallel *teaching-style model,* which classifies instructional methods according to how well they address the proposed learning style components. The learning and teaching style dimensions that define the models are shown in the box.

Most of the learning and teaching style components parallel one another.***** A student who favors intuitive over sensory perception, for example, would respond well to an instructor who emphasizes concepts (abstract content) rather than facts (concrete content); a student who favors visual perception would be most comfortable with an instructor who uses charts, pictures, and films.

***** The one exception is the active/reflective learning style dimension and the active/passive teaching style dimension, which do not exactly correspond. The difference will later be explained.

The proposed learning style dimensions are neither original nor comprehensive. For example, the first dimension—sensing/intuition— is one of four dimensions of a well-known model based on Jung's theory of psychological types,[1,2] and the fourth dimension—active/reflective processing—is a component of a learning style model developed by Kolb.[3] Other dimensions of these two models and dimensions of other models[4,5] also play important roles in determining how a student receives and processes information. The hypothesis, however, is that engineering instructors who adapt their teaching style to include both poles of each of the given dimensions should come close to providing an optimal learning environment for most (if not all) students in a class.

There are 32 (2^5) learning styles in the proposed conceptual framework, (one, for example, is the sensory/auditory/deductive/active/sequential style). Most instructors would be intimidated by the prospect of trying to accommodate 32 diverse styles in a given class; fortunately, the task is not as formidable as it might at first appear. The usual methods of engineering education adequately address five categories (intuitive, auditory, deductive, reflective, and sequential), and effective teaching techniques substantially overlap the remaining categories. The addition of a relatively small number of teaching techniques to an instructor's repertoire should therefore suffice to accommodate the learning styles of every student in the class. Defining these techniques is the principal objective of the remainder of this paper.

Models of Learning & Teaching Styles

A student's learning style may be defined in large part by the answers to five questions:

1) What type of information does the student preferentially perceive: *sensory* (external)—sights, sounds, physical sensations, or *intuitive* (internal)—possibilities, insights, hunches?

2) Through which sensory channel is external information most effectively perceived: visual—pictures, diagrams, graphs, demonstrations, or *auditory—words,* sounds? (Other sensory channels—touch, taste, and smell—are relatively unimportant in most educational environments and will not be considered here.)

3) With which organization of information is the student most comfortable: *inductive—facts* and observations are given, underlying principles are inferred, or *deduc*tive—principles are given, consequences and applications are deduced?

4) How does the student prefer to process information: *actively*— through engagement in physical activity or discussion, or *reflectively*— through introspection?

5) How does the student progress toward understanding: *sequentially—in* continual steps, or *glob*ally—in large jumps, holistically?

Teaching style may also be defined in terms of the answers to five questions:

1) What type of information is emphasized by the instructor: concrete—factual, or *abstract—concep*tual, theoretical?

2) What mode of presentation is stressed: visual—pictures, diagrams, films, demonstrations, or *verbal*— lectures, readings, discussions?

3) How is the presentation organized: inductively—phenomena leading to principles, or *deductively*— principles leading to phenomena?

4) What mode of student participation is facilitated by the presentation: active—students talk, move, reflect, or passive—students watch and listen?

5) What type of perspective is provided on the information presented: sequential—step-by-step progression (the trees), or global—context and relevance (the forest)?

Dimensions of Learning and Teaching Styles

Preferred Learning Style		*Corresponding Teaching Style*	
sensory intuitive	perception	concrete abstract	content
visual auditory	input	visual verbal	presentation
inductive deductive	organization	inductive deductive	organization
active reflective	processing	active passive	student participation
sequential global	understanding	sequential global	perspective

Sensing and Intuitive Learners

In his theory of psychological types, Carl Jung[6] introduced *sensing* and *intuition* as the two ways in which people tend to perceive the world. Sensing involves observing, gathering data through the senses; intuition involves indirect perception by way of the unconscious—speculation, imagination, hunches. Everyone uses both faculties, but most people tend to favor one over the other.

