then wonder why those same students react negatively to questioning.

In this article, we suggest that questioning is one of the most valuable tools in the teacher’s toolbox. But, like any tool, it needs to be used for an appropriate purpose, and like any tool, it must be learned before it can be used effectively.

Effective questioning turns a passive classroom into an active learning environment in which the professor controls the course of events, but everyone is participating in the learning process. Effective questioning engages students in the subject matter, stimulates critical thinking, and adds variety to the student’s classroom experience. Done well, questioning can also be used as a vehicle to build positive rapport between the teacher and students (Wankat and Oreovicz 1993, p. 99).

About Questions and Questioning Techniques

Questioning isn’t easy. Good questions have to be thought through in advance and timed so they will have the greatest learning value. Good questions are short, clear, and unambiguous—characteristics that usually can’t be achieved without considerable planning and forethought (Wankat and Oreovicz 1993, p. 101).

In the last issue of the Journal, we introduced board notes and used a statics class on friction to illustrate the application of this tool. And while board notes are intended primarily to enhance lesson organization, they can also be used to facilitate questioning. Board notes help the instructor identify logical times to ask questions, to emphasize key points, review prior knowledge, or provide transitions between topics.

There are several distinctly different types of questions, each of which is best suited for a particular circumstance or desired effect. Rather than simply listing these types and describing their uses, let’s listen in on that same friction class and see if we can pick up some pointers. As we listen, we will occasionally refer to the associated board notes (Figs. 1–3) for this portion of the class.

Class in Progress

Prof: Let’s look at Problem #7. Sam, would you read it for us?
Sam: A rectangular block weighing 300 pounds is resting on a
20° inclined ramp (Fig. 1). A horizontal force, $P$, of 120 pounds is applied as shown. The coefficients of static and kinetic friction are $\mu_s=0.3$ and $\mu_k=0.2$, respectively. Solve for the normal and friction forces. Will the block experience either sliding or tipping?

Commentary: Having a student read the problem is not exactly an innovative technique, but it is a cost-free way to get a student to participate. It also frees the instructor to start writing a figure on the board or set up a demonstration while the student reads the problem.

Prof: Okay, what’s the first thing we do when solving for forces? Everybody!

All Students in Unison: Draw a free-body diagram.

Commentary: This type of question is affectionately known as the *choir*. It is best used to reinforce a concept that has been emphasized in previous lessons and that everyone should readily know without hesitation.

Prof: Great! Let’s draw a free-body diagram of the rectangular block. What is the first force that you want to put on it (pause). Amy?

Amy: The weight of the block.

Commentary: This is the default question, which should be used most often. The instructor poses the question, pauses, and calls on a specific student (Wankat and Oreovicz 1993, p. 101). The pause forces all students to contemplate the answer, at least until Amy is called upon to respond. Only then can everyone else relax—but only for a little while. The instructor will make a concerted effort to ask every student at least one question in every class. Many professors avoid calling on students who have given no indication that they wish to answer, on the grounds that these students may be intimidated, and that interpersonal rapport in the classroom will be damaged as a result (Lowman 1995, p. 183). We acknowledge that some students may be intimidated by direct questioning at first, but we contend that interpersonal rapport is greatly enhanced when all students in a class can be persuaded to participate fully in classroom discussions. The professor can best achieve this end by convincing students that he or she is asking questions to create an engaging, enjoyable learning environment, not to put them on the spot. Questioning in a positive, nonthreatening manner is the key to creating such an environment.

Prof: Okay, what is the direction of the force and where do I apply it?

Amy: It acts downward through the center of mass.

Commentary: Amy gave a good answer, but the instructor decides to use a follow-up question to further test her understanding. Since the instructor gave the student the opportunity to choose any force on the free-body diagram, the instructor is now obligated to use any correct answer that she provides. Asking questions for which there are several possible correct answers requires that the instructor be more flexible and better prepared.

Prof: Super! Let’s place the 300 lb. force on the free body diagram and resolve it into its parallel and perpendicular components. Heidi, what is the parallel component?

Commentary: In this case, the instructor varies from the default question by calling on Heidi first and then asking the question. After asking Amy a series of questions, this lets Amy and the rest of the students know that it is someone else’s turn. Also, the instructor might have noticed that Heidi was not paying attention (Wankat and Oreovicz 1993, p. 101). Calling on Heidi breaks her trance, and calling her name prior to asking the question increases the chances that she will hear the question and answer it intelligently. Of course, this technique also has a significant disadvantage: as soon as Heidi’s name is called, the other students in the class know they will not be called on. They will relax and may not think about the question as the instructor is directing it to Heidi.

