# AC 2012-5051: BOTH SIDES OF THE EQUATION: LEARNER AND TEACHER

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# Both Sides of the Equation: Learner and Teacher


## Abstract

An engineering professor decided to retake a first-semester calculus course under the tutelage of the chair of mathematics at Boise State University. While completing the course with 37 other students, she had in-depth experiences as a student of a calculus class as well as an experienced educator with a strong background on STEM retention. During the course, she recorded her observations and experiences in the classroom. The math professor also shared reflections on his teaching, observations of his students, and perspectives on the influence of her presence in his class.

The two professors' reflections enabled us to identify a set of student assumptions and learning behaviors that would likely influence their learning outcomes in both positive and negative ways. We developed a survey questionnaire based on the identified student assumptions and learning behaviors. At the end of the course, we administered the survey with the calculus students in order to obtain the students' perspectives. By triangulating the three sources of information and through our self-reflections on the results, we have generated recommendations on teaching strategies to which math and engineering instructors might need to pay attention, in order to better understand students and to provide them with more meaningful learning experiences.


## Introduction

Of the many factors affecting student success in engineering, competency in mathematics is among the most frequently cited. Indeed mathematics proficiency is at the heart of national conversations about education at all levels. News headlines and policy reports warn that U.S. K-12 declining mathematics test scores portend concerns for national competitiveness[1]. "Change the Equation," the national initiative led by more than 100 corporate CEOs, underscores math proficiency as essential to achieve STEM literacy and to stimulate technological innovation and economic prosperity. The recent February 2012 report by the President's Council of Advisors on Science and Technology includes a focus on mathematics preparation as one of five key strategies to produce one million additional college graduates with degrees in science, technology, engineering and mathematics over the next decade[2].

Like the rest of the country, Boise State University has implemented research projects and initiatives to study and improve mathematics success among engineering students, with particular emphasis on freshman retention. An engineering professor who has led several of these initiatives decided to experience freshman-level calculus firsthand by re-taking Calculus 1 nearly 30 years after her own freshman days. Her instructor was the chair of the mathematics department, a professor with whom she has collaborated on numerous research projects. The evidence presented in this paper is based on the experiences of these two professors. The information presented may provide other instructors with insights of use to them in their instructional strategies.

The paper is structured in six sections. First is a collection of observations from the perspective of the engineering professor, the Learner. These were written approximately mid-semester without comment or review from the Calculus professor, the Teacher. Next is a similar section from the point of view of the Calculus professor, written in the same time-frame. This was also written without any knowledge of the engineering professor's comments or any input or feedback. The third section is a third party analysis of data collected from students and the two professors after obtaining institutional review board approval late in the semester. The next two sections are the thoughts of the two professors *after* reading each others' commentary and the third party analysis. Finally, a set of actions that have already been taken or that are planned as a result of being experiencing "both sides of the equation," are listed.

**[1] The Learner's Experience**

Our professor came to class today with a giant packet of exams. By now, he knows all our names, having practiced daily with index cards we created on the first day, with our name and favorite movie. I admit I am a little nervous about getting my exam back. I believe I did okay; I think it's possible that I did very well. I was able to answer all the questions, but I have a superstition about this – when I think I've done well on an exam, I often wind up with a low score (meaning, a B, instead of an A; or the rare C). So, I'm a little nervous.

My exam is now in my hands – both parts. I can't see a score readily visible; there are two stapled sections, each with multiple problems, each problem with a score. I start adding them up to see my total. My professor has a very interesting model for giving math exams. Because our class periods are only 50 minutes in duration, he allots two days for each exam, so that we have enough time to answer the problems. He gives the exam in two parts. Part 1 was given on Wednesday, in the fifth week of classes, and was worth 80% of the possible points. We read on the professor's website[3] that part 1 is designed with a strategy of being a combination of "type 1" and "type 2" questions – the sorts of questions we've been practicing on, in our homework. Part 1 is closed book; we can use any form of calculator we want, but cannot connect to the internet. There are two versions of Part 1, as the class sits in relatively close quarters. The exams are put in front of us in different colored envelopes so the professor can easily see which version you have as he distributes them across the classroom. Part 2 of the exam was given on Friday, and worth 20% of the grade. Part 2 is open book, open notes; designed to be a higher level of problem solving, or as my professor calls them, "type 3" questions. Each day, I finished within the time-frame, with time to check my work and even time beyond that; but I noticed other students used every minute of the time available.

Today is the following Wednesday, and the professor already has both parts of the exam graded. If my addition is right, I got a 95! Feeling good, I look to my friends on my left and right – some have small smiles; others look a little tense. The distribution is put on the board, and we are told the average was a little higher than normal, at 78. I have the fifth highest score in the class. What a great feeling! But, about a third of the class has a score below a 70, and these students are invited to meet with the professor, to make an appointment to see him. He tells them to "bring everything – your notes, your homework, your exam." He will do his best to diagnose some things that they can try to do differently to help them correct their course.

Perhaps you realize by now that I am not a "normal" calculus student. I am retaking it. Not because I failed it the first time, but because when I last took calculus, Jimmy Carter was President and I was enrolled in calculus as an undecided first-semester freshman. I attended a large lecture three days a week, and a discussion section two days a week. I have zero recollection of the math professor and only slightly more recollection of the subject matter. I was the sort of student who went to all the classes, and did the assigned homework. With weekly quizzes and collected homework in my Jimmy Carter calculus class, I earned an A – which likely influenced my decision to stay in a "STEM" major.

My motivation for taking calculus under the presidency of Obama began at first with my desire to be able to help first-year engineering residents with their math homework. I'm the Engineering Residential College's Faculty in Residence at a metropolitan university in the northwest. This means that I live in an apartment in a residence hall on campus, on a floor with 18 engineering students. And I get asked lots of questions – some of them about homework. I can generally rally on the chemistry questions, and reason through the physics, but my memory of calculus has faded dramatically over the years due to lack of use. This fuzzy memory was embarrassing to me, so I decided to retake the class. It has been an interesting experience, and I have recorded some of my observations, from the perspective of a student who has taught as a materials science and engineering professor for nearly twenty years.

