MEET YOUR STUDENTS

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Felder, Richard, "Meet Your Students: 1. Stan and Nathan."
Chem. Engr. Education, 23(2), 68-69 (Spring 1989).

MEET YOUR STUDENTS

1. STAN AND NATHAN: *The sensor and the intuitor on the Myers-Briggs Type Indicator.*

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Stan and Nathan are juniors in chemical engineering and roommates at a large midwestern university. They are similar in many ways. Both enjoy partying, midnight pizza runs, listening to rock and watching TV. Both did well in science and math in high school, although Nathan's grades were consistently higher. Both found their mass and energy balance course tough (although they agree the text was superb), thermodynamics incomprehensible, English boring, and other humanities courses useless. Both have girl friends who occasionally accuse them of being "too logical."

For all their similarities, however, they are fundamentally different. If single words were chosen to describe each of them, Stan's would be "practical" and Nathan's would be "scholarly" (or "spacy," depending on whom you ask). Stan is a mechanical wizard and is constantly sought after by friends with ailing cars and computers, while changing a light bulb is at the outer limits of Nathan's mechanical ability. Stan notices his surroundings, tends to know where he put things, and remembers people he only met once; Nathan notices very little around him, misplaces things constantly, and may not recognize someone he has known for years. Nathan subscribes to *Scientific American* and reads science fiction and mystery novels voraciously; Stan only reads when he has to. Stan has trouble following lectures; Nathan follows them easily, but when instructors spend a lot of class time going through detailed derivations or homework assignments he already understands he gets bored and his attention wanders.

When Stan takes a test he reads the first problem, reads it again, and if the test is open--book tries to find an identical worked--out problem and copy the solution. If he can't find one, he searches for suitable formulas to plug into. He frequently rereads the problem while working on it and repeats each numerical calculation just to be on the safe side. When he has gone as far as he can go, he repeats the process on the second problem. He usually runs out of time and gets class average or lower on the test. Nathan reads test problems only up to the point where he thinks he knows how to proceed and then plunges in. He works quickly and usually finishes early and gets high grades. However, he sometimes blows tests because he makes careless errors and lacks the patience to check his calculations, or he fails to read a question thoroughly enough and misses important data or answers a different question than was asked.

The one place where Stan outshines Nathan academically is the laboratory. Stan is sure--handed and meticulous and seems to have an instinct for setting up and running experiments, while Nathan rarely gets anything to work right. Nathan almost had a nervous breakdown in analytical chemistry: he would repeat a quantitative analysis five times, get five completely different results, and finally average the two closest estimates and hope for the best. Stan, on the other hand, would do the analysis twice, get almost perfect agreement between the results, and head for a victory soda while Nathan was still weighing out the reagents for his second attempt.

Stan did well in only one non--laboratory engineering course. The instructor used a lot of visual demonstrations---transparencies, pictures and diagrams, and actual equipment; provided clear outlines of problem solution procedures; and gave practical applications of all theories and formulas the students were required to learn. Stan claimed that it was the first course he had taken that seemed to have anything to do with the real world. Nathan thought the course was okay but he could have done with a bit less plug-and-chug on the homework.

Stan is a sensor; Nathan is an intuitor.(1) Sensors favor information that comes in through their senses and intuitors favor internally-generated information (memory, conjecture, interpretation). Sensors are attentive to details and don't like abstract concepts; intuitors can handle abstraction and are bored by details. A student who complains about things having nothing to do with the real world is almost certainly a sensor. Sensors like well-defined problems that can be solved by standard methods; intuitors prefer problems that call for innovation. Individuals of both types may be excellent engineers: the observant and methodical sensors tend to be good experimentalists and plant engineers, and the insightful and innovative intuitors tend to be good theoreticians, designers, and inventors.

The degree to which someone favors sensing or intuition can be determined with the *Myers--Briggs Type Indicator*, a personality inventory that has been administered to hundreds of thousands of people including many engineering students and faculty members. Most undergraduate engineering students have been found to be sensors and most engineering professors are intuitors. A mismatch thus exists between the teaching styles of most professors, who emphasize basic principles, mathematical models and thought problems, and the learning styles of most undergraduates, who favor observable phenomena, hard facts, and problems with well-defined solution methods. Intuitive students would consequently be expected to enjoy a clear advantage in school, and indeed intuitors have been found to get consistently higher grades except in courses that emphasize facts, experimentation, and repetitive calculations.

For many sensing students, the disparity between the way they learn best and the way they are generally taught is too great: they get poor grades no matter how hard they work, become disillusioned, and drop out. Felder and Silverman(1) give several ways instructors can accommodate the learning styles of these students without compromising their own teaching styles or their ability to get through the syllabus. The accommodation is well worth attempting: sensors are sorely needed in industry and may do exceptionally well there if they manage to survive school.

Postscript: 15 years later. Nathan graduated *magna cum laude*, went to graduate school and got a Ph.D., worked for several years in the research and development division of a major chemical company, got several important patents, moved to manufacturing, and ended up as a group leader supervising a team of designers and systems analysts. Stan struggled through the curriculum, graduated in the bottom third of his class, and got a production engineering job in the same company Nathan went to work for. His mechanical talents soon became apparent and he was put in charge of a trouble--shooting team that came to be in great demand throughout the plant. His managerial skills then led to a rapid series of promotions culminating in his becoming the youngest corporate vice president in company history. Among the thousands of employees in the branch he heads is Nathan, with whom he gets together occasionally to talk over old times. Stan thoroughly enjoys these meetings; Nathan also enjoys them but perhaps not as much.

Footnotes

1. See R.M. Felder and L.K. Silverman, "Learning and Teaching Styles in Engineering Education," *Engineering Education 78*(7),674(1988), and G. Lawrence, *People Types and Tiger Stripes*, Center for Applications of Psychological Type, 2nd Edition, Gainesville, 1982. Stan is a representative sensor and Nathan a representative intuitor, but not all sensors are just like Stan and not all intuitors are just like Nathan. Sensation and intuition are preferences, not clear--cut categories, and all human beings exhibit characteristics of both types to different degrees.

