TEACHING AND LEARNING IN UNDERGRADUATE SCIENCE & ENGINEERING

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INTRODUCTORY ESSAY

Research on undergraduate education in the sciences, technology, engineering, and mathematics (STEM) has shown that effective teaching promotes student engagement, achievement, and retention in these fields, particularly for underrepresented groups. Yet undergraduate instructors commonly enter the classroom with no prior preparation for teaching. Institutions and professional associations are increasingly investing in pedagogical initiatives to improve STEM instructors’ effectiveness and, thus, student outcomes. Some programs are targeted to current faculty members, with attention to both teaching practice and the significant organizational barriers that hinder pedagogical change in departments and schools. Others target those in the academic pipeline in hopes of creating new cohorts of STEM professionals prepared for and committed to effective instructional practice. Most “Preparing Future Faculty” programs serve graduate students, but undergraduates with faculty aspirations may also benefit from training in education. Such programs would support students in identifying and developing their attitudes and commitments to teaching during their most formative period. Additionally, such courses could cultivate undergraduates’ metacognitive skills—understanding themselves as learners—which have been shown to improve learning and engagement.

The half-semester course described below, offered at an engineering college in the northeastern U.S., was designed to build a foundation for future science and engineering educators’ pedagogical expertise.

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1 There is an extensive body of research and practice reports on undergraduate education in these fields. In addition to publications included in the syllabus, recent high-profile attention to the state of the field can be found in a series of reports from the National Academy of Sciences (http://www.nap.edu/topics.php?topic=350) and through the Association of American Universities’ 2011 Undergraduate STEM Education Initiative (http://www.aau.edu/policy/article.aspx?id=12588).


3 See, for example, The Preparing Future Faculty Program at http://www.preparing-faculty.org/.


Its aims and objectives were devised based on interviews and site visits to understand students’ backgrounds and needs and the institution’s culture and aims. The course was meant primarily for juniors and seniors—those who had identified areas of specialization and had begun shaping their professional goals (most expecting to become engineering professors and/or concurrently working as teaching assistants)—but interested underclass students and cross-registrants from an affiliated liberal arts institution were welcomed. Insights from the scholarship on learning and teaching, along with this sense of the course context and purpose, informed the instructional design.  

The course emphasized active engagement with selected concepts and practices in STEM education. The fifteen participants functioned as a teaching community, working through discussions, small- and whole-group tasks, and projects to analyze and apply new ideas. Rather than treat the course materials as a “playbook” of best theories and practices to adopt, our efforts focused on whether and why a given approach is considered successful, when and how it should be used, and how it might be adapted or extended. Class sessions often turned “meta” as we modeled practices from the reading or discussed how our own in-class experiences related to those the participants were studying and practicing.

Over the term, each student crafted, taught, and reflected on an original lesson on a STEM topic of their choosing. Weekly writing assignments served as a scaffold for this larger project by supporting students in connecting insights from research, theory, discussion, and experience to problems of practice (and from practice back to theory and discussion). Together, the writing assignments and lesson materials comprised a teaching portfolio that served as an “authentic” tool for learning and assessment, as it challenged students to apply and represent their knowledge and skills in the same way professional teachers do. Indeed, the portfolio is intended to be a living professional resource that will change and grow in tandem with participants’ careers.

In their feedback, students reported that the course enriched their understanding of STEM education in various ways: they felt better prepared to teach, more reflective about and engaged in the pedagogy of their other courses, and more committed to their own learning processes. They appreciated that the course helped them link research and theory to practice, provided meaningful hands-on experience, and welcomed diverse viewpoints. Student suggestions focused on logistics—they proposed shorter but more frequent class meetings held later in the day, and more time for projects, reading, and discussion.

6 The scholarly literature is extensive; for examples and additional sources specific to undergraduate STEM education, see Peter C. Taylor, Penny J. Gilmer, and Kenneth Tobin, eds., Transforming Undergraduate Science Teaching: Social Constructivist Perspectives (New York: Peter Lang, 2002).

7 Lee S. Shulman, “Teaching as Community Property: Putting an End to Pedagogical Solitude,” Change 25, no. 6 (1993), 6-7.

8 Stephen D. Brookfield, Becoming a Critically Reflective Teacher (San Francisco: Jossey-Bass, 1995).


10 Since completing the course, a number of students have used their portfolios to obtain teaching jobs in universities and high schools, while others have become teacher-leaders in their graduate programs.

11 One student even commented that our emphasis on relating theory to practice had reshaped his/her approach to engineering problems!
The course was considered a successful proof-of-concept in educational coursework at the college, and student feedback informed its adoption and expansion to a full-semester elective.