Note that the instructor decided a priori that the problem would be solved with respect to coordinate axes parallel and perpendicular to the incline. She did not offer the students the option of using an $x$-$y$ (horizontal-vertical) frame of reference. The instructor may not have been prepared to solve the problem that way and therefore limited the options. Furthermore, the problem is solved most easily in the parallel-perpendicular reference frame, but students are unlikely to recognize the advantages of this problem-solving strategy yet. After the problem is solved, the instructor may ask the class, “Why didn’t we use the $x$-$y$ coordinate system?” By that point, an insightful student may recognize that the $x$-$y$ system would have resulted in simultaneous equations for the normal and friction forces.

Heidi: It would be 300 times the sine of 20°.

Prof: Bill, is she right?

Commentary: Yes, of course she’s right. But students often have difficulty resolving a force vector into its parallel and perpendicular components, so the instructor wants to give everyone an opportunity to think about it one more time. Bill needs to think really hard, because he would normally expect to be asked “is she right?” only if Heidi had answered incorrectly. By asking it after a correct response, the instructor catches everyone off guard. Her unpredictability keeps the students alert.

Bill: Uhhhh…yes?
The instructor begins by engaging the students with a question about the normal force on their feet. The normal force is the force exerted by the floor on the student's feet. The instructor asks if the normal force is off the body, and students are encouraged to think about the implications of this question. The instructor then asks if the normal force should go through the center of mass of the student's foot. This question is designed to have the volunteer answer—Donald, in this case—to ensure that the discussion is not too challenging for students who may not realize that they were being misled. The instructor calls on Troy, who probably has a good answer but will not volunteer on his own. Effective questioning requires that the professor know the students’ personalities, as well as their names.

The instructor continues by asking if the normal force is located off the body. The students are then asked if that is physically possible. If not, they can assume a negative number for the normal force. If the value for d places the normal force on the body, then the body does not tip. Conversely, if the normal force is off the body, then the body will have already tipped. The instructor then asks if the normal force is off the body, and if the body will have already tipped. Suppose we get a value of d = 4 ft. What does that indicate, (pause) Troy? The instructor pauses from the questions to summarize and bring everything together (Lowman 1995, p. 182). In doing so, she forcefully dismisses the students’ misconception about the normal force acting through the center of mass. The instructor finishes the summary with another thought-provoking question—a situation the students will encounter in the future.

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**Commentary**: The pause is to let the concept sink in and to conclude that key idea. It allows the students to collect their thoughts before proceeding.

**Kristi**: The force $P$.
**Prof**: And the parallel component is?
**Kristi**: 120 times sine 20°.
**Prof**: Perpendicular component, David?
**David**: 120 times cosine 20°.
**Prof**: Any more forces, Bowie?
**Commentary**: The professor picks up the pace during this sequence of questions. There is no new learning taking place, but the steps are necessary to complete the problem.

**Bowie**: No. I think we have them all.
**Prof**: (Pause) Does everyone agree?
**Commentary**: The instructor asks a *volunteer* question and slows the pace back down. Note that she does not chastise Bowie for an incorrect answer.

**Omarosa**: We left out the friction force.
**Prof**: Omarosa, you’re exactly right. In which direction does the friction force act?
**Omarosa**: Parallel to the surface.
**Prof**: Absolutely. Good answer. Should I draw it in the direction going up the surface or going down the surface?
**Commentary**: This is a good but incomplete answer. The instructor praises the student but continues to probe for the information that will bring out the key learning point (Wankat and Oreovicz 1993, p. 102).

**Omarosa**: Friction always opposes motion. Since the block is being pushed up the surface, the friction force should go down the surface.
**Prof**: You are absolutely right that the direction of the friction force is opposite the direction of motion. Nice job remembering that from last class. Do you know for sure that the block wants to move up the incline?
**Commentary**: This is a case where the instructor seizes the correct portion of the answer and praises the student. She then probes to correct the portion that is not correct.

**Omarossa**: I think so.
**Prof**: Does anyone want to pose a counter argument? (Heidi raises hand.) Yes, Heidi.
**Commentary**: The instructor seeks a volunteer for a conceptually challenging question (Lowman 1995, p. 183).

**Heidi**: Looking at the free body diagram, we have 300 cos 20° going down the ramp and 120 sin 20° going up the ramp, so it appears the block will go down the ramp.
**Prof**: Great point and I totally agree with you. Suppose there were three or four known forces and even an unknown force acting on the free-body diagram, would you be able to tell the direction of motion by inspection?
**Commentary**: This student has given a great answer. The challenge here is to praise the student but expose that this is a unique situation and the direction of motion will not always be so apparent.