**Observation #1, Help Students Connect!** Students don't reach out to each other much. At first, in the class, hardly anyone spoke to each other. After hearing the professor actively encourage group study sessions, I became relatively proactive in the back of the room, and got students exchanging cell numbers with me, and with each other, and even put one student in charge of distributing the information about informal study sessions they subsequently organized. I am pretty sure that this study session, involving about 10 people from time to time would not have formed without my instigation. By the sixth week of classes, they sorted themselves into smaller groups, pairs and triplets of students who study together and routinely sit next to each other.

**Observation #2**, **Engaging the Class:** My math professor is an excellent instructor. He uses a variety of techniques to engage the students. He has us do in-class exercises, "warm-ups" he calls them, and says we should be able to differentiate as fast as he can write the statements on the board. He has us work in small groups with each other. He smiles in class and has a wry sense of humor; the class chuckles from time to time and students genuinely seem to enjoy class. Students feel very comfortable asking in-class questions, and he will deviate from his lecture to accommodate as many questions as we have about the homework or what we've been covering. He uses interesting analogies – for example, he refers to the rules of differentiation as "power tools." And then goes on to explain, "You have to know how and where to use them so you don't hurt yourself." And: "Practice, practice. You want to get to a point where your fingers remember even if your brain forgets!"

**Observation #3**, **Assumptions:** As professors, we make assumptions. For example – my professor assumed that we knew it was okay for us to work on our homework together. As a student, this was not obvious to me – and so in class, the second week, I asked aloud the question – "What do you think about study groups?" I think my professor was getting a little tired of questions from me by then, and he replied concisely, "They're good." "Why?" I replied. He elaborated – and his words were important to the class. He explained that generally, students who work in study groups, do better on exams, and that a lot of research has been done on this. In his view, it boils down to students in study groups having a more rapid feedback loop when doing homework. The key thing that he said was, "I encourage you to work with other students when you're doing homework." This was important to state aloud because the "honest" student might have imagined that it was unethical to work together; that we were expected to be doing all our own work. In fact – we were encouraged to work with each other. Having this explicitly allowed was important, and as instructors I propose that we all make a point of stating our views on study groups in the first or second week of classes. It could be put into our syllabi as being explicitly permitted and encouraged.

**Observation #4**, **Weekly Graded Homework Is Important**. In my calculus class, we have four homework assignments a week, one for each day of class, and they are collected on Fridays into two piles. We do not have any discussion sections – the professor is there every day. Pile 1 – a thicker stack, is for a grader (an undergraduate paid by the hour) to briefly examine and assign a grade. Pile 2 is for the professor, a shorter stack – he is careful with his time, but gives each of us a few minutes every week, as he evaluates our work. The very interesting aspect of this professor's homework grading – is that the homework grade for the week is a product of the two pieces[1]. So – you could get a 9 from the professor, and an 8 from the grader, making a grade of 72 for your homework that week. I really like this homework model, and plan to implement it next time I teach a class.

**Observation #5, Women:** About one-third of my calculus class is female. Nationally, about 20% of engineering degrees are conferred to females[4]. A recent, comprehensive article examining the causes behind the under-representation of women in engineering concludes that one of the underlying reasons for this is recruitment – more women need to be recruited, through outreach, into engineering disciplines[5]. I have made it a point to speak with many of the women in class; about half of us are in a large clump in the far back row. Has anyone considered students taking Calculus 1 as an engineering recruitment pool? I think it a great opportunity for an engineering professor to reach out to the calculus professors, and to let them know if they ever want a substitute one day, that they'd be delighted to speak to the class about some applications of calculus. Send a dynamic professor in, and then follow up with an invitation to an event, or to have coffee with you if they have questions about engineering as a career choice.

**Observation #6, Vision:** My eyesight has changed! It's a different experience, wearing readers in class. My vision has always been exceptional. This changed for me recently, and I now use fairly weak readers – but they make a crucial difference. I made two mistakes on the exam – and one was a transcription error, I didn't see one of the numbers. With about 14 million Americans aged 12 years and older having self-reported visual impairment[6], I see no reason not to use a 14 point font on exams and homework assignments.

**Observation #7, Distractions:** Students text in class. I couldn't believe my eyes; one student sitting next to me was routinely texting in class. I happen to know that my professor is one of the best math instructors we have at this university. I told the student this. And then on another occasion when we were working together and the student was glancing at her phone, I asked her to please put it away. Nearly all the other students seemed quite focused and did not look at their phones with any measurable frequency. This particular student unfortunately did poorly on her first exam, and I subsequently had a conversation with her about how educational theory shows that it takes several minutes to refocus after receiving a text – and how by then, another text has been received, so altogether texting while studying attending class or studying renders the time spent relatively ineffective. Next time I teach a class, I plan to show students some research on this issue. And then ask the class to agree on some ground rules for the class, because it distracts the people nearby as well as the person engaged in the activity.

**Observation #8, Love of Learning; Reasonableness:** I had forgotten – or perhaps never realized – that I love to learn! I enjoy solving problems. It is satisfying to correctly answer a math problem. My professor keeps asking questions about rabbits, and how the population of rabbits grows, and what rate of change the rabbit population has when there are 500 rabbits, and so forth. I find it fun to figure out the rate of change in the rabbit population. My skills in reasonableness are helpful. At some point in my college education, I learned how to judge an answer as being reasonable. When did I learn to apply this "reasonableness" judgment? At some point, I developed this expertise. How can we teach this to freshmen?

**Observation #9, Self-Efficacy Matters:** I am confident in my mathematical abilities now and it makes a difference in my classroom mentality. Knowing you can actually perform, given enough time is a great feeling. As instructors, the things that we can do to build up the self-efficacy of our students in terms of their ability to apply what they've been learning, are important. Here's an example of how my professor enables mastery experiences, which help shape self-efficacy[7]. He has 100% of his old exams – and their solutions – on his website, with statistics of student performance on each question. This allows students to practice problems that are similar to the types of problems they will see on their upcoming exam. Having a straightforward exam, with opportunity for practice and enough time to answer the questions by using two days for the exam gives students a fair opportunity to perform to their level of preparation.

**Observation #10, Calculator Competency:** Calculator competency is all over the map in terms of the freshmen at this metropolitan university. For this course, I began to use a spreadsheet application, to calculate the various secant slopes required in the homework. This was incredibly efficient, but I knew that for exams I had better start using my new TI-89, as I couldn't whip out my laptop during an exam. I painstakingly turned it on and started using it. In the Jimmy Carter days, I used reverse polish notation, and there were no graphing calculators available for use in examinations.