In the 1940s Isabel Briggs Myers developed the *Myers-Briggs Type Indicator* (MBTI), an instrument that measures, among other things, the degree to which an individual prefers sensing or intuition. In the succeeding decades the MBTI has been given to hundreds of thousands of people and the resulting profiles have been correlated with career preferences and aptitudes, management styles, learning styles, and various behavioral tendencies. The characteristics of intuitive and sensing types[7] and the different ways in which sensors and intuitors approach learning[1,2] have been studied.

Sensors like facts, data, and experimentation; intuitors prefer principles and theories. Sensors like solving problems by standard methods and dislike "surprises"; intuitors like innovation and dislike repetition. Sensors are patient with detail but do not like complications; intuitors are bored by detail and welcome complications. Sensors are good at memorizing facts; intuitors are good at grasping new concepts. Sensors are careful but may be slow; intuitors are quick but may be careless. These characteristics are tendencies of the two types, not invariable behavior patterns: any individual—even a strong sensor or intuitor—may manifest signs of either type on any given occasion.

An important distinction is that intuitors are more comfortable with symbols than are sensors. Since words are symbols, translating them into what they represent comes naturally to intuitors and is a struggle for sensors. Sensors' slowness in translating words puts them at a disadvantage in timed tests: since they may have to read questions several times before beginning to answer them, they frequently run out of time. Intuitors may also do poorly on timed tests but for a different reason—their impatience with details may induce them to start answering questions before they have read them thoroughly and to make careless mistakes.

Most engineering courses other than laboratories emphasize concepts rather than facts and use primarily lectures and readings (words, symbols) to transmit information, and so favor intuitive learners. Several studies show that most professors are themselves intuitors. On the other hand, the majority of engineering students are sensors,[8-10] suggesting a serious learning/teaching style mismatch in most engineering courses. The existence of the mismatch is substantiated by Godleski,[11,12] who found that in both chemical and electrical engineering courses intuitive students almost invariably got higher grades than sensing students. The one exception was a senior course in chemical process design and cost estimation, which the author characterizes as a "solid sensing course" (i.e. one that involves facts and repetitive calculations by well-defined procedures as opposed to many new ideas and abstract concepts).

While sensors may not perform as well as intuitors in school, both types are capable of becoming fine engineers and are essential to engineering practice. Many engineering tasks require the awareness of surroundings, attentiveness to details, experimental thoroughness, and practicality that are the hallmarks of sensors; many other tasks require the creativity, theoretical ability, and talent at inspired guesswork that characterize intuitors.

To be effective, engineering education should reach both types, rather than directing itself primarily to intuitors. The material presented should be a blend of concrete information (facts, data, observable phenomena) and abstract concepts (principles, theories, mathematical models). The two teaching styles that correspond to the sensing and intuitive learning styles are therefore called *concrete* and *abstract.**

Specific teaching methods that effectively address the educational needs of sensors and intuitors are listed in the summary.

* Concrete experience and abstract conceptualization are two poles of a learning style dimension in Kolb's experiential learning model[7] that are closely related to sensing and intuition.

Visual and Auditory Learners

The ways people receive information may be divided into three categories, sometimes referred to as modalities: *visual*—sights, pictures, diagrams, symbols; *auditory*— sounds, words; *kinesthetic*—taste, touch, and smell. An extensive body of research has established that most people learn most effectively with one of the three modalities and tend to miss or ignore information presented in either of the other two.[13-17] There are thus visual, auditory, and kinesthetic learners.*

Visual learners remember best what they see: pictures, diagrams, flow charts, time lines, films, demonstrations. If something is simply said to them they will probably forget it. Auditory learners remember much of what they hear and more of what they hear and then say. They get a lot out of discussion, prefer verbal explanation to visual demonstration, and learn effectively by explaining things to others.

Most people of college age and older are visual[13,18] while most college teaching is verbal—the information presented is predominantly auditory (lecturing) or a visual representation of auditory information (words and mathematical symbols written in texts and handouts, on transparencies, or on a chalkboard). A second learning/teaching style mismatch thus exists,

* Visual and auditory learning both have to do with the component of the learning process in which information is perceived, while kinesthetic learning involves both information perception (touching, tasting, smelling) and information processing (moving, relating, doing something active while learning). As noted previously, the perception-related aspects of kinesthetic learning are at best marginally relevant to engineering education; accordingly, only visual and auditory modalities are addressed in this section. The processing components of the kinesthetic modality are included in the active/reflective learning style category.