**Heidi**: Probably not.
**Prof**: Exactly right. Through her masterful insight, Heidi has deduced it, but in many cases we won’t know the direction of motion. In past problems, what did we do when we did not know the direction of a force, (pause) Sam?

**Commentary**: Students often learn by making connections to things they have seen before. The professor is attempting to make such a connection here.

**Sam**: We assumed a direction.
**Prof**: Good. And how did we ultimately know if we assumed correctly?
**Sam**: We got a positive answer.
**Prof**: Right again, and we’ll do the same thing here. When we use the equilibrium equations to solve for the friction force, if we get a positive number for the answer, we know that we assumed correctly. A negative number means we assumed incorrectly. Based on our discussion of friction in our last class, what is the magnitude of the friction force, (pause) Bowie?

**Commentary**: Sam gave a great shorthand answer and it would have been sufficient if Sam and the professor were having a private conversation. For the benefit of the other students who may not see the point, the professor agrees but also praises and amplifies Sam’s answer in greater and more complete detail.

**Bowie**: It is either $\mu_s N$ or $\mu_k N$; I’m not sure which one to use.
**Prof**: You are on the right track. Let’s review the diagram (Fig. 3) that we constructed last class. If the block is moving, what is our friction force?
**Commentary**: The answer is not correct, but Bowie has demonstrated some knowledge. This is another chance to use the best of a student’s response and probe to correct the portion that indicates a misunderstanding.

**Bowie**: $\mu_k N$
**Prof**: Right, if the block is moving, the friction force is equal to the coefficient of kinetic friction times the normal force. And what if the block is not moving, Kwami?
**Kwami**: It is somewhere between 0 and a maximum value of $\mu_s N$.
**Commentary**: Engineering problems use standard letters and symbols for specific variables. In the interest of time and efficiency, instructors and students often refer to just the variable names. When the concepts are still new, the instructor needs to reinforce what the symbols mean, whenever practical. Here, for example, she says "coefficient of kinetic friction" rather than "$\mu_k$.".

**Prof**: Absolutely. Bowie did you catch that? The friction force is only equal to $\mu_s N$ right before it begins to slide. Before that, it is something less. So, let’s talk strategy here. How are we going to determine whether the block slides or not, (pause…silence) anybody? (pause) Yes, Bill, what do you think?

**Commentary**: The instructor uses Bowie’s name to catch his attention, since he initially made the error. The *jump ball* question is a variation on the *volunteer* question. It provides extra notice that the question is open to anybody brave enough to jump in.

**Bill**: We could assume that it slides, set friction equal to $\mu_s N$ and then check our assumption.
**Prof**: Bill, that’s a terrific thought. How are you going to verify your assumption?
**Bill**: I really don’t know.
**Prof**: I don’t know either and that’s the rub. There is no good way to check if you are right or not, but your thought process is right on. Suppose we take Bill’s suggestion, but let’s assume the block does not slide. We solve for the friction force. How can I check the assumption? (pause) Anybody? (pause) Yes, Heidi.

**Commentary**: This was not the answer the instructor was look-
Heidi: If the friction force turns out to be greater that \( \mu_s N \), then the block must have slid.

Prof: Excellent! That’s exactly what we will do. We will treat the friction force as an unknown and use our equilibrium equations to solve for the value. If the friction force is greater than the coefficient of static friction times the normal force (pointing to the diagram, Fig. 3), it means the block has slid. Otherwise, the block does not slide. Let’s summarize the strategy before we go through the numbers...(summary) Any questions? Yes, Nick.

Commentary: Again, the instructor praises a good answer and then amplifies it for the benefit of the rest of the students. This is a key learning point of the lesson and needs to be reinforced. Note this is the first time that the students have asked the instructor a question. The principles for answering student questions are similar to those for asking questions. The professor’s answers should be concise, lucid, accurate, positive, and directed toward the question that is being asked. Achieving these standards demands that the instructor listen carefully to ensure that she hears and understands the student’s question.

Nick: Our friction equation seems to be a function of the normal force and the roughness of the surface. My dad and I used to build dragsters in our garage. We always used extra-fat tires, and he said it was because the greater surface area increased friction and gave us a better grip on the road. Why don’t we include surface contact area in our friction equation?

Prof: Nick, what a great question. I honestly don’t know. I’ll have to give that some thought. Can I get back to you next class? Any other questions? Yes, Amy.