Now – my past experiences made me aware that there is definitely a way to store a number in a calculator. Yet how to do this was not obvious to me in peering with my readers down at the tiny notation on the calculator side-buttons. During an in-class exercise, hand-calculating a series of secant slopes, I realized how it would be useful to store the outcome of X times "e" raised to the X, where X was 1.003476. As an experienced "networker," I have realized that simply "asking one who knows" is a faster way of figuring out how to do things than reading the manual. So – I asked the person on my right, how to store a number. She didn't know. My eyebrows arose, internally marveling at this deficit. I asked the person on my left, who also did not know. And then the person to the left of left, and right of right. The people in the row in front of me. I actually got to my feet to get to more people and had surveyed almost one-third of the class before finding ONE student who would show me how to store a number in calculator memory. I shared how to store this number with all who were interested. I also shared it with the professor, who was unsurprised. Yet – this is a performance issue, and I am still astounded by the lack of calculator knowledge in our freshmen. Their calculator "know-how" is not even. This has motivated our university to develop and hold a calculator help session in spring, 2012; we may also introduce some topics in the Introduction to Engineering class that engineering students usually take concurrently with Calculus 1.

**Observation #11, Networking:** Students don't know how valuable a resource they are to each other. I think that this is where experience plays in, and I believe I learned some of this during my upper division education as a chemical engineering student, and the rest during the research phase of my Ph.D. I learned to ask for help, to consult with multiple people about how to approach a task that I hadn't done before. I applied my networking skills like crazy in this course. It is definitely helpful to be living on a floor of fellow engineers, because when I hit a task on my calculator that I need help with, I go down the hall looking for a student who can help me. One student in particular has been incredibly helpful to me, even though he wasn't familiar with the Ti-89, he knew that what I needed to do, could be done, and fiddled with it until he figured it out. One thing I asked him was how to program an equation in to calculate a series of numbers – this was in about week four of the class. I learned from him that it could not only do that, it could also graph it by just hitting two more keys.

You can probably guess what I did with this information – the next day I was demonstrating this to the students I sat near. Some already knew, but more didn't. One of them was dumbfounded and wished she'd known how to do this three weeks ago, before we started doing hundreds of secant slopes by hand. By showing my fellow students what I had learned from another student, I was hoping to be teaching them more than just that one new skill. I hoped that I taught them that there is a wealth of information to be obtained from your peer group. Network and ask your classmates.

**Observation #12**: **Thank You, Newton!** Differentiation is a LOT FASTER than taking secant slopes – even if you know how to program your calculator! By the time we were introduced to the derivative, we were definitely ready for it.

**Summary**: It is now the end of the semester, and grades are in. Although I didn't formally register for the class, I did take all the exams, including the final. I attended every class when I was not out on travel. I did most of the homework. My grades on the exams were pretty good: I certainly achieved my original goal of relearning calculus.

**[2] The Teacher's Experience**

When the engineering professor first broached this idea I was immediately attracted, but for no concrete reason that I could articulate at the time. Mostly the positive feeling arose from my respect for her dedication to improving instruction at our institution. It also helps that we have a history of productive collaborations on educational initiatives at our institution. At the same time, through, there was a sense of trepidation. Probably no teacher is immune to a little doubt or nervousness when there is a peer or professional observer watching – and what she proposed was an entire semester of it. It's also worth noting that I had a weak understanding of why she wanted to do this. I have to admit that her claim of wanting to relearn Calculus seemed odd – and this seemed like a weirdly large investment of time to achieve that end. I was a bit skeptical, and suspected that she was just as much interested in a close-up look at teaching methods, at least as practiced by one person from the math department.

Although I did not have specific expectations of the value that the experience might provide, my intuition was that it would be both useful and interesting, and well worth any potential downside. It was easy to say "yes" to the proposal.

**Observation #1, A Different Audience:** Teaching is at some level a performance. There is usually a real-time feedback loop running in my head in which I am asking and answering questions like "Is this working?" "Are they getting it?" The engineering professor's attendance in my class has altered my sense of the audience. While I teach, I hear questions in my head. Often it's "Did she get that?" but I also extrapolate to, "If she is not getting this, surely others are not," and, "Looks like she is getting this. I wonder how it comes off to the others."

**Observation #2, New Signals:** When she looks puzzled, sometimes I'm not sure why. Is this because she doesn't get the math that was just explained, or is it meta-puzzlement? Maybe the math makes sense to her but she is wondering why I chose to say it that way or how on earth I could think that freshman would understand what I just said. Sometimes I wonder if she is puzzled-on-behalf-of-others. That is, she gets it, but worries that the students don't, and she's sending a signal so that I will notice and respond with an alternate explanation. Sometimes I wonder this when she asks a question, too.

**Observation #3, Student Questions:** I start almost all classes by checking to see if anyone has questions. The intent is to answer questions about last night's homework, but I take anything. It is not unusual for this to garner complete silence. Some of this is probably students' anxiety or fear of being the first to ask a question. The engineering professor breaks the ice. I'm never sure if she's asking about homework she struggled with or if she is acting as spokeswoman for other students. No doubt there is a spokeswoman effect, since it is not uncommon for students to take the approach of hoping that someone else asks about the problem that they got stuck on. Sometimes I worry if she does too much of this, since I want an atmosphere in which students are taking advantage of the question period and not just waiting, hoping someone else will ask. If she does a lot of this, students may come to rely on it rather than develop the habit of asking themselves.

**Observation #4, Introspection on Difficulty:** I find myself introspecting more than I normally would on the level of difficulty I have designed into the course. From ungraded homework all the way to the most difficult exam questions, I find myself wondering if she thinks this is too hard for first year calculus students, or perhaps too easy. I also wonder what she thinks about where this is all going. That is, why should students bother to learn this stuff (or more accurately, why should they be required to learn it)?

**Note:** Observations 1-4 reflect thoughts that were fairly prominent in my mind early in the semester; less so as the semester progressed.