"Inductive learners need to see phenomena before they can understand underlying theory."

this one between the preferred input modality of most students and the preferred presentation mode of most professors. Irrespective of the extent of the mismatch, presentations that use both visual and auditory modalities reinforce learning for all students.[4,14,19,20] The point is made by a study carried out by the Socony-Vacuum Oil Company that concludes that students retain 10 percent of what they read, 26 percent of what they hear, 30 percent of what they see, 50 percent of what they see and hear, 70 percent of what they say, and 90 percent of what they say as they do something.[21]

How to teach both visual and auditory learners: Few engineering instructors would have to modify what they usually do in order to present information auditorily: lectures accomplish this task. What must generally be added to accommodate all students is visual material—pictures, diagrams, sketches. Process flow charts, network diagrams, and logic or information flow charts should be used to illustrate complex processes or algorithms; mathematical functions should be illustrated by graphs; and films or live demonstrations of working processes should be presented whenever possible.

Inductive and Deductive Learners

Induction is a reasoning progression that proceeds from particulars (observations, measurements, data) to generalities (governing rules, laws, theories). *Deduction* proceeds in the opposite direction. In induction one infers principles; in deduction one deduces consequences.

Induction is the natural human learning style. Babies do not come into life with a set of general principles but rather observe the world around them and draw inferences: "If I throw my bottle and scream loudly, someone eventually shows up." Most of what we learn on our own (as opposed to in class) originates in a real situation or problem that needs to be addressed and solved, not in a general principle; deduction may be part of the solution process but it is never the entire process.

On the other hand, *deduction is the natural human teaching style*, at least for technical subjects at the college level. Stating the governing principles and working down to the applications is an efficient and elegant way to organize and present material *that is already understood.* Consequently, most engineering curricula are laid out along deductive lines, beginning with "fundamentals" for sophomores and arriving at design and operations by the senior year. A similar progression is normally used to present material within individual courses: principles first, applications later (if ever).

Our informal surveys suggest that most engineering students view themselves as inductive learners. We also asked a group of engineering professors to identify their own learning and teaching styles: half of the 46 professors identified themselves as inductive and half as deductive learners, but all agreed that their teaching was almost purely deductive. To the extent that these results can be generalized, in the organization of information along inductive/deductive lines—as in the other dimensions discussed so far—a mismatch thus exists between the learning styles of most engineering students and the teaching style to which they are almost invariably exposed.

One problem with deductive presentation is that it gives a seriously misleading impression. When students see a perfectly ordered and concise exposition of a relatively complex derivation they tend to think that the author/instructor originally came up with the material in the same neat fashion, which they (the students) could never have done. They may then conclude that the course and perhaps the curriculum and the profession are beyond their abilities. They are correct in thinking that they could not have come up with that result in that manner; what they do not know is that neither could the professor nor the author the first time around. Unfortunately, students never get to see the real process—the false starts and blind alleys, the extensive trial-and-error efforts that eventually lead to the elegant presentation in the book or on the board. An element of inductive teaching is necessary for the instructor to be able to diminish the students' awe and increase their realistic perceptions of problem-solving.

Much research supports the notion that the inductive teaching approach promotes effective learning. The benefits claimed for this approach include increased academic achievement and enhanced abstract reasoning skills;[22] longer retention of information;[23,24] improved ability to apply principles;[25] confidence in problem-solving abilities;[26] and increased capability for inventive thought.[27,28]

Inductive learners need motivation for learning. They do not feel comfortable with the "Trust me—this stuff will be useful to you some day" approach: like sensors, they need to see the phenomena before they can understand and appreciate the underlying theory.