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Felder, Richard, "Meet Your Students: 2. Susan and Glenda."
Chem. Engr. Education, 24(1), 7-8 (Winter 1990).

MEET YOUR STUDENTS

2. SUSAN AND GLENDA: *The sequential learner and the global learner on the Felder/Silverman learning styles model.*

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Susan and Glenda are seniors in chemical engineering at a private northeastern university. They are both bright and personable. They like to study with friends and enjoy the lengthy bull sessions that the study sessions sometimes turn into. They both have a hard time saying no to requests for help with classwork, even if they don't have the time for it. Neither one cares for laboratory courses. They have almost identical grade point averages---about 3.2/4.0.

The resemblance ends there, however. Susan was an outstanding student in junior high and high school, and in college she has gotten B's in almost all of her courses, with an occasional A. Her instructors have an easy time grading her homework and test papers: the solutions are neatly laid out, with each step clearly following the preceding one, and she gets a great deal of credit even when her answers are incorrect.

Glenda is another story. Her transcript is a mixture of A's and C's. She usually starts out in a class by doing poorly on the homework and failing the first quiz, and she may spend the rest of the semester trying to catch up. Her problem solutions are jumbles of apparently unrelated numbers and equations with the answer magically appearing at the end; she rarely gets much partial credit, and if anyone asks her to explain what she did she has an extremely difficult time doing so.

Sometimes, however, Glenda seems to undergo a transformation. She begins to solve homework and test problems with ease, occasionally using methods that were not taught in class. She may then go on to get an easy A in the course, or, if the class moves on to completely new material, she may revert to her previous performance level and struggle until either another breakthrough is achieved or the semester ends. Even after she makes a breakthrough, her problem solutions are frequently incomprehensible to anyone else; the difference is that the answer that suddenly appears at the end is correct. She has been hurt on several occasions by instructors who implied that she had cheated, although no one ever had any proof. (In fact, she never cheated.)

Susan is a *sequential learner*, Glenda is a *global learner*.(1) Sequential learners tend to gain understanding in a linear fashion, with each new piece of information building logically from previous pieces. They tend to solve problems the way they learn---in a linear, stepwise fashion---and their solutions make sense to others. They generally have little trouble in school because of their sequential way of learning and solving problems: their courses, books, and teachers are all geared to their style.

Global learners function in a much more all-or-nothing fashion. They absorb information almost randomly, in no apparent logical sequence. In consequence, when they are first learning a subject nothing may make sense to them, and they may be incapable of solving trivially simple problems. But then at some point a key piece of data is taken in, a critical connection is made, the light bulb goes on, and they "get it." They may be fuzzy about details after that, but they see the big picture in a way that most sequential learners never achieve. Thereafter, when presented with new material that they can fit into this picture they may appear to assimilate it instantly, and when solving problems they may leap directly to the solution without seeming to go through the required intermediate steps. They may also see surprising connections between newly-learned material and material from other subjects and disciplines.

Strongly global learners often have difficulty in school. Before they make their mental breakthrough in a given subject, their struggle to solve problems that their sequential counterparts handle with ease makes them feel stupid. Even after they make breakthroughs, their inability to explain their problem-solving processes can get them into trouble, as when Glenda was suspected of cheating. These difficulties---which most of them experience from the first grade on---are truly unfortunate, since global learners collectively constitute one of society's most valuable and underutilized resources. If they are allowed to progress in their seemingly disjointed manner, some of them will go on to become our most creative researchers, our systems analysts---our global thinkers.

Felder and Silverman(1) suggest ways that engineering instructors can accommodate the learning styles of global learners. Most of these suggestions involve providing a broad perspective on the course material, relating it to material in other courses and disciplines and to the students' prior experience. Perhaps the best thing we can do for these individuals, however, is to watch for them, and when we find them (which we will), explain and affirm their learning process to them. They probably already know all about the drawbacks of their style but it usually comes as a revelation to them that they also have advantages---that their creativity and breadth of vision can be exceptionally valuable to future employers and to society. Any encouragement we provide could substantially increase the likelihood that they will succeed in school and go on to apply their unique abilities after they graduate.

Postscript: 10 years later. Susan graduated and went on to get a masters degree in chemical engineering, got a number of good job offers, and went to work in the process design division of a large petrochemical company. She did extremely well, and is now making rapid progress up the technical management ladder. Glenda went through a lengthy job search when she graduated---all those C's on her transcript worried prospective employers---and finally found a position with a small firm of design consultants. Her first project involved designing and installing process simulation software for a pharmaceuticals manufacturer. She did almost nothing on the project for months, despite increasing pressure from her supervisor. Then she came up with a package that not only did the required simulation but also used it to schedule production, manage inventory, and determine production bottlenecks and the best methods of eliminating them. The company estimated that the program led to savings of two million dollars in its first year of use. Glenda now gets the problems too difficult for anyone else in the firm to solve. Sometimes long periods go by without any apparent results, but no one pressures her any more.

Footnotes

1. See R.M. Felder and L.K. Silverman, "Learning and Teaching Styles in Engineering Education," *Engineering Education 78*(7), 674(1988). Susan is a representative sequential learner and Glenda is a representative global learner, but not all sequentials are just like Susan and not all globals are just like Glenda. These labels simply denote tendencies that may be strong or weak in any given individual, and everyone exhibits characteristics of both types to different degrees.

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Felder, Richard, "Meet Your Students: 3. Michelle, Rob, and Art."
Chem. Engr. Education, 24(3), 130-131 (Summer 1990).

