Questioning: Bring Your Students Along on the Journey

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Value of Questioning

During our ExCEEd Teaching Workshops, no topic causes more angst, trepidation, and resistance from participants than questioning techniques. The idea of calling on a student by name, asking a direct question, and waiting patiently for an answer is anathema to even many experienced teachers. Excuses for not asking questions range from "it takes too much time and I'll never cover the material" to "my students will resent it and will give me bad teacher ratings" to "you can get students to answer questions at West Point because you control their lives, but my students would never play along." We find, however, that most teachers who doubt the value of questioning have never actually tried it. Others have made half-hearted attempts to teach interactively, but have quickly given up when their students were unresponsive or, worse yet, when students answered every question with, "I don't know." Some instructors use questions in an adversarial way—to identify students who have not done their homework, for example—and 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

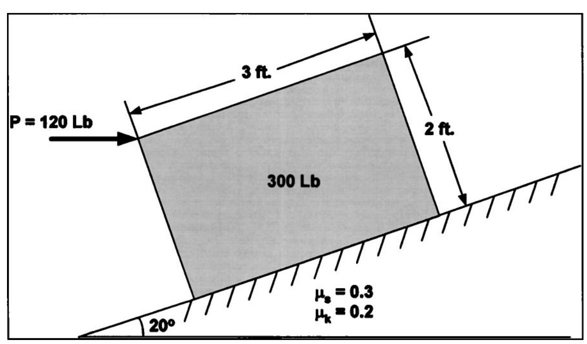

Fig. 1. Board notes for friction class: problem statement

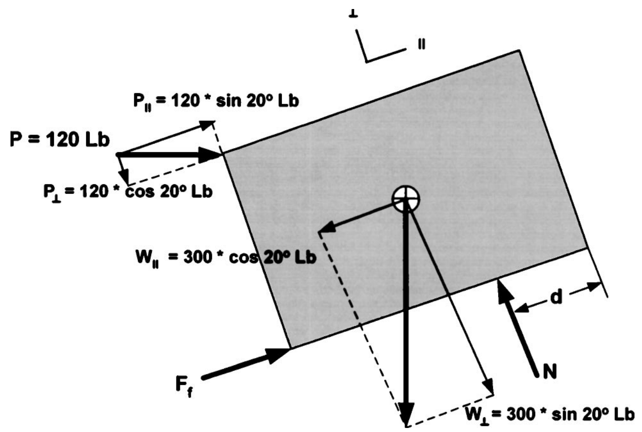

Fig. 2. Board notes for friction class: free-body diagram

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.

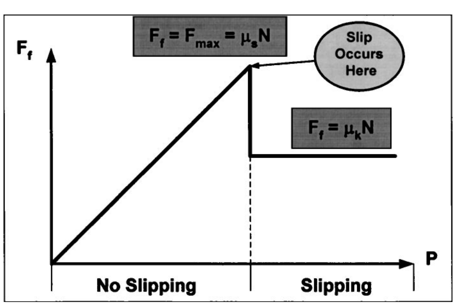

Fig. 3. Board notes for friction class: behavior of the friction force

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?

Prof: Yes, of course she's right! So what would the parallel component be, Donald?
Commentary: This time the instructor does not pause after asking the question, because she wanted this *softball* question to go to Donald, a student who is currently struggling in the course. Questioning has the most positive effect when students are challenged but can ultimately respond successfully. The bright student who appears to be bored with the slow pace of a class should receive thought-provoking questions, at least occasionally. Struggling students like Donald should receive simpler, but still meaningful, questions. With each successful response, Donald's confidence and ability to answer more challenging questions will improve.

Donald: 300 times cosine 20°.
Prof: Good. Now give me another force, (*pause*) Katrina?
Katrina: The normal force.
Prof: And what direction does it go?
Katrina: Perpendicular to the surface.
Prof: And I place the line of action through the center of mass, right?
Commentary: This is a deliberately *misleading* question that can be used occasionally to emphasize a common student misconception or erroneous preconceived notion. But be careful, the instructor needs to emphatically correct the premise of the misleading question for the benefit of those students who may not realize that they were being misled.

