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REACHING THE SECOND TIER: LEARNING AND TEACHING STYLES IN COLLEGE SCIENCE EDUCATION

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In her recent study of college science instruction, Sheila Tobias [19] defines two *tiers* of entering college students, the first consisting of those who go on to earn science degrees and the second those who have the initial intention and the ability to do so but instead switch to nonscientific fields. The number of students in the second category might in fact be enough to prevent the shortfall of American scientists and engineers that has been widely forecast for the coming decade.

The thrust of Tobias's study is that introductory science courses are responsible for driving off many students in the second tier. The negative features of the courses she cites include their (1) failure to motivate interest in science by establishing its relevance to the students' lives and personal interests; (2) relegation of students to almost complete passivity in the classroom; (3) emphasis on competition for grades rather than cooperative learning; and (4) focus on algorithmic problem-solving as opposed to conceptual understanding.

Recent educational research provides theoretical support for Tobias's assertions, which are based largely on anecdotal accounts. The research shows that students are characterized by significantly different *learning styles*: they preferentially focus on different types of information, tend to operate on perceived information in different ways, and achieve understanding at different rates [2-4,6-8,10-13,17,18]. Students whose learning styles are compatible with the teaching style of a course instructor tend to retain information longer, apply it more effectively, and have more positive post-course attitudes toward the subject than do their counterparts who experience learning/teaching style mismatches. All of the points raised by Tobias about the poor quality of introductory college science instruction can be expressed directly as failures to address certain common learning styles.

Felder and Silverman [10] have synthesized findings from a number of studies to formulate a learning style model with dimensions that should be particularly relevant to science education. In the sections that follow, the model dimensions are briefly summarized and instructional methods are then proposed that should reach students who span the spectrum of learning styles, including students in Tobias's second tier.

DIMENSIONS OF LEARNING STYLE

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

1. What type of information does the student preferentially perceive: *sensory*—sights, sounds, physical sensations, or *intuitive*—memories, ideas, insights?

2. Through which modality is sensory information most effectively perceived: *visual*—

pictures, diagrams, graphs, demonstrations, or *verbal*—sounds, written and spoken words and formulas?

3. With which organization of information is the student most comfortable: *inductive*—facts and observations are given, underlying principles are inferred, or *deductive*—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 a logical progression of small incremental steps, or *globally*—in large jumps, holistically?

The dichotomous learning style dimensions of this model (sensing/intuitive, visual/verbal, inductive/deductive, active/reflective, and sequential/global) are continua and not either/or categories. A student's preference on a given scale (e.g. for inductive or deductive presentation) may be strong, moderate, or almost nonexistent, may change with time, and may vary from one subject or learning environment to another.

Sensing and Intuitive Perception

People are constantly being bombarded with information, both through their senses and from their subconscious minds. The volume of this information is much greater than they can consciously attend to; they therefore select a minute fraction of it to admit to their "working memory" and the rest of it is effectively lost. In making this selection, *sensing learners* (sensors) favor information that comes in through their senses and *intuitive learners* (intuitors) favor information that arises internally through memory, reflection, and imagination. (These categories derive from Carl Jung's theory of psychological types. The strength of an individual's preference for sensation or intuition can be assessed with the *Myers-Briggs Type Indicator* [13,16].)

Sensors tend to be practical; intuitors tend to be imaginative. Sensors like facts and observations; intuitors prefer concepts and interpretations. A student who complains about courses having nothing to do with the real world is almost certainly a sensor. Sensors like to solve problems using well-established procedures, don't mind detail work, and don't like unexpected twists or complications; intuitors like variety in their work, don't mind complexity, and get bored with too much detail and repetition. Sensors are careful but may be slow; intuitors are quick but may be careless [7].

Sensing learners learn best when given facts and procedures, but most science courses (particularly physics and chemistry) focus on abstract concepts, theories, and formulas, putting sensors at a distinct disadvantage. Moreover, sensors are less comfortable than intuitors with symbols; since words and algebraic variables—the stuff of examinations—are symbolic, sensors must translate them into concrete mental images in order to understand them. This process can be a lengthy one, and many sensors who know the material typically run out of time on tests. The net result is that sensors tend to get lower grades than intuitors in lecture courses [11]; in effect, they are selectively weeded out, even though they are as likely as intuitors to succeed in scientific careers [7].