MEET YOUR STUDENTS

3. MICHELLE, ROB, AND ART: *Three different approaches to learning (deep, surface, and strategic), and the conditions that induce students to take a deep approach.*

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The scene is the AIChE student chapter lounge at a large southeastern university. Three juniors---Michelle, Rob, and Art---are studying for the second quiz in the introductory transport course. Art got the high grade in the class on the first quiz, Michelle was close behind him, and Rob got 15 points below class average. They've been at it for over an hour.

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Michelle: "What about this stuff on non-Newtonian flow---I don't think I really get it."

Art: "I think we can forget it---I've got copies of Snavely's tests for the last five years and he's never asked about it."

M: "Maybe, but it's the real stuff...you want to analyze blood flow, for instance, Newtonian won't work."

A: "So what...the only blood flow we're going to have to worry about is ours on this test if we don't stick to the stuff Snavely *is* going to ask."

M: "Yeah, but if we don't..."

Rob: "Hey Art, is there going to be any of that Navier-Stokes trash on the quiz?"

A: "Yeah, there usually is, but no derivations---you just have to know how to simplify the equation."

R: "Rats---I hate that garbage."

M: "I've been looking through Bird, Stewart, and Lightfoot...there are all sorts of Navier-Stokes problems in there---we could try to set some of them up."

R: "Nah, too much grind---I just need to do enough to get my C, my degree, and my MG...Art my man, why don't you haul out those old tests and let's just memorize the solutions."

A: "Okay, but that may not...hey, look at this question---he's used it for three years in a row...Parts (a) and (b) are just plug-and-chug, but he throws a real curve ball here in Part (c)---I don't know how to do it."

R: "How much is Part (c) worth?"

M: "Never mind that---let me see it...okay, he's asking about velocity profile development---you just need to use the correlation for entrance length."

A: "What are you talking about---I never heard of that stuff."

M: "He never talked about it in class but it's in the reading---you need to calculate the Reynolds number and then substitute it in this dimensionless correlation, and that gives you..."

R: "I'm gonna grab a Coke from the machine, guys---when you get it all straight just tell me what formula I plug into, okay?"

A: "Yeah, sure. So it's just this correlation, huh Michelle---do I need to dig into where it comes from?"

M: "Probably not for the test, but I was trying to think why you would want to know the entrance length, and it seems to me that if you're designing a piping system that has a lot of short pipe segments it would be important to know how well your pressure drop formulas will work...blood flow again, in capillaries, or maybe lubricating oil in a car engine, or..."

A: "Forget it---that stuff's not going to be on this test...even Snavely wouldn't be that tricky...now look at this problem here..."

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These three students illustrate what Entwistle[1] calls *orientations to studying*. Michelle has a *meaning orientation*, Rob a *reproducing orientation*, and Art an *achieving orientation*. The characteristics of the orientations are as follows:

Meaning orientation. Michelle tends to take a *deep approach* to learning, meaning that she tries not just to learn facts but to understand what they mean, how they are related, and what they have to do with her experience. Meaning-oriented learners are characterized by an *intrinsic motivation* to learn (I want to learn this material because it interests me and I find it relevant to my life) and a tendency to question conclusions offered in lectures and readings.
Reproducing orientation. Rob almost always takes a *surface approach* to learning---following routine solution procedures but not trying to understand where they come from, memorizing facts but not trying to fit them into a coherent body of knowledge. Reproducing learners are characterized by an *extrinsic motivation* to learn (I've got to learn this to pass the course, to graduate, to get a good job) and an unquestioning acceptance of everything in the book and in lectures. They often do poorly in school.
Achieving orientation. Art's primary goal is to get the highest grade in the class, whatever it takes. Achieving learners take a *strategic approach* to learning, which involves finding out what the instructor wants and delivering it---digging deep when they have to, staying superficial when they can get away with it.

Sooner or later most faculty bull sessions lapse into complaints that most of our students are Robs and pitifully few are Michelles. Unfortunately, few of us do anything in class to stimulate our students to take a deep approach: we just give them tricky tests to see if they can "do more than plug in," and then gripe that they're apathetic and incompetent when they can't. Fortunately, there's something we can do besides complain. The following conditions in a class have been shown to increase the likelihood that students will adopt a deep approach to learning [1,2].

- Student-perceived relevance of the subject matter. Students will not struggle to achieve a deep understanding of material that seems pointless to them, any more than we would. To motivate them to do it, let them know up front what the material has to do with their everyday lives (e.g. fluid flow in their cars and circulatory systems, heat and mass transfer and reaction in the atmosphere and their homes and respiratory and digestive systems) and with significant problems they will eventually be called on to solve (e.g. fabricating improved semiconductors, developing alternative energy sources, avoiding future Bhopals).

- Clearly stated instructional objectives, practice, and feedback. Students are not born knowing how to analyze deeply, and little in their precollege experience is likely to have fostered that ability. To get them to pull meaning out of lecture material and solve problems that go beyond those in the text, spell these objectives out and give concrete examples of the kind of reasoning desired. Then explicitly ask the students to carry out deep analysis in class and on homework and give them constructive feedback on their attempts.

- Appropriate tests. *Provided the preceding conditions have been met,* include questions that call for deep analysis on all tests. If the students know they will only get surface questions (closed-ended exercises that require only standard solution procedures) they will likely take a surface approach to learning the material. If they expect some deep questions (more open-ended questions that require greater understanding), all of the Michelles, most of the Arts, and perhaps some of the Robs will see a need to take a deep approach and do so.

- Reasonable workload. If students have to spend all their time and energy just keeping up, they'll fall back on a surface approach.

- Choice over learning tasks. Provide bonus problems and/or optional projects and/or alternatives to quizzes and/or optional self-paced study and/or choices between group and individual efforts.

The research indicates that by establishing these conditions we may substantially increase the number of our students who think critically about the material we are presenting, try to discover its meaning and its relationship with other material they have previously learned, and routinely question the inferences and conclusions that we present in class. Whether or not we'll know what to do with these people once we have them is a question for another occasion.