**Observation #5, Facilitation:** Sometimes I want students to do work at their desks, either for a very brief period to warm up to what I want to talk about, or for most or all of the class period. The engineering professor helps this come off better than it might otherwise. Some of her contributions:

- She always jumps into the work. Sometimes the rest of the class is a little reluctant to get going and needs some prodding.
- She immediately involves a few other students sitting near her. Frequently the rest of the class needs more than a little prodding to do this.
- At the very least, this gets some small number of students immediately working and immediately involved in some sharing and discussion. Sometimes this seems to work as a social example and get other students to do likewise.
- When the student work occupies a full class period I like to move about the room keeping tabs on what each group is managing in the way of forward progress. There are 37 students, and usually a dozen groups, so I can't make rounds fast enough. Sometimes she will jump up and circulate also. This is *very* valuable on days that are primarily centered on student work. It is also a new experience for me to have an additional, equally able, facilitator to make the rounds. I seems like there is an opportunity here for me to learn a very different approach to group work that could rely on a number of sufficiently able facilitators and serve a potentially much larger group of students.

**Observation #6, Direct Feedback:** She is highly complimentary of my teaching. It feels shallow to care, but I do and it's nice. She is never not-complimentary. Nor has she offered specific advice or constructive (or other) criticism. If she did, it would probably bug me a little, and then I would feel shallow about that, too.

She should do it anyway. It seems likely that she has advice that she would like to share. It's possible that she feels constrained to silence by the social dynamics or by the nature of the experiment we are conducting. However, if what we are doing could possibly be a vehicle for increasing teaching effectiveness, then it must include an open channel for advice and constructive criticism.

**Observation #7, Classroom Dynamic:** When I was much younger it was normal for a more senior faculty member to conduct an occasional classroom observation. My recollection of this is that students were well aware of the unique situation on the day of an observation, and that there was a tangible difference in the classroom dynamic. Interestingly, I sense no such phenomenon generated by this observer. It could be because it's more of an every-day thing. It could be that she manages to convey a non-authoritarian presence, whereas other observers did. Maybe, her consistent attendance and her participation on homework and exams made her role one of student/learner, like them, rather than observer.

**Observation #8, Graded Work:** It is revealing to grade the engineering professor's work next to student work. She's pretty good. She gets most everything right, but then so do a lot of other students. But there is a huge difference in the quality of communication conveyed on her exam papers. I am intrigued, but unable to pin down what's actually happening here. Whatever she is doing it is very much what I (and probably many, many other college instructors) wish students would do. It is probably worth a close examination of what she does differently and how she learned to do it.

**Observation #9, Study Groups:** I believe that one of her goals is to foment the formation of stable study groups. It is unclear if her presence does this (except as noted already for in-class work). If so, it is also unclear if her presence changed what would have happened.

**Summary**: The entire experiment – having an engineering professor in my Calculus class – gave me a stronger sense of education as a collaborative effort instead of a solo act. I don't know how much I respond or adapt to her presence, but I do find myself searching out her face each morning. Without knowing why, it seems that my first thought at the beginning of each class is whether or not she's there.

### [3] Students' Perspectives Compared to the Professor and the Learner

Based upon reflections on the two professors' observations, we identified several main issues to pay attention to:

1. Importance of help-seeking and networking - Wouldn't it be important for students to provide and seek help to/from each other and to network with each other?
2. Expectations and effectiveness about collaborative homework - Are the instructor's and students' expectations/assumptions on collaborative homework same or different? Did students find the weekly graded homework as effective as intended?
3. Perceived effectiveness of instructional methods - Did students find the instructor's instructional strategies and characteristics to be effective?
4. Perceived effectiveness of multi-tasking during class - Did students understand the potentially negative effects of multi-tasking in classroom?
5. Effects of timed tests - Is our method of timed tests the best way to measure student competence?
6. Impacts of the engineering professor's presence on other students - Did her presence have an effect on students?

We then developed a survey questionnaire (see Appendix A) to measure students' perspectives on those identified issues. Thirty-seven students enrolled in this Calculus class. We administered the anonymous survey on the last day of the class without the presence of the math professor and the engineering professor in class – 30 students voluntarily submitted the survey (21 male and 9 female). The average age of the survey participants was 21 years old (*Min.* = 18, *Max.* = 32). The math professor and the engineering professor also independently completed the same survey to provide their perspectives.

**Finding #1: Importance of help-seeking and networking** (Q3-Q9)

Is it important for students to provide and seek help to/from each other and to network with each other? Research has shown that the answer is usually yes, although the help-seeking behavior is complex and often influenced by motivational and attitudinal factors[8].

Both the math professor and the engineering professor either *agreed* or *strongly agreed* that in order for students to be successful in this class, it would be important for them to provide help to, or seek help from, their classmates.

A majority of students (80%) also *strongly agreed* (33.3%) or *agreed* (46.7%) that it would be important to collaborate with their peers. Students perceived that about 3 or 4 members in a study group would be an optimal number (*M* = 3.43, *Min.* = 1, *Max.* = 6).

Students reported that they *occasionally* provided help to their classmates, sought help from them, and shared information with them. As shown in Figure 1, the engineering professor's observation supports the students' self-report on these help-seeking and networking behaviors, likely because of her experience as a student in class (see 2.7 vs. 3.0, 2.7 vs. 3.0, and 2.9 vs. 3.0 in Figure 1).

The more important students think it is to provide help to, or seek help from, classmates to be successful in the class,

- the more frequently they actually helped their classmates (*rho* = .606, $p < .001$)
- the more frequently they sought help from classmates (*rho* = .459, $p = .011$)
- the more frequently they shared useful information with each other (*rho* = .738, $p < .001$)

Several students reported difficulty in finding knowledgeable peers as a problem in trying to help or seek help (e.g., “they were as stuck as I was”). The engineering professor’s observation confirmed this problem; she recalled, “their fellow students may not have been able to help them. For example, when I was seeking help with my calculator, I had to consult with about 8 students before I found one who could help me.” The math professor also observed a similar issue during small group activities in class: “[I] did not have sufficient opportunity to observe students seeking help from each classmate. The only chances I had were during small group work in class. On those days my time is mostly spent on groups that are completely stalled.”