Visual and Verbal Input.

Visual learners get more information from visual images (pictures, diagrams, graphs, schematics, demonstrations) than from verbal material (written and spoken words and mathematical formulas), and vice versa for *verbal learners* [1,2]. If something is simply said and not shown to visual learners (e.g. in a lecture) there is a good chance they will not retain it.

Most people (at least in western cultures) and presumably most students in science classes are visual learners [2] while the information presented in almost every lecture course is overwhelmingly verbal—written words and formulas in texts and on the chalkboard, spoken words in lectures, with only an occasional diagram, chart, or demonstration breaking the pattern. Professors should not be surprised when many of their students cannot reproduce information that was presented to them not long before; it may have been expressed but it was never heard.

Inductive and Deductive Organization.

Inductive learners prefer to learn a body of material by seeing specific cases first (observations, experimental results, numerical examples) and working up to governing principles and theories by inference; *deductive learners* prefer to begin with general principles and to deduce consequences and applications. Since deduction tends to be more concise and orderly than induction, students who prefer a highly structured presentation are likely to prefer a deductive approach while those who prefer less structure are more likely to favor induction.

Research shows that of these two approaches to education, induction promotes deeper learning and longer retention of information and gives students greater confidence in their problem-solving abilities [10,14]. The research notwithstanding, most college science instruction is exclusively deductive—probably because deductive presentations are easier to prepare and control and allow more rapid coverage of material. In the words of a student evaluating his introductory physics course, "The students are given premasticated information simply to mimic and apply to problems. Let them, rather, be exposed to conceptual problems, try to find solutions to them on their own, and then help them to understand the mistakes they make along the way" [19, p. 25]. The approach suggested by this student is inductive teaching.

Active and Reflective Processing.

Active learners tend to learn while doing something active—trying things out, bouncing ideas off others; *reflective learners* do much more of their processing introspectively, thinking things through before trying them out [12]. Active learners work well in groups; reflective learners prefer to work alone or in pairs. Unfortunately, most lecture classes do very little for either group: the active learners never get to do anything and the reflective learners never have time to reflect. Instead, both groups are kept busy trying to keep up with a constant barrage of verbiage, or else they are lulled into inattention by their enforced passivity.

The research is quite clear on the question of active and reflective versus passive learning. In a number of studies comparing instructor-centered classes (lecture/demonstration) with student-centered classes (problem-solving/discussion), lectures were found to be marginally more effective when students were tested on short-term recall of facts but active classroom environments were superior when the criteria involved comprehension, long-term recall, general problem-solving ability, scientific attitude, and subsequent interest in the subject [15]. Substantial benefits are also cited for teaching methods that provide opportunities for reflection, such as giving students time in class to write brief summaries and formulate written questions about the material just covered [15,20].

Sequential and Global Understanding.

Sequential learners absorb information and acquire understanding of material in small connected chunks; *global learners* take in information in seemingly unconnected fragments and achieve understanding in large holistic leaps. Sequential learners can solve problems with incomplete understanding of the material and their solutions are generally orderly and easy to follow, but they may lack a grasp of the big picture—the broad context of a body of knowledge and its interrelationships with other subjects and disciplines. Global learners work in a more all-or-nothing fashion and may appear slow and do poorly on homework and tests until they grasp the total picture, but once they have it they can often see connections to other subjects that escape sequential learners [17].

Before global learners can master the details of a subject they need to understand how the material being presented relates to their prior knowledge and experience, but only exceptional teachers routinely provide such broad perspectives on their subjects. In consequence, many global learners who have the potential to become outstanding creative researchers fall by the wayside because their mental processes do not allow them to keep up with the sequential pace of their science courses [8].