References

1. N. Entwistle, "Motivational Factors in Students' Approaches to Learning," in R.R. Schmeck, ed., *Learning Strategies and Learning Styles,* New York, Plenum Press (1988), Ch. 2.
2. P. Ramsden, "Context and Strategy: Situational Influences on Learning," in R.R. Schmeck, ed., *op. cit.*, Ch. 7.

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Felder, Richard, "Meet Your Students: 4. Jill and Perry."
Chem. Engr. Education, 25(4), 196-197 (Fall 1991).

MEET YOUR STUDENTS

4. JILL AND PERRY: *The judger and the perceiver on the Myers-Briggs Type Indicator.*

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Jill and Perry are senior engineering students. They met at their freshman orientation seminar, started dating soon afterward, and have been together ever since. A friend once remarked that they had the only perfect relationship he had ever seen: there wasn't a single thing they agreed about!

They had an appointment to meet in the student lounge at 3:00 this afternoon. It is now well past 4:00. Jill is sitting at a table alone, trying to work but frequently looking over at the door and scowling. Perry finally walks in, greets a few friends, walks over to Jill's table, and sits down.

Perry (brightly): "Hi---get it all figured out yet?"

Jill (glaring): "Where were you?"

Perry: "Oh, a few of us in Tau Beta Pi got going on the plans for the Awards Banquet and I lost track of the time...I'm not *that* late, am I?"

Jill: "Not for you, maybe, but for normal people an hour and 20 minutes might qualify for *that* late. Am I wrong or did we agree Sunday that we'd study for the design test from 3 to 4 today?

Perry: "Come on, lighten up. We still have a couple of hours till supper and the exam's not until Friday---you know Professor Furze postponed it yesterday."

Jill: "I know he did but we still had an appointment...and I've got a 331 lab report due Thursday and I planned to work on it between 4 and 6 today and I told you I'd go to a movie with you tonight. If we study for the test now and go to the movie, when am I supposed to do the report?"

Perry: "You and your ridiculous schedules...couldn't you have worked on the report while you were waiting for me?"

Jill: "Look, my ridiculous schedules are the only reason we're seniors now---if it were up to you to plan our lives we'd still be working on our sophomore course assignments and the only time we'd ever study for a test is all night the night before...that is, if you managed to remember we were *having* a test."

Perry: "That's not true...besides, which of us got the highest grades on the first two design exams?"

Jill: "That has nothing to do with anything! Anyway, it's 4:30 and we haven't started yet...let's see...maybe if we study for about 45 minutes now, then I'll work on the report and we can get a pizza delivered, and that way we can leave at 7 to get to the movie...yeah, I think that should..."

Perry: "Why don't we just get started and see where we are at 7 and decide then what to do---we can always skip the movie or go and study some more when we get back if we need to."

Jill: "No, we need to set it up now or else we'll just drift along and never get anything done. OK, let's say we work through these Chapter 5 problems for about 20 minutes and then we...now what?"

Perry: "I'm just going for a Coke---be right back. Want something?"

Jill: "Yeah, I want you for once in your life to sit still for more than 30 consecutive seconds and do what you said you would do---I've just been sitting here for over an hour waiting, and you finally get here and ten minutes later you're taking off again!"

Perry: "Relax---I'll just be a minute." (Disappears.)

Jill: (Censored)

Jill is a judger and Perry is a perceiver.(1) Judgers tend to be organized and decisive: they like to set and keep agendas and reach closure on issues. Perceivers tend to be spontaneous, flexible, and open-minded: they like to keep their options open as long as possible and postpone decision-making until they feel sure they have all the relevant information.

Judgers plan ahead for most things. As students they budget their time for homework and study so they don't have to do it all at the last minute and they can usually be relied on to turn in assignments on time. However, they tend to jump to conclusions, make decisions prematurely, and doggedly adhere to agendas that may no longer be appropriate. In their classes, judging students want clearly defined expectations, assignments, and grading criteria, and they don't like rambling lectures or class discussions that seem to have little point.

Perceivers do as little planning as possible, preferring to remain flexible in case something better comes up. They tend to work in fits and starts, alternating between periods of unfocused activity and frantic races to meet deadlines. They have trouble sticking to agendas, tend to start many more projects at one time than they can possibly finish, and are often in danger of missing assignments and doing poorly on tests due to insufficient study time. However, they are more likely than judgers to be aware of facts or data that don't fit their mental picture of a situation and in fact may go out of their way to look for such contradictions. When they don't fully understand something they tend to keep it open, gathering more information or simply waiting for inspiration to strike rather than accepting the first plausible explanation that occurs. Their flexibility and tolerance of ambiguity will make some of them superb researchers.

While students of both types may become excellent engineers and managers, the working habits of strong perceivers may make getting through school a major challenge for them and anything that can be done to help them survive is worth attempting. They benefit from opportunities to follow their curiosity and work best on tasks that they have chosen themselves. They are not helped much by advice to work at a steady pace and not leave things for the last moment, which may be too radical a departure from their natural style to be manageable; however, it might help to ask them to figure out how late they can start to work on the assignment or study for the test and still do everything else they have to do. Perceivers rarely look at the holes they are digging themselves into through lack of planning. If they can be persuaded to itemize the things they *intend* to do, they might be convinced that without some planning they don't have a prayer of doing the things they *have* to do.

Epilogue: Ten years later.