The syllabus below can be adapted to serve a particular institution or group, including graduate students and current instructors, and may be updated to incorporate new developments in STEM education. Instructors offering such a course are advised to consider limiting enrollment or enlisting teaching assistants to support the active and creative learning described here.

SYLLABUS

This course will examine select topics in teaching and learning in undergraduate science, technology, engineering, and mathematics (STEM) courses. The goal of the course is to help participants become effective tutors, teaching assistants, mentors, and future instructors in these fields. In a seminar format, participants will discuss research on best practices in pedagogy and curriculum design, cognition and learning, student classroom experiences, diversity, and assessment. Participants will gain experience in instructional design, pedagogy, and assessment, and will develop a teaching portfolio.

OBJECTIVES

This course is designed to help participants become more effective science and/or engineering teachers, particularly at the undergraduate level. By the end of the course, students will: 1) be able to read, discuss, analyze, and critically evaluate research-based approaches to learning and teaching in science and engineering, 2) apply and adapt findings from the educational literature to their own STEM teaching interests, and 3) design, implement, and demonstrate their own successful pedagogic approaches.12

COURSE FORMAT AND EXPECTATIONS

This course is intended to become a space where we will co-construct knowledge about effective and exciting teaching that is relevant to your interests and professional goals. To get the most out of this course, you should be prepared to engage deeply and participate vigorously in the course discussions and activities. You should complete all reading assignments before class and come prepared to analyze, synthesize, and extend the readings with your classmates. You will also be asked to share your experiences and writings about teaching, and we will sometimes “workshop” ideas and skills with the class. You should be open to giving and receiving constructively critical feedback, to trying on and trying out new ideas. The collective knowledge and experience we share will form a foundation for your ongoing work as educators and learners.

12 The objectives of this course were devised in reference to a set of core competencies the institution aims to cultivate in its students. Among these are: qualitative analysis of problems, communication (oral and written), lifelong learning, and developing creative and effective designs to solve real problems.
A SPECIAL NOTE ON DIVERSITY

We will discuss issues surrounding diversity and STEM education throughout the course and will devote some special attention to the topic in week 6. This approach is intended to highlight the importance of diversity by acknowledging that creating inclusive learning environments is both an everyday concern, related to all aspects of instruction, and a special topic worthy of concentrated attention.

ASSESSMENT

Your progress toward the objectives outlined above will be assessed through weekly written assignments, a final project, and in-class activities and discussions based on the assigned readings. Course grades will be allocated as follows: class participation (15%), six individual written assignments (10% each), and final project (25%).

ASSIGNMENTS

PARTICIPATION

You are expected to attend each class session. If you must miss a class meeting due to illness or extenuating circumstances, please let me know in advance. To compensate for missing class, I will ask you to write an essay about the week’s readings in order to support you in engaging with, analyzing, and extending the material.

You should read all of the assigned readings before class and arrive prepared to discuss them in depth. All readings will be available through the course website, along with a handout providing background and context for the reading and a set of guiding questions. During some weeks, you will be asked to prepare a presentation or lead discussion in class; this will constitute a portion of your participation requirement.

WEEKLY WRITTEN ASSIGNMENTS

Each week you will be asked to complete a short written assignment (typically 1-2 pages) designed to contribute to your understanding of and skills in STEM teaching. These assignments provide a basis for the final project, described below. I will provide details about each assignment in class, along with criteria for evaluating them.

The schedule of weekly written assignments is:

1. Description of your topic, learners, and objectives (due Week 2).
2. Analysis of the cognitive dimensions of your teaching project (due Week 3).
3. Draft lesson/unit plan, including one or two of the pedagogical approaches discussed in class, and a brief analysis of why and how these approaches suit your learners, their cognitive habits, and your objectives (due Week 4).
4. Analysis of your lesson plan in light of the research on student experiences, along with a discussion of how you will adapt your plan to account for that research (due Week 5).

5. Draft of assessment plan and tools, and a brief analysis of how this plan addresses your objectives and suits your pedagogical choices (due Week 6).

6. Brief essay on addressing diversity in your lesson/unit plan (due Week 7).

Essays will be evaluated using a rubric based on the following criteria:

- Meeting the deadline, length, and content requirements.
- Clarity and organization of the writing.
- Thoroughness.
- Logic of the analysis, including evidence where appropriate to justify choices.