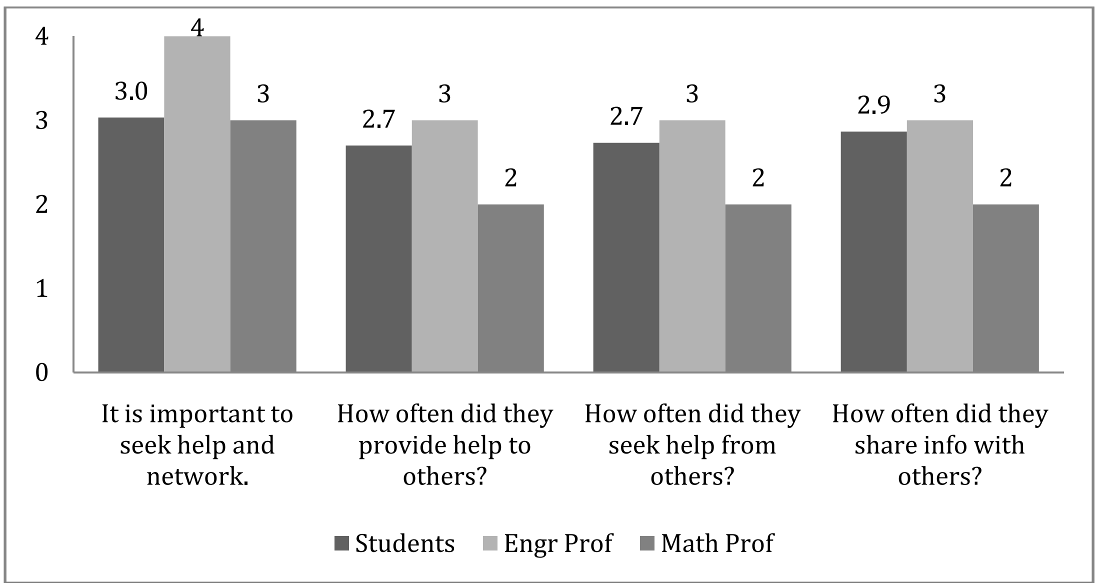


Figure 1. Importance and frequency of help-seeking and networking.
(1 = strongly disagree or never, and 4 = strongly agree or frequently)

**Finding #2: Expectations and effectiveness about collaborative homework** (Q14-Q18)

Students were assigned to complete weekly homework which was counted toward 16.7% of the total grade. All students except one thought that the weekly graded homework assignments *tremendously* (66.7%) or *fairly* (26.7%) helped them improve their knowledge in Calculus, which was supported by the math professor’s expectation and the engineering professor’s observation.

However, students tended to work in a study group for only *some* of the homework assignments (on a 4-point scale of none, some, most, and all), although they thought that it was *fairly effective* to work with classmates in a study group to compete their homework assignments. Students experienced difficulty in scheduling for meeting and not having anyone in their team capable of solving difficult problems.

Another possible reason is a lack of understanding of the instructor's expectation. A meta-analysis on the effects of small-group learning on undergraduate science, math and engineering courses has shown positive outcomes on academic performance, and attitudes toward and persistence in learning[9]. Supported by the meta-analysis, the math professor's expectation was that students were allowed to work with their classmates to complete their homework assignments. However, both the engineering professor and the math professor predicted that in the beginning of the class, students might have not been sure about whether they had to complete the homework assignments alone or collaboratively.

Indeed, the student survey showed that eighteen students (60%) knew from the beginning that they could collaborate with classmates to complete homework, but three students (10%) were not sure about the expectation and nine students (30%) thought they had to do it alone. In other words, 40% of the students (the last two groups) did not clearly understand the instructor's expectation in the beginning.

Overall, the students and the engineering and math professors shared similar perspectives about the frequency and effectiveness of collaborative work in a study group when completing homework assignments (Figure 2).

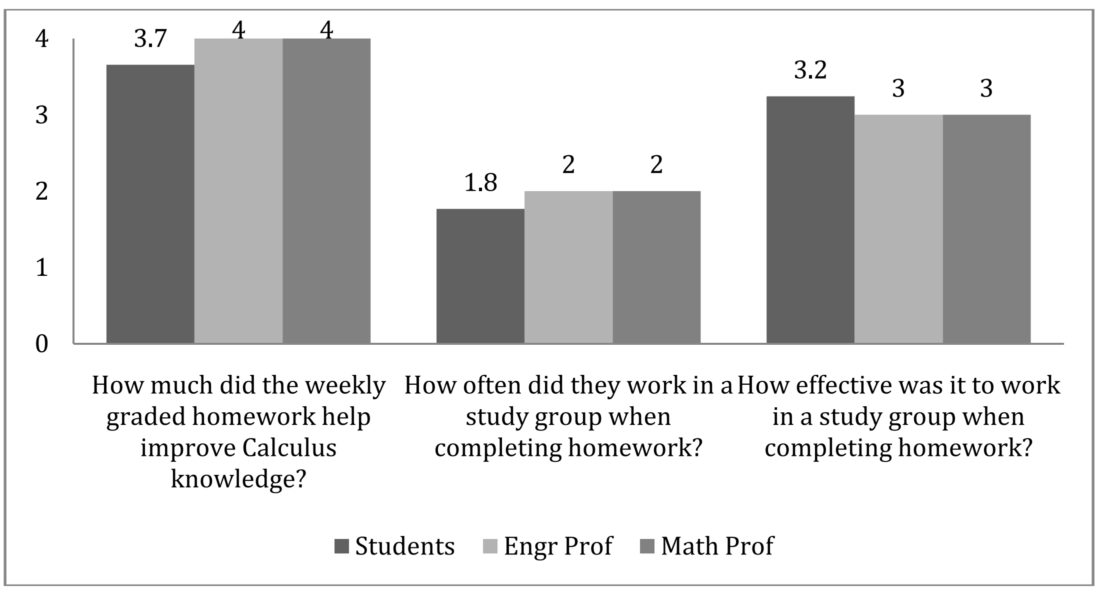


Figure 2. Frequency and effectiveness of collaborative work in a study group.
(1 = none or not effective, and 4 = tremendously, all homework, or extremely effective)

**Finding #3: Perceived effectiveness of instructional methods** (Q10-Q13)

What do the students think about the instructor's teaching strategies and characteristics? During the class, the engineering professor observed the math professor using several effective instructional methods – e.g., having a Q/A session in the beginning of each class, providing warm-ups exercises, showing a sense of humor, and having students work in small group activities. The students confirmed in the survey that those instructional methods were helpful (Figure 3). Encouraging students to ask questions in each class helps them self-monitor their understanding of Calculus and develop self-regulative behaviors, which likely facilitate higher learning outcomes[10]. Research has also shown positive outcomes of using small group activities in learning math[11, 12].