How to teach both deductive and inductive learners: An effective way to reach both groups is to follow the scientific method in classroom presentations: first induction, then deduction. The instructor precedes presentations of theoretical material with a statement of observable phenomena that the theory will explain or of a physical problem the theory will be used to solve; infers the governing rules or principles that explain the observed phenomena; and deduces other implications and consequences of the inferred principles. Perhaps most important, some homework problems should be assigned that present phenomena and ask for the underlying rules. Such problems play to the inductive learners strength and they also help deductive learners develop facility with their less-preferred learning mode. Several such exercises have been suggested for different branches of engineering.[29]

Active learners do not learn much in situations that require them to be passive, and reflective learners do not learn much in situations that provide no opportunity to think about the information being presented.

Active and Reflective Learners

The complex mental processes by which perceived information is converted into knowledge can be conveniently grouped into two categories: *active experimentation* and *reflective observation.*[3] Active experimentation involves doing something in the external world with the information—discussing it or explaining it or testing it in some way—and reflective observation involves examining and manipulating the information introspectively. * An "active learner" is someone who feels more comfortable with, or is better at, active experimentation than reflective observation, and conversely for a reflective learner. There are indications that engineers are more likely to be active than reflective learners.[20]

Active learners do not learn much in situations that require them to be passive (such as most lectures), and reflective learners do not learn much in situations that provide no opportunity to think about the information being presented (such as most lectures). Active learners work well in groups; reflective learners work better by themselves or with at most one other person. Active learners tend to be experimentalists; reflective learners tend to be theoreticians.

At first glance there appears to be a considerable overlap between active learners and sensors, both of whom are involved in the external world of phenomena, and between reflective learners and intuitors, both of whom favor the internal world of abstraction. The categories are independent, however. The sensor preferentially selects information available in the external world but may process it either actively or reflectively, in the latter case by postulating explanations or interpretations, drawing analogies, or formulating models. Similarly, the intuitor selects information generated internally but may process it reflectively or actively, in the latter case by setting up an experiment to test out the idea or trying it out on a colleague.

In the list of teaching-style categories (table 1) the opposite of active is passive, not reflective, with both terms referring to the nature of student participation in class. "Active" signifies that students do something in class beyond simply listening and watching, e.g., discussing, questioning, arguing, brainstorming, or reflecting. Active student participation thus encompasses the learning processes of active experimentation *and* reflective observation. A class in which students are always passive is a class in which neither the active experimenter nor the reflective observer can learn effectively. Unfortu-

* The active learner and the reflective learner are closely related to the extravert and introvert, respectively, of the Jung-Myers-Briggs model.[1] The active learner also has much in common with the kinesthetic learner of the modality and neurolinguistic programming literature.[14,15]

nately, most engineering classes fall into this category.

As is true of all the other learning-style dimensions, both active and reflective learners are needed as engineers. The reflective observers are the theoreticians, the mathematical modelers, the ones who can define the problems and propose possible solutions. The active experimenters are the ones who evaluate the ideas, design and carry out the experiments, and find the solutions that work—the organizers, the decision-makers. How to teach both active and reflective learners: Primarily, the instructor should alternate lectures with occasional pauses for thought (reflective) and brief discussion or problem-solving activities (active), and should present material that emphasizes both practical problem-solving (active) and fundamental understanding (reflective). An exceptionally effective technique for reaching active learners is to have students organize themselves at their seats in groups of three or four and periodically come up with collective answers to questions posed by the instructor. The groups may be given from 30 seconds to five minutes to do so, after which the answers are shared and discussed for as much or as little time as the instructor wishes to spend on the exercise. Besides forcing thought about the course material, such brainstorming exercises can indicate material that students don't understand; provide a more congenial classroom environment than can be achieved with a formal lecture; and involve even the most introverted students, who would never participate in a full class discussion. One such exercise lasting no more than five minutes in the middle of a lecture period can make the entire period a stimulating and rewarding educational experience.[31]

Sequential and Global Learners

Most formal education involves the presentation of material in a logically ordered progression, with the pace of learning dictated by the clock and the calendar. When a body of material has been covered the students are tested on their mastery and then move to the next stage.

Global learners should be given the freedom to devise their own methods of solving problems rather than being forced to adopt the professor's strategy, and they should be exposed periodically to advanced concepts before these concepts would normally be introduced.