Jill and Perry got married shortly after graduation, managing (barely) to survive Perry's 20-minute late arrival at the church and Jill's insistence on laying out an hour-by-hour schedule for their honeymoon. Jill got a job in a design and construction firm, eventually became a highly successful project manager, and is now in line for a vice presidency. Perry went on to graduate school, got a Ph.D., and is now an eminent researcher at a national laboratory. It took years, but they finally figured out a good way to get along with each other.(2)

References

1. G. Lawrence, *People Types and Tiger Stripes*, 2nd Edn., Center for Applications of Psychological Type, Gainesville, FL, 1982.
2. M.H. McCaulley, E.S. Godleski, C.F. Yokomoto, L. Harrisberger, and E.D. Sloan, "Applications of Psychological Type in Engineering Education," *Engineering Education, 73*(5), 394-400 (1983).

Footnotes

1. The degree to which one favors one or the other of these types can be determined with the *Myers-Briggs Type Indicator*, a personality inventory based on Jung's theory of psychological types that has been administered to over one million people, including many engineering students and professors.[1,2] Jill and Perry are illustrative of the two types but not all judgers are just like Jill and not all perceivers are just like Perry. The two categories represent preferences, not mutually exclusive categories: the preferences may be strong or weak, and all people exhibit characteristics of both types to different degrees.

2. Unfortunately, I haven't been able to figure out what it might be.

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Felder, Richard, "Meet Your Students: 5. Edward and Irving."
Chem. Engr. Education, 28(1), 36-37 (Winter 1994).

MEET YOUR STUDENTS

5. EDWARD AND IRVING: *The extravert and the introvert on the Myers-Briggs Type Indicator.*

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The scene is a dormitory room, shared by two senior engineering students. Irving is hunched over his computer, looking at an open manual next to the keyboard, as Edward breezes in.

Ed: "Yo, Irv---shut it down and move it out...it's party time."

Irv: (Silence)

E: "Come on, ace---the brew is losing its head...up and away!"

I: "Chill out, Eddie---I'm trying to figure out how to install this upgrade on my operating system. Why don't you go on ahead and I'll get there later."

E: "Right---just like last week, when you were going to get there in 15 minutes and you never showed at all."

I: "I told you I got involved with the control homework and lost track of time...anyway, you know I don't enjoy these parties---you guys are lunatics."

E: "We can't be lunatics, we're engineers---we're all nerds, we solve differential equations for kicks, most of us wear glasses...besides, I knew the campus security guard wouldn't really call the police last Friday---he just likes to blow smoke. Here, I'll bet I can figure that out...a few line commands here, a couple of mouse clicks there, and we're off for the bright lights and the beautiful...

I: "Eddie, get your grubby hands off that machine and let me read the manual and do it right. Remember how you were going to help me program my VCR to record Star Trek last week, and you didn't need the instructions, and we ended up with a two-hour PBS special on pancreas transplants?"

E: "That was only because I..."

I: "And how about that physics lab where you shorted out the whole building? 'Let's just do it---lab manuals are for weenies,' he says, just before the explosion."

E: "Yeah, but don't forget whose crazy idea got a patent application on his summer job...your problem is you spend so much time studying about what you're planning to do and worrying about why it might not work that you never get around to doing it...but it's ok, read all night if you can stand it, I'm out of here...oh, and don't forget, I asked Jake and Marty and Amy and a couple of the others to get together here tomorrow to study with us for the design test."

I: "Dammit, Eddie, why do you keep doing this to me? You know I study better alone---besides, you have an attention span of about 20 seconds, and if those jokers are over here you can forget studying or anything else but..."

E: "No way---I'm really serious this time. I just like to have people around---keeps things from getting too dull."

I: "Too dull? You..."

E: "Later, my man. I'll save some foam for you..."

I: (Low growling noise)

Ed and Irv have been best friends since elementary school, and no one was surprised when they enrolled in the same engineering school and became roommates. What was surprising was that they became friends in the first place, since their personalities are polar opposites. Ed loves big parties, and even if he doesn't know a soul when he walks in, everyone knows his life story by the time he leaves. Irv, on the other hand, doesn't like parties at all except for small quiet gatherings of people he knows well. Privacy is a sacred concept to Irv and a relatively alien one to Ed. They react much differently when faced with unfamiliar tasks or situations. "Let's try this out and see what happens," says Ed, as he dives in. "Hold on---let's think it through," responds Irv, as he dips his toe in the water.

The two of them have dramatically different approaches to schoolwork. Irv puts on some soft music, arranges his books on his desk, and immerses himself. Even when Ed is there, puttering around the room, fixing himself a snack, watching TV, or even talking directly to Irv, Irv goes right on working, occasionally mumbling responses to questions he really didn't hear. Ed sometimes tries to work like that but can't do it; he's constantly up and down, making comments about what he's reading or asking Irv questions about it, and if he hears a conversation down the hall or suspects that one might be about to start he's off like a shot to make sure he doesn't miss anything. He likes to see how others approach problems and to try out his solution ideas on them, and he drives Irv crazy by assembling crowds to study or work on homework assignments when Irv wants to work in solitude.

Edward is an *extravert* and Irving is an *introvert*.(1) Although the popular ideas of these terms (the extravert is the one at the party wearing the lampshade and the introvert is the one hiding under the couch) are exaggerations, they have some basis in reality. Extraverts tend to be gregarious and active, introverts tend to be reserved and contemplative. Extraverts are energized by being with people---the more the better---while introverts find it draining to spend much time with people they don't know well, and they may need to go off somewhere by themselves afterwards to recharge their batteries. Extraverts need to experience things to understand them; introverts want to understand them first. Science and engineering require the strengths of both types---the thoughtfulness, capacity for sustained concentration, and desire for understanding of the introvert and the quick thinking, verbal fluency, and willingness to take risks of the extravert. Introverts may spend so much time thinking about potential difficulties with new ideas that they never quite get around to trying the ideas out, while extraverts are comfortable with trial-and-error learning and will not wait too long to take action. However, lacking the introverts' characteristic cautiousness, extraverts may get into trouble by jumping into things before thinking them through, and being less able to focus on one task for a long time, they are more likely to accept superficial problem solutions. Extraverts are well suited to jobs like technical sales and management that require strong interpersonal and communication skills and jobs like consulting and emergency troubleshooting that require quick thinking and responding, while introverts work better in areas like research and design that allow them to take information in, process it introspectively, and *then* respond.