TOWARD A MULTISTYLE APPROACH TO SCIENCE EDUCATION

Students whose learning styles fall in any of the given categories have the potential to be excellent scientists. The observant and methodical sensors, for example, make good experimentalists, and the insightful and imaginative intuitors make good theoreticians. Active learners are adept at administration and team-oriented project work; reflective learners do well at individual research and design. Sequential learners are often good analysts, skilled at solving convergent (single-answer) problems; global learners are often good synthesizers, able to draw material from several disciplines to solve problems that could not have been solved with conventional single-discipline approaches.

Unfortunately—in part because teachers tend to favor their own learning styles, in part because they instinctively teach the way they were taught in most college classes—the teaching style in most lecture courses tilts heavily toward the small percentage of college students who are at once intuitive, verbal, deductive, reflective and sequential. This imbalance puts a sizeable fraction of the student population at a disadvantage. Laboratory courses, being inherently sensory, visual, and active, could in principle compensate for a portion of the imbalance; however, most labs involve primarily mechanical exercises that illustrate only a minor subset of the concepts presented in lecture and seldom provide significant insights or skill development. Sensing, visual, inductive, active, and global learners thus rarely get their educational needs met in science courses.

The mismatches between the prevailing teaching style in most science courses and the learning styles of most of the students have several serious consequences [10]. Students who experience them feel as though they are being addressed in an unfamiliar foreign language: they tend to get lower grades than students whose learning styles are better matched to the instructor's teaching style [11] and are less likely to develop an interest in the course material [6]. If the mismatches are extreme, the students are apt to lose interest in science altogether and be among the more than 200,000 who switch to other fields each year after their first college science courses [19]. Professors confronted by inattentive classes and poor student performance may become hostile toward the students (which aggravates the situation) or discouraged about their professional competence. Most seriously, society loses potentially excellent scientists.

These problems could be minimized and the quality of science education significantly enhanced if instructors modified their teaching styles to accommodate the learning styles of all the students in their classes. Granted, the prospect of trying to address 32 different learning styles simultaneously in a single class might seem forbidding to most instructors; the point, however, is not to determine each student's learning style and then teach to it exclusively but simply to address each side of each learning style dimension at least some of the time. If this balance could be achieved in science courses, the students would all be taught in a manner that sometimes matches their learning styles, thereby promoting effective learning and positive attitudes toward science, and sometimes compels them to exercise and hence strengthen their less developed abilities, ultimately making them better scholars and scientists.

Major transformations in teaching style are not necessary to achieve the desired balance. Of the ten defined learning style categories, five (intuitive, verbal, deductive, reflective, and sequential) are adequately covered by the traditional lecture-based teaching approach, and there is considerable overlap in teaching methods that address the style dimensions short-changed by the traditional method (sensing, visual, inductive, active, and global). The systematic use of a small number of additional teaching methods in a class may therefore be sufficient to meet the needs of all of the students:

- **Motivate presentation of theoretical material with prior presentation of phenomena that the theory will help explain and problems that the theory will be used to solve** (*sensing, inductive, global*). Don't jump directly into free body diagrams and force balances on the first day of the statics course; first describe problems associated with the design of buildings and bridges and artificial limbs, and perhaps give the students some of those problems and see how far they can go with them before they get all the tools for solving them.

- **Balance concrete information**—descriptions of physical phenomena, results from real and simulated experiments, demonstrations, and problem-solving algorithms (*sensing*)—**with conceptual information**—theories, mathematical models, and material that emphasizes fundamental understanding (*intuitive*)—**in all courses.** When covering concepts of vapor-liquid equilibria, go through Raoult's and Henry's law calculations and nonideal solution behavior...but also discuss the meaning of weather reports (the temperature is 27 degrees Celcius, barometric pressure is 29.95 inches, and the relative humidity is 68%), the manufacture of carbonated beverages, and what you would observe if you poured 50 ml liquid benzene and 50 ml liquid toluene into an open flask, heated the flask, and monitored the liquid volume, temperature, and composition. Give the relations between torque, moments, and angular motion—but first get students to exert pressure on a door at different perpendicular distances from the hinges and then have them try to interpret the results.