Some students are comfortable with this system; they learn *sequentially*, mastering the material more or less as it is presented. Others, however, cannot learn in this manner. They learn in fits and starts: they may be lost for days or weeks, unable to solve even the simplest problems or show the most rudimentary understanding, until suddenly they "get it"—the light bulb flashes, the jigsaw puzzle comes together. They may then understand the material well enough to they apply it to problems that leave most of the sequential learners baffled. These are the *global learners.*[32]

Sequential learners follow linear reasoning processes when solving problems; global learners make intuitive leaps and may be unable to explain how they came up with solutions. Sequential learners can work with material when they understand it partially or superficially, while global learners may have great difficulty doing so. Sequential learners may be strong in convergent thinking and analysis; global learners may be better at divergent thinking and synthesis. Sequential learners learn best when material is presented in a steady progression of complexity and difficulty; global learners sometimes do better by jumping directly to more complex and difficult material. School is often a difficult experience for global learners. Since they do not learn in a steady or predictable manner they tend to feel out-of-step with their fellow students and incapable of meeting the expectations of their teachers. They may feel stupid when they are struggling to master material with which most of their contemporaries seem to have little trouble. Some eventually become discouraged with education and drop out. However, global learners are the last students who should be lost to higher education and society. They are the synthesizers, the multidisciplinary researchers, the systems thinkers, the ones who see the connections no one else sees. They can be truly outstanding engineers—if they survive the educational process.

How to teach global learners: Everything required to meet the needs of sequential learners is already being done from first grade through graduate school: curricula are sequential, course syllabi are sequential, textbooks are sequential, and most teachers teach sequentially. To reach the global learners in a class, the instructor should provide the big picture or goal of a lesson before presenting the steps, doing as much as possible to establish the context and relevance of the subject matter and to relate it to the students' experience. Applications and "what ifs" should be liberally furnished. The students should be given the freedom to devise their own methods of solving problems rather than being forced to adopt the professor's strategy, and they should be exposed periodically to advanced concepts before these concepts would normally be introduced.

A particularly valuable way for instructors to serve the global learners in their classes, as well as the sequential learners, is to assign creativity exercises—problems that involve generating alternative solutions and bringing in material from other courses or disciplines—and to encourage students who show promise in solving them.[31,33] Another way to support global learners is to explain

Teaching Techniques to Address All Learning Styles

- Motivate learning. As much as possible, relate the material being presented to what has come before and what is still to come in the same course, to material in other courses, and particularly to the students' personal experience *(inductive/global).*
- Provide a balance of concrete information (facts, data, real or hypothetical experiments and their results) *(sensing)* and abstract concepts (principles, theories, mathematical models) *(intuitive).*
- Balance material that emphasizes practical problem-solving methods *(sensing/active)* with material that emphasizes fundamental understanding *(intuitive/reflective).*
- Provide explicit illustrations of intuitive patterns (logical inference, pattern recognition, generalization) and sensing patterns (observation of surroundings, empirical experimentation, attention to detail), and encourage all students to exercise both patterns *(sensing/intuitive).* Do not expect either group to be able to exercise the other group's processes immediately.
- Follow the scientific method in presenting theoretical material. Provide concrete examples of the phenomena the theory describes or predicts *(sensing/ inductive);* then develop the theory or formulate the mod*(intuitive/inductive/ sequential);* show how the theory or modcan be validated and deduce its consequences *(deductive/sequential);* and present applications *(sensing/deductive/sequential).*
- Use pictures, schematics, graphs, and simple sketches liberally before, during, and after the presentation of verbal material *(sensing/visual).* Show films *(sensing/visual.)* Provide demonstrations *(sensing/visual),* hands-on, if possible *(active).*
- Use computer-assisted instruction—sensors respond very well to it[34] *(sensing/active).*
- Do not fill every minute of class time lecturing and writing on the board. Provide intervals—however brief—for students to think about what they have been told *(reflective).*
- Provide opportunities for students to do something active besides transcribing notes. Small-group brainstorming activities that take no more than five minutes are extremely effective for this purpose *(active).*
- Assign some drill exercises to provide practice in the basic methods being taught *(sensing/active/sequential)* but do not overdo them *(intuitive/reflective/ global).* Also provide some open-ended problems and exercises that call for analysis and synthesis *(intuitive/reflective/global).*
- Give students the option of cooperating on homework assignments to the greatest possible extent *(active).* Active learners generally learn best when they interact with others; if they are denied the opportunity to do so they are being deprived of their most effective learning tool.
- Applaud creative solutions, even incorrect ones *(intuitive/global).*
- Talk to students about learning styles, both in advising and in classes. Students are reassured to find their academic difficulties may not all be due to personal inadequacies. Explaining to struggling sensors or active or global learners how they learn most efficiently may be an important step in helping them reshape their learning experiences so that they can be successful (all *types).*