**FINAL PROJECT**

The final project for this course is to develop, practice, and analyze a lesson or unit on some scientific or engineering topic. Your lesson or unit should be designed to take anywhere from 1-3 hours of instructional time, and may be contained to a single period or spread across several sessions. Your design should be grounded in the course content and so should reflect your thoughtful consideration and incorporation of topics addressed throughout the term (e.g. theories of learning, effective assessment, etc.). In particular, you should investigate and incorporate into your lesson/unit some pedagogical innovation(s) that we have discussed during the course, or that you identify and discuss in advance with me. You should also conduct at least one practice teaching session outside of class and, if possible, record it. (More specific guidelines and suggestions will be provided in a separate document.) You will be able to complete your final project based on class readings and discussions, but your learning experience and your project will be even richer if you consult additional resources on your chosen content, learners, pedagogies, and assessment techniques. I will provide advice on finding these resources.

*Important note about working with minors: If you intend to devise a project for learners under 18 years of age, you will need to obtain parental permission for their participation in your practice session. Please make an appointment to talk with me about this by Week 2.*

You will demonstrate completion of this project in the final weeks of class by delivering an in-class presentation on one aspect of your project and by submitting a teaching portfolio. Presentations will be on the last day of class; these will be open to the college community. The length of your oral presentation will depend on course enrollment. We will discuss the goals and content of these presentations in detail; they will focus on analyzing a dilemma or puzzle you confronted in developing and teaching your lesson.

Your portfolios are due one week after the last class. These may be in digital or print form. They will be modeled on those required by faculty search committees in higher education. An increasing number of colleges and universities require individuals applying for faculty positions to submit a portfolio to demonstrate experience and expertise in teaching. (Most K-12 schools also require portfolios of job
applicants, though the contents may vary from those of teachers in higher education. Since this course is primarily focused on undergraduate teaching, we will use the standard higher education portfolio as our model.) As the job market in higher education becomes more competitive, and as institutions become more focused on improving teaching and learning, a candidate with a solid teaching portfolio will often stand out over candidates who do not ably demonstrate their commitment to teaching. The portfolio you create in this course is intended to be a starting place—it should grow and change over the years ahead along with your experience and goals.

Your submitted portfolio should include:

1. The lesson or unit plan you develop in this course.
2. Teaching materials you develop throughout the term for use with this lesson (e.g. handouts, assignments, activities, models or simulations, etc.).
3. Essay about your lesson (adapted from weekly assignments, but revised and updated based on my comments or our discussions, changes in your thinking, and/or your practice teaching).
4. A teaching philosophy statement.
5. Any prior teaching materials or a resume of prior teaching experience, if available.
6. Samples of student work, recordings or photos of your teaching, and/or evaluations of your teaching, if available.

ASSIGNMENT SCHEDULE GRID

<table>
<thead>
<tr>
<th>Week</th>
<th>Readings</th>
<th>Written assignments due</th>
<th>Participation (in addition to participating in class each week)</th>
<th>Ongoing, final project-related work</th>
<th>Optional</th>
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<tbody>
<tr>
<td>By Week 1 class meeting</td>
<td>Readings</td>
<td></td>
<td>Brainstorm topic and learners</td>
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<tr>
<td>By Week 2</td>
<td>Readings</td>
<td>Essay on topic, learners, objectives</td>
<td>Identify target learners and arrange a practice date</td>
<td>Conduct a “baseline” practice session</td>
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<tr>
<td>By Week 3</td>
<td>Readings</td>
<td>Analysis of cognitive dimensions</td>
<td>In-class presentations on pedagogy readings</td>
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<tr>
<td>By Week 4</td>
<td>Readings</td>
<td>Draft lesson, with analysis of pedagogical choices</td>
<td>½ of class leads reading discussion</td>
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<tr>
<td>By Week 5</td>
<td>Readings</td>
<td>Analysis of student experiences</td>
<td>½ of class leads reading discussion</td>
<td>Draft your teaching philosophy</td>
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<td>By Week 6</td>
<td>Readings</td>
<td>Draft of assessment plans and analysis</td>
<td></td>
<td>Complete a practice teaching session</td>
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<td>By Week 7</td>
<td>Readings</td>
<td>Essay on addressing diversity; final presentations</td>
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<td>Compile portfolios</td>
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<tr>
<td>By Week 8</td>
<td>Readings</td>
<td>Portfolios due</td>
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**TECHNOLOGY**

I ask that you to video- or audio-record your teaching practice sessions, if possible. You may check out A/V equipment from the college’s IT services. You may upload your recordings to the course website, provide me with a link to your own site, or turn in a disc or flash drive. I will provide comments, but the main purpose of making these recordings is to facilitate self-assessment: they offer a chance to identify your stumbles and successes, and, importantly, to see how your thinking and skills are changing over time.