Katrina: Yes.
Prof: Do you agree, (*pause*) Nick?
Nick: Yes.
Prof: Does anybody disagree?
Commentary: The *volunteer* question ("Anybody?") is intended to evoke a response from anyone willing to venture an opinion.

Class: (*Silence*)
Commentary: The silence is not surprising, as the students are probably beginning to recognize that they have been set up. This is not necessarily bad, if the instructor has piqued their curiosity and they wonder how the set-up is going to unfold.

Prof: Everybody on your feet. Stand-up straight and place your hands in the small of your backs, like me. Let's call this *normal force aerobics*. The floor is exerting a normal force on your foot. Where do you feel this force, (*pause*) Ereka?
Commentary: A physical demonstration adds variety to a class and enhances understanding. We will discuss physical demonstrations in greater detail in a future "Teaching Lessons Learned" article.

Ereka: Distributed all around my foot.
Prof: Great. Now everybody lean forward. Where do you feel the normal force now, David?
David: On my toes.
Prof: How about that! Now lean forward as far as you possibly can. Feel the normal force on the point of your toes. If you go forward any further, what will happen David?
David: I'll tip over.
Commentary: This line of questioning is designed to have the students discover for themselves that the normal force can move along the body.

Prof: Exactly, you'll tip over. Now lean backwards. Where is the normal force now, everybody?
All in Unison: On our heels.
Commentary: The instructor uses a *choir* question because the answer should be obvious but is still needed for completeness.

Prof: Terrific. Have a seat. So, Katrina, I ask again, where should we put the normal force?
Commentary: The instructor returns to Katrina, who originally agreed that the normal force should go through the center of mass.

Katrina: I don't know.
Prof: Superb answer! We don't know. So let's put the force at some distance d from a known point on the body. (Fig. 2) Notice that d is an unknown that we will have to solve for. What happens if d turns out to be a negative number? (*pause…silence*) Troy, what do you think? Is it even possible to get a negative number for d?
Commentary: Because the idea of a negative distance is conceptually challenging, the instructor initially uses a *volunteer* question. In the context of Bloom's taxonomy, this question requires analysis-level thought (Bloom 1956). When no one answers, the instructor calls on Troy, a bright but shy student 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.

Troy: Probably, or you wouldn't have asked.
Prof: You're right. Let's assume we got a negative number for d and it was the correct answer, what does that indicate?
Commentary: The instructor will continue this line of questioning until Troy makes an attempt at real thought.

Troy: It means the normal force is located off the body.
Prof: Is that physically possible?
Troy: I don't think so.
Prof: David, think back to the aerobics we just conducted where the normal force slid back and forth across the bottoms of our feet as we shifted our weight.
Commentary: Satisfied that Troy has successfully engaged his brain, the instructor now returns to David, who first recognized the concept of tipping during the normal force aerobics demonstration.

David: It means the block has tipped.
Prof: Excellent! Does everyone follow what David has just stated? When the normal force is at the edge of the body, tipping is impending—just as our bodies were about to tip forward when the normal force was at our toes. And, that's how we will answer the question in this problem. 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. Suppose we get a value of $d = 4$ ft. What does that indicate, (*pause*) Jessie?
Commentary: 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.

Jessie: It means the block has tipped the other way.
Prof: Absolutely. This is a key concept in today's class; are there any questions? (*pause*) Okay, give me another force, (*pause*) Kristi.

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 "μ_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 $\mu_k N$ 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-

ing for, but it shows great insight on the part of the student. The challenge is to praise the student for the insight but get the class moving back in the right direction. The best way is to prepare thoroughly and think through the class in sufficient detail to anticipate this comment and have an answer that makes this a learning point. Otherwise, the instructor could easily get side-tracked on a peripheral point that ultimately will only cause confusion among the students.

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 μ_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 $\mu_k N$. 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 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

(Lowman 1995, p. 173). 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*.

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