their learning process to them. While they are painfully aware of the drawbacks of their learning style, it is usually a revelation to them that they also enjoy advantages—that their creativity and breadth of vision can be exceptionally valuable to future employers and to society. If they can be helped to understand how their learning process works, they may become more comfortable with it, less critical of themselves for having it, and more positive about education in general. If they are given the opportunity to display their unique abilities and their efforts are encouraged in school, the chances of their developing and applying those abilities later in life will be substantially increased.

Conclusion

Learning styles of most engineering students and teaching styles of most engineering professors are incompatible in several dimensions. Many or most engineering students are visual, sensing, inductive, and active, and some of the most creative students are global; most engineering education is auditory, abstract (intuitive), deductive, passive, and sequential. These mismatches lead to poor student performance, professorial frustration, and a loss to society of many potentially excellent engineers.

Although the diverse styles with which students learn are numerous, the inclusion of a relatively small number of techniques in an instructor's repertoire should be sufficient to meet the needs of most or all of the students in any class. The techniques and suggestions given on this page should serve this purpose.

Professors confronted with this list might feel that it is impossible to do all that in a course and still cover the syllabus. Their concern is not entirely unfounded: some of the recommended approaches—particularly those that involve the inductive organization of information and opportunities for student activity during class—may indeed add to the time it takes to present a given body of material.

The idea, however, is not to use all

A class in which students are always passive is a class in which neither the active experimenter nor the reflective observer can learn effectively. Unfortunately, most engineering classes fall into this category.

the techniques in every class but rather to pick several that look feasible and try them; keep the ones that work; drop the others; and try a few more in the next course. In this way a teaching style that is both effective for students and comfortable for the professor will evolve naturally and relatively painlessly, with a potentially dramatic effect on the quality of learning that subsequently occurs.

References

1. Lawrence, *G., People Types and Tiger Stripes: A Practical Guide to Learning Styles,* 2nd edit., Center for Applications of Psychological Type, Gainesville, Fla., 1982.

2. Lawrence, G., "A Synthesis of Learning Style Research Involving the MBTI," *J. Psychological Type 8,* 2-15 (1984).

3. KoIb, D.A., *Experiential Learning: Experience as the Source of Learning and Development,* Prentice-Hall, Englewood Cliffs, N.J., 1984.

4. Dunn, R., T. DeBello, P Brennan, J. Krimsky, and P. Murrain, "Learning Style Researchers Define Differences Differently," *Educational Leadership,* Feb. 1981, pp. 372-375.

5. Guild, P.B. and S. Garger, *Marching to Different Drummers,* ACSD, *1985.*

6. Jung, C.G., *Psychological Types,* Princeton University Press, Princeton, N.J., 1971. (Originally published in 1921.)

7. Myers, lB. and Myers, PB., *Gifts Differing,* Consulting Psychologists Press. Palo Alto, Calif., 1980.

8. McCaulley, M.H., "Psychological Types of Engineering Students—Implications for Teaching," *Engineering Education,* vol. 66, no. 7, Apr. 1976, pp. 729-736.

9. McCaulley, M.H., E.S. Godleski, C.F. Yokomoto, L. Harrisberger, and E.D. Sloan, "Applications of Psychological Type in Engineering Education," *Engineering Education,* vol. 73, no. 5, Feb. 1983, pp. 394-400.

10. Yokomoto, C.E and J.R. Ware, "Improving Problem Solving Performance Using the MBTI," *Proceedings, ASEE Annual Conference,* College Station, Tex., 1982, pp. 163-167.