**ON-CAMPUS SUPPORTS**

While I consider myself a resource for all of you, there may be times when you want advice or support from someone else. Students seeking guidance and feedback on their writing are encouraged to contact the college’s writing tutors. Students seeking additional resources on STEM education or advice on research strategies are encouraged to consult with the library staff.

**HONOR CODE**

Students are expected to comply with the college’s honor code. Your work must be entirely your own and, when informed by other individuals or written sources, should include citations of all resources consulted.
TIMELINE

WEEK 1: PURPOSES, OBJECTIVES, & CURRICULUM IN SCIENCE AND ENGINEERING EDUCATION

READINGS:


OPTIONAL ADDITIONAL READING:


IN-CLASS ACTIVITIES:

- Introductions, including a description of a ‘best’ or ‘worst’ experience in a science or engineering course. These personal experiences are framed as a foundation on which we will build new learning.
- Brief discussion of course objectives and syllabus. (Each successive class meeting begins with a list of the day’s objectives.) Establish a climate of collaboration and active participation by engaging students in interpreting/extending the course purposes—why might this course be offered, what should it achieve, what makes college education different from high school?
• Small group activity: define ‘science’ and ‘engineering.’ Share definitions with another group and then revise in original group. Full-group discussion: How hard is it to describe the broad disciplines we’re trying to teach? How may differences in our definitions shape our teaching approaches?
• Full-class, seminar-style discussion of readings. Guiding questions focus on synthesis and comparison, and on connecting the readings to students’ ‘best/worst’ experiences and goals.
• Small-group analysis of sample course descriptions and syllabi, drawing on concepts from the readings and discussion.
• Sign up for a topic to research and present in Week 3.

Assignment due by Week 2 class meeting:
• Description of your topic, learners, and objectives.
• Optional: Conduct a brief practice teaching session with a volunteer and write a paragraph (approximately 250 words) reflecting on the experience.

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WEEK 2: COGNITION AND LEARNING IN STEM
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READING:
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OPTIONAL ADDITIONAL READING:
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**IN-CLASS ACTIVITIES:**

- Mini-lecture: background on constructivism in STEM education, including the role of prior learning, schemata, active and meaningful learning, models and analogies, and critiques.
- Full-class discussion of the film and readings, including how these relate to one another and to previous course topics.
- Small-group activity: Identify characteristics of good explanations and problem-solving strategies. Share in the full group, then provide handout summarizing research-based suggestions.
- Small-group activity: Each group analyzes a different sample lesson plan, focusing on how the plan engages concepts from the reading and discussion, any promising or problematic aspects, and suggestions for revision. Groups present their findings for discussion and feedback.
- Workshopping: Student pairs discuss ways of applying ideas about cognition and learning to the lessons they proposed to develop.
- Sign up to lead discussion in Weeks 4 and 5.

Assignments due by Week 3 class meeting:

- Analysis of the cognitive dimensions of your teaching project. (See Appendix for guidelines; rubric available on request.)
- Prepare group presentations on pedagogy.

**WEEK 3: PEDAGOGY**

**READING:**


Additional readings on particular pedagogies will be assigned to your group.

OPTIONAL ADDITIONAL READINGS:


Acitelli, Linda, Beverly Black, and Elizabeth Axelson. *Learning and Teaching During Office Hours*. Ann Arbor, MI: Center for Research on Learning and Teaching, University of Michigan, n.d.

IN-CLASS ACTIVITIES:

- Present framing questions for thinking about peers’ presentations.
- Student presentations on prevalent or innovative pedagogical approaches and tools. In this iteration of the course, students presented on: concept mapping, simulations and animations, small group work, clickers, effective lecturing, case studies, and problem- and project-based learning. Presentations required analysis of what future teachers would need to know about a given topic, including any relevant research findings, potential benefits and drawbacks, subjects and students it best serves, and resource and logistical demands. Presenters modeled the tools and practices. Q&A followed.
- Full-class discussion of presentations, focused on comparative and synthetic analysis and relation of tools/approaches to previous discussions of educational objectives, cognition and learning, and disciplinary and institutional contexts.
- Workshopping: Small-group discussions of pedagogical approaches and tools to use in students’ lessons.