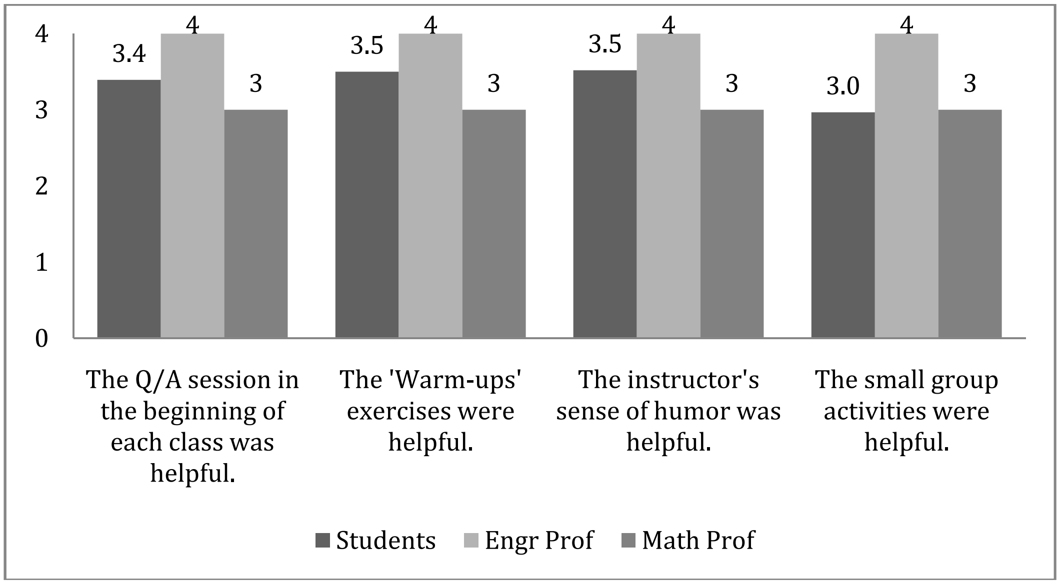


Figure 3. Perceived effectiveness of instructional methods.
(1 = strongly disagree, and 4 = strongly agree)

**Finding #4: Perceived effectiveness of multi-tasking during class** (Q19-Q21)

The engineering professor observed that some students engaged in off-tasks during the lecture such as reading and sending text messages, and she strongly believed that multi-tasking during the class would reduce learning effectiveness, as supported by research[13]. This multi-tasking behavior in class was confirmed by students' self-report, although students also shared the same belief that multi-tasking could reduce learning effectiveness (Figure 4). More than half of them (51.7%) either *frequently* (3.4%), *occasionally* (17.2%), or *sometimes* (31.0%) engaged in multi-tasking such as reading/sending text messages during the lecture, even though all students *strongly agreed* (75.9%) or *agreed* (24.1%) that it would be important to focus on lecture without multi-tasking.

The more confident in learning Calculus students were, the more strongly they agreed that it would be important to avoid multi-tasking during the class (*rho* = .432, *p* = .019).

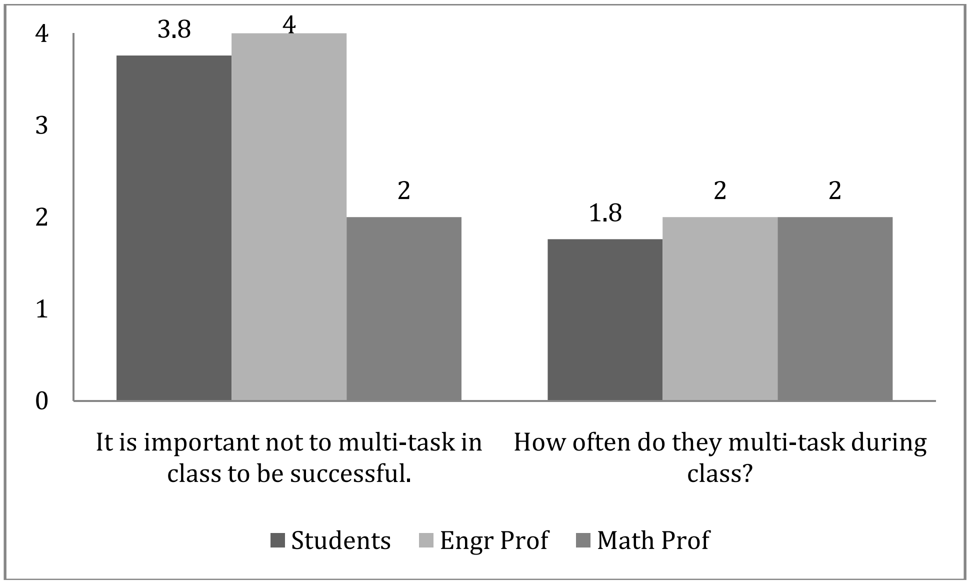

Figure 4. Perceived effectiveness of multi-tasking during class.
(1=strongly disagree or never, and 4=strongly agree or frequently)

**Finding #5: Effects of timed tests** (Q22-Q24, Q26)

Is timed testing an appropriate measure of student competence? Sixteen students (57.1%) reported that they *sometimes* had to submit a test without completing all questions because they ran out of time (also see Figure 5). Not surprisingly, the more strongly they *disagree* that speed is an important measure of student competence in Calculus, the more strongly students think they could produce a better score if they were given more time during the test (*rho* = -.457, *p* = .013). Also, students who experienced lack of time during the test tended to expect to receive a lower grade (*rho* = -.396, *p* = .037). Research seems to support these outcomes; one study has shown that both low- and high-achieving students performed better on their statistics exam under the ‘no time limits’ condition than under the ‘timed’ condition, and that students with high anxiety (often lower performers) had greater benefits from the untimed condition[14].