Unfortunately, while both extraverts and introverts can become excellent scientists and engineers, the usual way these subjects are taught---straight lectures, homework done individually, minimal hands-on experience---stacks the deck in favor of the introverts. Extraverts tend to have shorter attention spans and find it hard to maintain their focus in long lectures when they have nothing to do but sit and take notes. They also do much of their best learning in company with others---discussing, arguing, working out their ideas by bouncing them off others; if they are forced to work individually all the time, they lose their most effective learning tool.

Several instructional techniques make classes more effective and enjoyable for both extraverts and introverts. Give students several minutes of small-group exercises during each class period---answering or generating questions, solving problems, or brainstorming. These exercises give extraverts occasions for activity and introverts opportunities to reflect on the course material. Bring experimental demonstrations---preferably hands-on---into lectures (for the extraverts) and give minilectures on interpretation of experimental results in laboratory courses (for the introverts). Use interactive computer tutorials and simulations: extraverts will enjoy the active learning they provide and introverts will get practice in trial-and-error analysis in a relatively risk-free environment. Assign some homework to teams of three or four rather than to individuals. Some introverts may complain about having to work in groups, but the extraverts will appreciate getting to function in their preferred learning mode for a change, and both types will learn the course material better while improving their interpersonal, leadership, and communication skills.(3)

Epilogue: Ten Years Later. Following graduation, Ed went to work as a product development engineer in the polymer division of a large chemical corporation and received several patents for new membrane formulations. After two years he decided that he enjoyed working with customers more than synthesis reactors and extruders, moved into marketing, and is currently associate marketing director in charge of international sales. Irv went to work for an environmental consulting firm, spent two years designing stack gas scrubbers, went back to graduate school for a Ph.D., and is now an associate professor at a large university not far from where Ed lives. They get together at least once a year. Ed always proposes making the rounds of his favorite bars with some drinking buddies he knows Irv will like a lot. Irv always looks pained, makes some reference to lunatics, and counters with a proposal to take in a chamber music concert or a poetry reading. Ed rolls his eyes in mock disgust, says something about "engineering nerds," and they compromise on dinner with their wives at a good restaurant and drinks afterwards at a quiet jazz lounge. They both thoroughly enjoy this routine and wouldn't think for a moment of changing it.

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3. D.W. Johnson, R.T. Johnson and K.A. Smith, *Cooperative Learning: Increasing College Faculty Instructional Productivity,* ASHE-ERIC Higher Education Report No. 4, George Washington University, 1991.

Footnotes

1. The degree to which one favors one or the other of these types can be determined with the *Myers-Briggs Type Indicator*, a personality inventory based on Jung's theory of psychological types that has been administered to over one million people, including many engineering students and professors.[1,2] Ed and Irv are illustrative of the two types but not all extraverts are just like Ed and not all introverts are just like Irv. The two categories represent preferences, not mutually exclusive categories: the preferences may be strong or weak, and all people exhibit characteristics of both types to different degrees.

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Felder, Richard, "Meet Your Students: 6. Tony and Frank."
Chem. Engr. Education, 29(4), 244-245 (Fall 1995).

MEET YOUR STUDENTS

6. TONY AND FRANK: *The thinker and the feeler on the Myers-Briggs Type Indicator.*

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Tony and Frank are second-year chemical engineering students. They knew each other in high school and have worked on homework and studied for tests together since they started college. Both of them got high averages in their first year and scored in the low 80's on the first stoichiometry test, but on the second test Tony got a 47 and Frank a 53, by far the lowest test grades either had ever received. The day after they got their tests back they met in the student lounge to start on the next homework assignment, which is where we find them.

Tony: "OK, look at Problem 1...we got benzene and nitrogen coming in and we're cooling and condensing, so we'll probably have to..."

Frank: "I still don't know why Talbot took off 20 points in Problem 2. He had to see that I knew how to do it but I just ran out of time."

T: "Get a grip - it's only one test grade...I figured out that if we get somewhere in the high 80's or 90's on the next test and the final, with our homework grade figured in we can easily pull B's and maybe even get up to..."

F: "&#%$#, Tony - there are bleeding bodies all over the place and you go into calculator mode! The point is that I knew that stuff cold and got trashed anyway - I could have come in knowing nothing, written pure garbage, and gotten the same lousy five points for that problem. I'm working my butt off here - I even spent three hours the day before the test tutoring Helen and those friends of hers who flunked the first test, and all I get for it is..."

T: "You sound like my girlfriend - `Don't get logical with me,' she says every time she's losing an argument. Look, we're in engineering, not psychology...an engineer designs something and either gets it right or wrong, and if it's wrong they don't give him partial credit and pat him on the back for how hard he worked, and neither does Talbot...I'd rather have him any day than Sloan with all that touchy-feely group stuff he's always dumping on us in organic..."

F: "Yeah, well at least Sloan treats us something like human beings and not centrifugal pumps - all Talbot and most of these other professors want to do is tear us down and weed us out. I've been at this place for over a year now and I've never once had one of them except Sloan tell me I did a good job, even when I got the high grade in the class."

T: "Me either, but that's cool...I don't need gold stars - as long as I know the rules and the rules make sense, no problem. Talbot's job is to get us ready to be chemical engineers, not to make us feel good, and if someone can't make the grade he should probably go into another field because..."

F: "I've been thinking about going into another field, to tell you the truth - I'm not sure I need three more years of these 10-hour assignments and all this grief from these stonefaces just so I can go out and separate benzene from nitrogen - fat lot of good *that* will do the world."

T: "Come on, save the world on your own time - right now just stick a bandaid on that bleeding heart of yours and let's see if we can draw the flow chart for this one." (Frank starts to reply, shakes his head, and turns to begin work on Problem 1.)