Commentary: When the instructor does not know the answer to a student’s question, she should say unequivocally that she does not know and will attempt to find out (Wankat and Oreovicz 1993, p. 100). Nothing could hurt a professor’s credibility more than to make up an answer that turns out to be wrong. The professor should set a goal to be so well prepared that she does not have to say “I don’t know” too often, because not knowing also damages credibility. And once the instructor states that she will get back to the student with an answer, she must actually do it.

Amy: Is it possible to have \( \mu_s \) greater than one?

Prof: Another great question. Amy has asked if the coefficient of static friction can be greater than one? Amy, what does your gut tell you?

Amy: All our problems use values like 0.2 and 0.3. We often normalize lots of stuff to 1.0. I thought that might be the case here.

Prof: I love the insight. Does anyone have any other thoughts on the matter? (pause) David do you see any reason why the friction coefficient might have an upper limit of one?

David: I don’t think so, but I’m really not sure.

Prof: It turns out that many surfaces can create a friction coefficient greater than one. Add this as a 5-point bonus question on the problem set I gave you today: provide an example of a surface with a coefficient of static friction greater than one, and cite your source. These are all super questions, any others?

Okay, let’s solve the problem using our equilibrium equations. Please give me the first equation, (pause) Jason.

Commentary: When a student asks a question, some effective techniques are to:

1. Repeat the question or, if necessary, rephrase it. Give the student a chance to answer her own question (Wankat and Oreovicz 1993, p. 100).
2. See if anyone else in the class knows the answer.
3. As a last resort, the instructor answers the question herself. It is a good thing that she anticipated the question in advance. Otherwise, it would have been two consecutive “I don’t knows” and the sharks might have smelled blood. The technique of adding a homework question forces each student to pursue the subject on his or her own. The risk is that the class will not ask more questions, for fear of another homework problem. If time is running out and the instructor needs to move on, this technique might prove to be effective.

Jason: I don’t know.

Prof: Okay, what are the possible choices?

Jason: I don’t know.

Prof: How many unknowns do we have on the free-body diagram?

Jason: I don’t know.

Prof: How many equations of equilibrium do we have available to us?

Jason: I don’t know.

Prof: Okay, open your textbook to Example 5.2 on page 130. What equations are used in that problem?

Jason: Sum forces in parallel direction, sum forces in perpendicular direction, and sum moments about point G.

Prof: Good, which of those would you like to start with?

Commentary: Jason clearly does not want to be bothered with questions; he would rather remain a passive observer in the classroom. This is a pivotal moment; the instructor cannot let Jason off the hook without some sort of an answer. Otherwise, “I don’t know” will be the standard answer from the rest of the students who do not wish to be called on. This situation can be a challenge, since the instructor does not wish to embarrass the student. One technique is to ask progressively more basic questions, until the student can no longer legitimately claim to be ignorant. Having elicited a positive response, the instructor then builds back toward the original question.

This is the third time in this script where a student has said “I don’t know.” Initially Katrina said it with respect to where to put the normal force. That was the best possible answer, since we do not know in advance where the force acts. Bill stated that he did not know when asked how he would verify his assumption that the friction force was equal to \( \mu_s N \). The response was perfectly understandable given the context of the conversation and the higher level question he was struggling with. This final example with Jason is clearly a case where the student should know the answer and wants to be left alone. Each case elicited a different sort of response from the instructor. There is no single best way to handle a student’s claim of “I don’t know.” The instructor’s response must be based on both the situation and the student.

Effective Questioning

While the “apprentice” engineers construct and solve equilibrium equations, let’s leave the class to solve the rest of the problem on their own. Problem solving is an ideal time to ask questions
In response to questions, students can build free body diagrams, develop equations, select sign conventions, and work out numerical answers. Review material, connections to previous concepts, and problem-solving methodologies are also ideal subjects for questioning. The presentation of unfamiliar concepts and introduction of new terminology are probably the most difficult occasions for asking questions, but the instructor who is committed to an interactive classroom environment will still find opportunities to do it.

Effective questioning requires practice and the willingness to take a risk. It might even require an explanation on the first day of class, so students understand why they are being asked questions. To ensure that classroom interaction is a positive experience for students, the instructor must praise correct answers, be supportive with wrong answers, encourage participation from everyone, and create a classroom atmosphere that is threat-free—perhaps, we dare say, even fun. Despite initial reluctance, students will grow to appreciate the questions as a sign that the professor cares about their learning and wants to involve them in the process.

Questioning affords yet another opportunity to enhance classroom instruction. Posing a thought-provoking question and then withholding the answer until the perfectly timed moment or producing an answer contrary to all expectations can help create drama. And, the art of creating drama in the engineering classroom just happens to be the subject of our “Teaching Lessons Learned” column for the next issue of the Journal.

References