11. Godleski, E.S., "Learning Style Compatibility of Engineering Students and Faculty," *Proceedings, Annual Frontiers in Education Conference,* ASEE/IEEE, Philadelphia, 1984, p. 362.

12. Godleski, E.S., "Faculty-Student Compatibility," Presented at the 1983 Summer National Meeting of the American Institute of Chemical Engineers, Denver, Aug. 1983.

13. Barbe, WB. and M.N. Milone, "What We Know About Modality Strengths," *Educational Leadership,* Feb. 1981, pp. 378-380.

14. Barbe, WB., R.H. Swassing and M.N. Milone, *Teaching Through Modality Strengths: Concepts and Practices,* Zaner-Bloser, Columbus, Oh., 1979.

15. Bandler, R. and J. Grinder, *Frogs into Princes,* Real People Press, Moab, Ut., 1979.

16. Dunn, R. and K. Dunn, Teaching Students Through Their Individual *Learning Styles: A Practical Approach,* Reston Publishing Division of Prentice-Hall Publishers, Reston, Va., 1978.

17. Waldheim, G.P, "Understanding How Students Understand," *Engineering Education,* vol. 77, no. 5, Feb. 1987, pp. 306-308.

18. Richardson, J., *Working With People,* Associate Management Inst., San Francisco, Calif., 1984.

19. Barbe, W.B. and M.N. Milone, "Modality Strengths: A Reply to Dunn and Carbo," *Educational Leadership,* Mar. 1981, p. 489.

20. Dunn, R. and M. Carbo, "Modalities: An Open Letter to Walter Barbe, Michael Milone, and Raymond Swassing," *Educational Leadership,* Feb. 1981, pp. 381-382.

21. Stice, J.E., "Using KoIb's Learning Cycle to Improve Student Learning," *Engineering Education,* vol. 77, no. 5, Feb. 1987, pp. 291-296.

22. Taba, H., *Teaching Strategies and Cognitive Functioning in Elementary School Children,* U.S.O.E. Cooperative Research Project No. 2404, San Francisco State College, San Francisco, Calif., 1966.

23. McConnell, T.R., "Discovery Versus Authoritative Identification in the Learning of Children," *Studies in Education,* 2(5), 13-60 (1934).

24. Swenson, E.J., *et al.,* "Organization and Generalization as Factors in Learning, Transfer, and Retroactive Inhibition," *Learning Theory in School Situations,* University of Minnesota Press, Minneapolis, Minn., 1949.

25. Lahti, A.M., "The Inductive-Deductive Method and the Physical Science Laboratory," *Journal of Experimental Education,* vol. 24, 1956, pp. 149-163. Cited in MeKeachie, W. J., *Teaching Tips* (7th edit.), Heath, Lexington, Mass., 1978, p. 33.

26. Kagan, J., "Impulsive and Reflective Children: The Significance of Conceptual Tempo," in J. Krumboltz, Ed., *Learning and the Educational Process,* Rand McNally, Chicago, Ill. 1965.

27. Chomsky, N., *Language and Mind,* Harcourt, Brace and World, New York, 1968.

28. Piaget, J., *Science of Education and the Psychology of the Child,* Orion Press, New York, 1970.

29. Felder, R.M. and L.K. Silverman, "Learning Styles and Teaching Styles in Engineering Education," Presented at the 1987 Annual Meeting of the American Institute of Chemical Engineers, New York, Nov. 1987.

30. Kolb, op. cit., ref. 3, p. 86.

31. Felder, R.M., "Creativity in Engineering Education," *Chemical Engineering Education,* 1988, in press.

32. Silverman, L.K., "Global Learners: Our Forgotten Gifted Children," Paper presented at the 7th World Conference on Gifted and Talented Children, Salt Lake City, Ut., Aug. 1987.

33. Felder, R.M., "On Creating Creative Engineers," *Engineering Education,* vol. 77, no. 4, Jan. 1987, pp. 222-227.

34. Hoffman, J.L., K. Waters and M. Berry, "Personality Types and Computer Assisted Instruction in a Self-Paced Technical Training Environment," *Research in Psychological Type 3,* 81-85 (1981).