- **Make extensive use of sketches, plots, schematics, vector diagrams, computer graphics, and physical demonstrations (*visual*) in addition to oral and written explanations and derivations (*verbal*) in lectures and readings.** Show flow charts of the reaction and transport processes that occur in particle accelerators, test tubes, and biological cells before presenting the relevant theories, and sketch or demonstrate the experiments used to validate the theories. "Look at this micrograph of a mammalian cell. Now here's a schematic showing the structures of the different organelles and their interrelations. OK, now let's consider individual organelle functions and how compartmentalization makes cell regulation and specialization possible."

- **To illustrate abstract concepts or problem-solving algorithms, use at least some numerical examples (*sensing*) to supplement the usual algebraic examples (*intuitive*).**

- **Use physical analogies and demonstrations to illustrate the magnitudes of calculated quantities** (*sensing, global*). "100 microns—that's about the thickness of a sheet of paper." "Think of a mole as a very large dozen." "Pick up this 100 ml bottle of water. Now pick up this 100 ml bottle of mercury. Now let's talk about density."

- **Give some experimental observations before presenting the general principles and have the students (preferably working in groups) see how far they can get toward inferring the latter (*inductive*).** Rather than giving the students Ohm's or Kirchoff's law up front and asking them to solve it for one unknown or another, give them experimental voltage/current/resistance data for several circuits and let them try to figure out the laws for themselves. Describe a situation in which a teakettle is placed on a stove burner and have the students estimate heat inputs and times required to boil and then completely vaporize the kettle contents, and then give them the necessary thermodynamic and mathematical tools and let them carry out the analysis rigorously [9].

- **Provide time in class for students to think about the material being presented (*reflective*) and for active student participation (*active*).** Occasionally pause during a lecture to allow time for thinking and formulating questions. Assign "one-minute papers" close to the end of a lecture period, having students write on index cards the most important point made in the lecture and the single most pressing unanswered question [20]. Assign brief group problem-solving exercises in class in which the students working in groups of three or four at their seats spend one or several minutes tackling any of a wide variety of questions and problems. ("Begin the solution to this problem." "Take the next step in the solution." "What's wrong with what I just wrote on the board?" "What assumptions are implicit in this result?" "Suppose you go into the laboratory, take measurements, and find that the formula we have just derived gives incorrect results: how many possible explanations can you come up with?")

- **Encourage or mandate cooperation on homework** (*active*). Students who participate in cooperative (team-based) learning experiences—both in and out of class—are reported to earn better grades, display more enthusiasm for their chosen field, and improve their chances for graduation in that field relative to their counterparts in more traditional competitive class settings [5].

- **Demonstrate the logical flow of individual course topics (** ***sequential*****), but also point out connections between the current material and other relevant material in the same course, in other courses in the same discipline, in other disciplines, and in everyday experience** (*global*). Before discussing cell metabolism chemistry in detail, describe energy release by glucose oxidation...and relate it to energy release by nuclear fission, electron orbit decay, waterfalls, and combustion in fireplaces, power plant boilers, and automobiles. Discuss where the energy comes from and where it goes in each of these processes and how cell metabolism differs from the other examples...and then consider the photosynthetic origins of the energy stored in the C-H bonds and the conditions under which the earth's supply of usable energy might eventually run out.

How can an instructor do all that and still get through the syllabus? One way is to put most of the material usually written on the board in handouts, go through the handouts quickly in class, and use the considerable class time saved for activities like those just suggested. The consequent gain in quantity and quality of the resulting learning will more than compensate for the photocopying costs.

A final suggestion is to talk to students about their learning styles, either in class or in advising. Many of them have been coping with mismatches between their learning style and their instructors' teaching styles since high school or earlier, attributing their difficulties to their own inadequacies. Telling struggling sensors or active or global learners in Sheila Tobias's second tier about their learning strengths, weaknesses, and educational needs may be the best way to get them to see for themselves that (in Tobias's phrase) "They're not dumb, they're different," and so to move some of them into the first tier, where they belong.

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