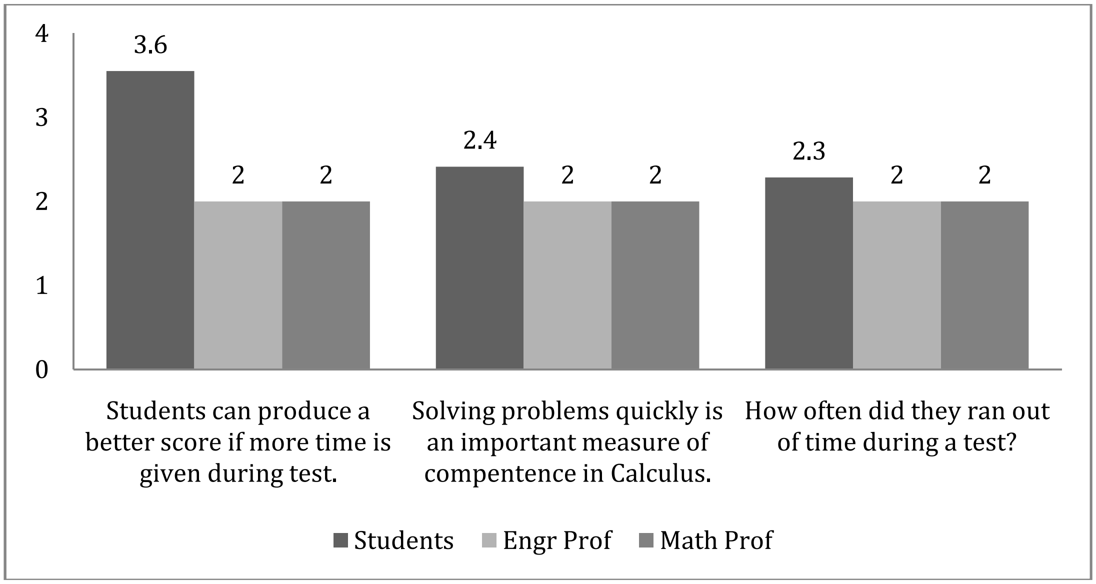

Figure 5. Effects of timed tests.
(1=strongly disagree or never, and 4=strongly agree or frequently)

**Finding #6: Impacts of the engineering professor's presence on other students** (Q27)

The engineering professor attended the Calculus class and engaged in class activities as other students did. She did not introduce herself as an engineering professor until the last week of the class. Did her presence have effect on other students in class?

Forty-eight percent of students reported that they thought she was just one of the students, and that her presence did not directly affect them. However, students reported various benefits they gained from her presence in class (Figure 6). Most of all, students acknowledged that her active involvement in class helped them ask more questions in class ($n$ = 11). This was one of things that the engineering professor was hoping for, and the math professor also pointed it out as one of the impacts that she made in class.

Students reported that her presence also helped them want to do homework with others ($n$ = 6), want to seek help when they needed help ($n$ = 6), pay attention to class ($n$ = 5), not to multi-task during the class ($n$ = 3), want to help other students when they needed help ($n$ = 3), and use their calculator more effectively ($n$ = 2).

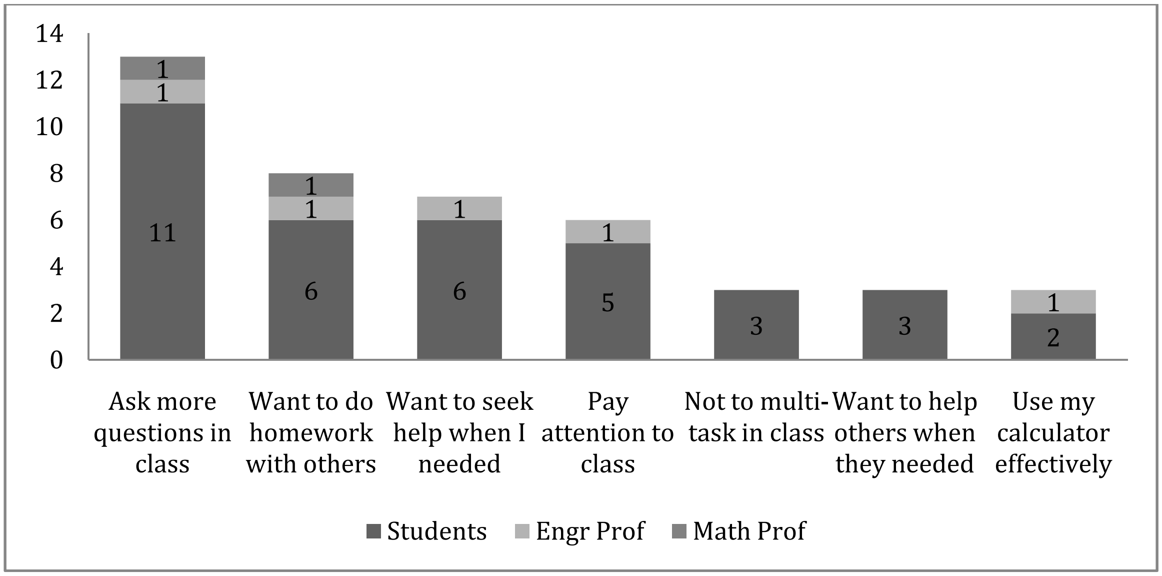


Figure 6. Impacts of the engineering professor's presence.

**[4] The Learner's Reflections**

In fall, 2011, I went to math class four days a week, from 8:40 to 9:30 a.m. I sat in the back of the class with other students who became my friends. Beyond content remastery, I gained an incredible perspective. I learned some new teaching tricks while also reconnecting with what it feels like to be a student. It is scary to be a student. We don't know some basic skills – how to network, how to use our calculators, how to study, how to focus, when it is and is not okay to study with others. As professors, we can help students with these skills, by actively talking about them. That is – in math, we can help students form study groups. We can encourage them to network when they get stuck on something. We can help them use their calculators. We can learn their names.

When asked during the semester what it was like to take calculus, and also in retrospect, I have this to say: "It was the favorite part of my day."

**[5] The Teacher's Reflections**

I could write another paper solely in response to thoughts generated by reading the comments from the engineering professor in section [1]. For brevity's sake I will restrict myself to a few of the more important lessons I believe I learned from this experience.

- I was a much more reflective teacher this semester, due wholly to the sustained presence of this colleague in my class.
- On a deeper level, my exposure to her written thoughts, and then subsequent iterations of my response to them and ensuing dialog, have proved to be much more valuable to me as an instructor than any amount of self reflection could ever be.
- The biggest single item from her observations that I plan to add to my teaching practices is to be deliberate about instructing students in successful habits.

Specifically, the formation of collaborative groups and an understanding of the value of homework. I've always known I should say more about these things, but semester after semester I end up not saying much. This needs to change.