Tony is a thinker and Frank is a feeler.(1) Thinkers tend to base decisions primarily on objective reasoning and will stick to their opinions until they are proven wrong logically. People with a strong preference for thinking are often thought of as impartial and rational, tend to be more truthful than tactful, and often consider strong feelers indecisive and overly sentimental ("*Stick a bandaid on that bleeding heart!*"). Feelers are inclined to give more weight to subjective, personal considerations in making decisions and place great value on building consensus and maintaining harmony. People with a strong preference for feeling are often thought of as warm and empathetic, tend to be more tactful than truthful, and often consider strong thinkers insensitive and overly analytical ("*At least Sloan treats us something like human beings and not centrifugal pumps!*").

The fact that people have a preference for one judgment mode (thinking or feeling) says nothing about their ability in the other mode - feelers may be logical and decisive, thinkers may be sensitive and compassionate, and both types have strengths that make them equally capable of becoming excellent engineers and scientists. As engineering and science students, however, the two types have different needs and difficulties, which manifest themselves in almost every aspect of education.

Course content and instructional format. Most engineering and science students and professors are thinkers, and these subjects tend to be presented (incorrectly) as being free of subjective considerations. This distortion generally poses no problems to the thinkers, as long as the course material is well organized and accurately presented. On the other hand, the impersonal nature of most technical instruction may alienate feelers, inducing them to switch to what they perceive as more humanistic subjects when in fact they could have been highly successful as engineers and scientists. Since proportionally more women than men are feelers, this alienation can have particularly unfortunate effects on the retention of women in technical fields.

The comfort level of feelers in technical courses can be raised by (a) bringing out the social relevance of the course material - e.g., applications to environmental or biological sciences or to anything that affects quality of life; (b) addressing some nontechnical topics - ethics, writing and oral presentation, teamwork and leadership skills, etc., and (c) using student-centered instructional approaches like cooperative learning rather than relying exclusively on lecturing and individual homework. While the thinkers in the class may grumble about that "touchy-feely stuff," they will tolerate it if the instructor can explain its relevance to their career objectives - for example, by showing them one of the many published surveys of employers listing teamwork and communication skills at the top of their wish list for new engineers, or by citing research demonstrating the effectiveness of cooperative learning in promoting academic success and employability [2,3].

Instructional policies. Every course involves a large number of policies regarding attendance, lateness, homework, tests, group work on assignments (forbidden, optional, mandatory), etc. The dynamics of a course are dictated in large measure by the degree to which the students believe the policies are reasonable. If they don't believe it, their resentment can make the course a dreary and unproductive experience for everyone concerned.

Thinkers resent treatment they regard as arbitrary or unfair, but will adjust to almost any policy they consider rational and consistently administered. ("*As long as I know the rules and the rules make sense, no problem*.") For example, they may protest bitterly if instructors test them on material in assigned readings that was never lectured on, but they will accept it (albeit grudgingly) if the instructors announce their intention to do so early in the course, explain why they are doing it, and always provide a clear picture of what the students will be held accountable for. ("You're responsible for everything in this 485-page text" doesn't quite do it.) Feelers also benefit if the policies are made clear from the beginning, but their buy-in depends less on the logical rationale for the policies than on a sense that the policies are intended to help them in some way and that the instructor can be flexible when circumstances warrant it. Some instructors who equate supportive policies and flexibility with "spoon-feeding" or "hand-holding" may have trouble conveying this sense. Feelers among the students may find classes taught by these instructors particularly difficult and stressful.

Feedback and evaluation. Thinkers want to be evaluated on the basis of what they do, feelers want to be valued for who they are. Thinkers are quicker than feelers to criticize and better than feelers at taking criticism as long as it seems fair to them; feelers thrive on praise and tend to take criticism personally. Tony didn't like his low test grade but he can deal with it since the strongly critical Professor Talbot (probably a thinker himself) gave a fair test and graded it strictly but consistently, while Frank takes the low test grade as a personal rejection and reacts emotionally to it. More generally, Frank resents the fact that his professors never compliment his good work but are always ready to point out his mistakes.

The most effective devices for helping feelers are acknowledgment and praise. Feelers are strongly motivated to perform well for instructors who can address them by name, establish a personal rapport with them, and offer an occasional "nice work" when they come up with a good question or problem solution or test score. The thinkers also appreciate compliments as long as they are really based on good work and not too effusive.

Epilogue: 15 years later. Tony and Frank both recovered from their initial setback in the stoichiometry course, did extremely well throughout the rest of the curriculum, went on to get Ph.D.'s in chemical engineering, and eventually joined the same faculty. Tony achieved international recognition for his research on heterogeneous catalysis and went on to become department head. He has done a great deal to help build the department's size and national reputation, although some of his faculty find him insensitive and unappreciative of their contributions. Frank does good research in environmental engineering but in his department he is better known as an outstanding teacher and advisor, and a large collection of students can usually be seen outside his office door waiting to talk to him. The two men still enjoy getting together frequently. Their arguments and insults have changed very little since they were sophomores.

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Footnotes

1. Thinking and feeling are the two poles of the judgment or decision-making function in Carl Jung's theory of psychological type. The degree to which someone prefers thinking or feeling can be determined with the Myers-Briggs Type Indicator, a personality inventory based on Jung's theory [1]. About 60% of the U.S. male population, 77% of male engineering students, 40% of the female population, and 61% of female engineering students show a preference for thinking [2]. Thinking and feeling are not mutually exclusive categories but preferences that may be mild, moderate, or strong, and all people exhibit characteristics of both types to differing degrees. While Tony is a representative thinker and Frank a representative feeler, not all thinkers are just like Tony and not all feelers are just like Frank.

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Felder, Richard, "Meet Your Students: 7. Dave, Martha, and Roberto."
Chemical Engineering Education, 31(2), 106-107 (1997).