- I am quite surprised by the how closely her and my answers to survey questions track with the average student responses. My *a priori* assumption was that students would display significantly different opinions and perceptions. I am particularly happy to see that students value homework.
- The two answers where there was significant distance between the students and the professors stand out. The first is the issue of time allowed on exams, which both professors felt was mostly irrelevant, while students felt it strongly affected performance. On this point I have no illuminating comment, other than that it is good to know their collective opinion.
- The other survey question with divergent answers was about student's multitasking during class. I felt it was largely irrelevant, but students and the observer felt it was very damaging (Even more than time pressure on tests!). I had long held a firm opinion about this – I assumed it was irrelevant because I think very little of what I say in lectures has much to do with student learning. I believe learning lives in the homework. What I do with my 50 minutes each morning is entirely aimed at inducing the doing of homework. For many students, direct instruction in how to work a homework problem is a pretty useful inducement, so I do a lot of that. On the other hand, there are many other ways for a student to find their way through a homework set. I don't presume to know whether or not watching me do examples is the thing that works for any particular student. If someone chooses to text instead of watching me, I would assume that this is because watching me work examples isn't what gets them traction on homework problems.

  However, the student response to this question is too extreme for me to remain comfortable with my prior belief. Clearly this bears additional thought. And perhaps it calls for a change in tactics in the classroom.

**[6] Specific Actions Taken**

As a result of reflecting deeply on both sides of the equation, learner and teacher, and the vast number of unintended positive consequences associated with the semester's experiences, we recommend and/or are institutionally adopting the following specific actions:

- A calculator "help session" will be offered in spring, 2012.
- We plan to support mathematics instructors who may be interested in taking a follow-on course, e.g. physics with calculus, in order to foster deeper relationships between instructors in different fields, student-centric teaching, share and learn teaching best practices and to help teach how mathematics is applied to solve problems in different fields.
- The chair of mathematics and the engineering professor hosted an informal brown-bag seminar, to discuss and disseminate their observations in December of

2011. It was the best attended STEM brown-bag lunch held at this university, with 21 attendees.

- The engineering professor wrote and published in the engineering student newsletter, “Become an Instigator (Instigator: leader, mastermind, troublemaker).” It shared her experiences as a calculus student and actively encouraged them to “become instigators in their classes.” To set up study groups; to speak with the person sitting next to them in class[15]. A follow-on student article is planned.
- Calculator functionality will be incorporated into the Introduction to Engineering class, which is taken concurrently with Calculus I at this university.
- The engineering professor plans to skip Calculus II and go right into Calculus III in spring, 2012. Wish her luck!

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**Appendix A. Student Survey**

Please respond to each question with your best answer. It is an anonymous survey and your name will not be associated with your responses.

Q1. I am __ male __ female.

Q2. I am ___ years old.

Please think about this class when you answer the following questions.

Q3. I think that it is important to provide help to, or seek help from, my classmates, in order to be successful in this class.
__ Strongly agree __ Agree __ Disagree __ Strongly disagree

Q4. How often did you provide help to your classmates in this class?
__ Frequently __ Occasionally __ Sometimes __ Never

Q5. How often did you seek help from your classmates in this class?
__ Frequently __ Occasionally __ Sometimes __ Never

Q6. How often did you share useful information with your classmates?
__ Frequently __ Occasionally __ Sometimes __ Never

Q7. When you need help with using your calculator, how likely are you to ask a classmate or friend for assistance?
__ Very likely __ Somewhat likely __ Somewhat unlikely __ Very unlikely

Q8. How many members in a study group do you think works best?
_____ members (including yourself)

Q9. If any, what problems did you experience while seeking help from your classmates?

Q10. My instructor's question/answer section in the beginning of each class was helpful.
__ Strongly agree __ Agree __ Disagree __ Strongly disagree
__ I don't remember having a question/answer section in the beginning of each class.

Q11. My instructor's "Warm-ups" exercises were helpful.
__ Strongly agree __ Agree __ Disagree __ Strongly disagree
__ I don't remember the "Warm-ups" exercises he used.

Q12. When my instructor showed a sense of humor during the class, it helped me learn the material better.
__ Strongly agree __ Agree __ Disagree __ Strongly disagree __ It did not matter.

Q13. The small group activities in this class helped me actively engage in learning.
__ Strongly agree __ Agree __ Disagree __ Strongly disagree
__ I don't remember having small-group activities in class.

Q14. In the beginning of the semester,
__ I thought I had to complete the homework assignments alone.
__ I knew I could complete the homework assignments with classmates in a study group.
__ I was not sure about whether I had to complete the homework assignments alone or if I could complete them with classmates in a study group.

Q15. How often did you work in a study group to complete your homework assignments?
__ All homework assignments
__ Most of the homework assignments
__ Some of the homework assignments
__ None of the homework assignments

Q16. How effective do you think it is to work with classmates in a study group to complete homework assignments?
__ Extremely effective __ Fairly effective __ Fairly ineffective __ Not effective at all

Q17. If any, what problems did you experience while working with classmates in a study group to complete homework assignments?

Q18. How much do you think the weekly graded homework helped you improve your knowledge in Calculus?
__ Tremendously __ Fairly __ Just a little bit __ Not at all

Q19. I feel confident about my ability to learn Calculus.
__ Strongly agree __ Agree __ Disagree __ Strongly disagree

Q20. I think that in order for me to successfully learn in this class, it is important that I focus on the instructor's lecture without multi-tasking such as reading/sending text messages.
__ Strongly agree __ Agree __ Disagree __ Strongly disagree

Q21. How often do you multi-task, such as reading/sending text messages, while listening to this math instructor's lecture?
__ Frequently __ Occasionally __ Sometimes __ Never

Q22. In this class, I think I can produce a better test score if I am given more time during the test.
__ Strongly agree __ Agree __ Disagree __ Strongly disagree

Q23. Solving problems quickly is an important measure of student competence in Calculus.
__ Strongly agree __ Agree __ Disagree __ Strongly disagree

Q24. How often did you have to submit a test without completing all questions because you ran out of time?
__ Frequently __ Occasionally __ Sometimes __ Never

Q25. After solving a problem, how often do you ask yourself, “Is this a reasonable answer? Does it make sense?”
__ Frequently __ Occasionally __ Sometimes __ Never

Q26. I think my grade in this class at the end of the semester will be:
__ A __ B __ C __ D __ F

Q27. In what way did the engineering professor’s presence in class affect you? Select all that apply.

Her presence in class helped me:
__ pay attention to class
__ ask more questions in class
__ want to help other students when they need help
__ want to seek help when I need help
__ not to multi-task during the class
__ want to do homework with others
__ use my calculator more effectively
__ Others – please describe:

Q28. Please describe your experience in having the engineering professor in your class, and provide any suggestions.

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