MEET YOUR STUDENTS

7. DAVE, MARTHA, AND ROBERTO: *Three students at different levels of Perry's Model of Intellectual Development.*

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Three engineering classmates are heading for lunch after a heat transfer test. Martha and Roberto are discussing the test and Dave is listening silently and looking grim.

Martha: "OK, so Problems 1 and 2 were pretty much out of the book, but Problem 3 was typical Brenner--he gives us a heat exchanger design and asks us to criticize it. I said the design might be too expensive, but we could say anything and he couldn't tell us we're wrong."

Roberto: "Sure he could--it was a lousy design. They were putting a viscous solution through the tube side so you'd have a big pressure drop to overcome, the flow was laminar so you'd have a low heat transfer rate, the salt would probably corrode those carbon steel tubes, the..."

M: "Maybe, but it's just a matter of opinion in questions like that--it's like my English teacher taking off points because of awkward expression or something when anyone with half a brain would know exactly what I was saying."

R: "Come on, Martha--most real problems don't have just one solution, and he's trying to..."

M: "Yeah, yeah--he's just trying to get us to think and I'm okay with that game as long as I don't lose points if my opinion isn't the same as his. What do you think, Dave?

Dave: "I think that problem sucks! Which formula are you supposed to use for it?"

M: "It's not that kind of question--not everything has a formula you can..."

D: "OK, so when did he tell us the answer? I memorized every lousy word he said after I bombed that last test and not one had anything to do with..."

R: "It's a thinking question--you have to try to come up with as many..."

D: "That's bull, man! I already know how to think--I'm here to learn how to be an engineer."

M: "Dave, not everything in the world is black and white--some things are fuzzy."

D: "Yeah, in those airhead humanities courses and those science courses where they spout all those theories but not in engineering-those questions have answers, and Brenner's job is to teach them to me, not to play guessing games or put us in those dumb groups and ask us to..."

M: "Yeah, I'm not too crazy about those groups either, but..."

D: "...and that's not all--Monday Roberto asked him that question about the best exchanger tube material and he starts out by saying 'it depends'...I'm paying tuition for the answers*, and if this bozo doesn't know them he shouldn't be up there."*

R: "Look, the teachers don't know everything...you have to get information wherever you can--like in those groups you two were trashing--and then evaluate it and decide for yourself, and then you can..."

D: "That's a crock of..."

M: "Um, what did you guys get for Problem 2? I used the Dittus-Boelter formula and got 4.3 square meters for the heat transfer area. How does that sound?"

R: "I don't think it's right. I did the same thing at first, but then I started to think about it some more and I remembered that you have to be in turbulent flow to use Dittus-Boelter and the Reynolds number was only 550, so I redid it with the laminar flow correlation and got..."

M: "Whoa-he never did anything like that in class."

D: "I say we go straight to the Dean!"

These three students illustrate three levels of the Perry Model of Intellectual Development.[1-3] The model was developed in the 1960's by William Perry, an educational psychologist at Harvard, who observed that students varied considerably in their attitudes toward courses and instructors and their own roles in the learning process. The Perry model is a hierarchy of nine levels grouped into four categories:

Dualism (Levels 1 and 2). Knowledge is black and white, every problem has one and only one correct solution, the authority (in school, the teacher) has all the solutions, and the job of the student is to memorize and repeat them. Dualists want facts and formulas and don't like theories or abstract models, open-ended questions, or active or cooperative learning ("I'm paying tuition for *him* to teach me, not to teach myself.") At Level 2, students begin to see that some questions may seem to have multiple answers but they still believe that one of them must be right. Like many entering college students, Dave is at Level 2.

Multiplicity (Levels 3 and 4). Some questions may not have answers now but the answers will eventually be known (Level 3) or responses to some (or most) questions may always remain matters of opinion (Level 4). Open-ended questions and cooperative learning are tolerated, but not if they have too much of an effect on grades. Students start using supporting evidence to resolve issues rather than relying completely on what authorities say, but they count preconceptions and prejudices as acceptable evidence and once they have reached a solution they have little inclination to examine alternatives. Many entering college students are at Level 3, and most college graduates are at Level 3 or 4. Martha is at Level 4.

Relativism (Levels 5 and 6). Students in relativism see that knowledge and values depend on context and individual perspective rather than being externally and objectively based, as Level 1-4 students believe them to be. Using real evidence to reach and support conclusions becomes habitual and not just something professors want them to do. At Level 6, they begin to see the need for commitment to a course of action even in the absence of certainty, basing the commitment on critical evaluation rather than on external authority. A few college graduates like Roberto attain Level 5.

Commitment within relativism (Levels 7-9). At the highest category of the Perry model, individuals start to make actual commitments in personal direction and values (Level 7), evaluate the consequences and implications of their commitments and attempt to resolve conflicts (Level 8), and finally acknowledge that the conflicts may never be fully resolved and come to terms with the continuing struggle (Level 9). These levels are rarely reached by college students.

The key to helping students move up this developmental scale is to provide an appropriate balance of challenge and support, occasionally posing problems one or two levels above the students' current position.[1,2] (They are unlikely to comprehend wider gaps than that.) If teaching is confined to single-answer problems, students will never be impelled to move beyond dualist thinking; on the other hand, expecting most freshmen to think critically when solving problems and to appreciate multiple viewpoints is a sure recipe for frustration. Instructors should assign open-ended real-world problems throughout the curriculum but should not make course grades heavily dependent on the outcomes, especially in the freshman and sophomore years. They should have students work in small groups (automatically exposing them to multiplicity), model the type of thinking being sought, and provide supportive feedback on the students' initial attempts to achieve it. While doing those things won't guarantee that all of our students will reach Level 5 or higher by the time they graduate, the more we move them in that direction the better we will be doing our job.

Acknowledgments

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