Assignment due by Week 4 class meeting:

- Draft lesson/unit plan, including description of pedagogical choices and a brief analysis of why and how these approaches suit your learners, their cognitive habits, and your objectives.
WEEK 4: STUDENT EXPERIENCES IN STEM CLASSROOMS

READING:


OPTIONAL ADDITIONAL READINGS:


IN-CLASS ACTIVITIES:

- Small-group discussion of readings, focused on how experiences and affect relate to learning and how affect is related to cognition, pedagogy, and students’ lesson plans.
- Faculty panel: Full-class discussion about teaching and learning in science and engineering with college faculty members. Drawing on coursework, students raised questions and directed the discussion.
- Mid-course feedback survey.

Assignment due by Week 5 class meeting:

- Analysis of your lesson plan in light of the research on student experiences, along with a discussion of how you will adapt your plan to account for that research.
WEEK 5: ASSESSMENT OF STEM LEARNING

READING:


OPTIONAL ADDITIONAL READINGS:


IN-CLASS ACTIVITIES:

- Student-led small-group discussion of readings, followed by full-class discussion, with attention to how assessment readings relate to prior course topics. Full-class debriefing on the discussion-leading process.
- Small-group activity: Develop a possible assessment tool for final presentations in this course. Assessments should tie together the assignment description, course objectives, and institutional student learning goals.
- Full-group activity: Class discussion and critique of each of three designs. In the original iteration of the course participants voted to refine and implement both a self-assessment and a peer-assessment instrument, in addition to the instructor’s assessment, for final presentations.
- Workshopping: Discussion in small groups focused on shaping an assessment plan for students’ lessons.

Assignment due by Week 6 class meeting:

- Draft of assessment plan and tools, and a brief analysis of how this plan addresses your objectives and suits your pedagogical choices.
WEEK 6: DIVERSITY AND STEM

READING:


OPTIONAL ADDITIONAL READINGS:


IN-CLASS ACTIVITIES:

• Establish safe classroom climate for discussion, advising students to respect different views and ways of speaking about diversity issues and reminding students that no one person represents any group of people.

• Small-group discussion: Use various grouping strategies (think-pair-share, pair-square-share, square-share) to discuss three case studies of students’ experiences feeling marginalized in STEM classrooms (see Appendix). Prompts ask students to consider the perspectives of each actor, how each handled the situation, how the situation related to their own experiences or observations, and suggestions for how it could be handled.

• Full-group discussion: How do these case discussions inform your thinking about inclusive learning environments and your role as a teacher?

• Workshopping: Discussion and feedback on lesson plans and presentation plans.

Assignment due by Week 7 class meeting:

• Brief essay on addressing diversity in your lesson plan.
WEEK 7: STUDENT PRESENTATIONS

READING:


IN-CLASS ACTIVITIES:

- Student presentations, including discussion and student-developed peer- and self-assessments.

WEEK 8: FINAL TEACHING PORTFOLIOS DUE

APPENDIX: SAMPLE COURSE MATERIALS

SAMPLE ASSIGNMENT GUIDELINES

Due Week 3: Analysis of the cognitive dimensions of your teaching project

This week’s readings and discussions focused on cognitive aspects of science and engineering learning. For your writing assignment, please craft a 400-600-word analysis of your lesson/unit topic in light of our study of cognition and learning. Some of the questions you might consider addressing are: What cognitive challenges does your topic present for your group of learners? What kind of learning needs to take place, and how do you think you might foster it? What might different theories or researchers suggest that you address in your teaching? If different scholars would suggest contradictory approaches, which is better suited to your goals? Why and how?

Outside of class, you should be using these thoughts and others’ feedback to refine your ideas in preparation for your final project.

Your essay will be evaluated based on the following criteria:

1. Meeting the deadline and length requirements.
2. Clarity and organization of the writing and thoroughness of the essay.
3. The logic connecting insights from the readings and discussion to your lesson/unit.

E-mail me your essay by 9 am before our Week 3 class meeting, in a Word or text file. Bring a copy to class for workshopping with your peers.
SAMPLE IN-CLASS ACTIVITY: WEEK 6 CASE STUDIES

CASE 1


Mark was a freshman in Professor Peterson’s introductory physics class. He spent most of his time studying for just this class but, regardless of the time and effort he spent studying, he got C’s on the assignments and exams. “It was difficult for me to accept this because I was used to earning A’s in my classes throughout high school,” he said later. He started studying well in advance of the midterm and was determined to prove to himself that he could get an A. He stared blankly at the page when Professor Peterson returned his exam with a “C.” Mark felt like a failure and didn’t understand what he was doing wrong. He went to meet with Professor Peterson to talk about how to improve his grade in the class.

He said, “Hello Professor, I wanted to discuss some problems that I’m having in the class. I’m having a difficult time grasping some of the concepts from the lecture…and no matter how much I study I can only manage to get C’s on all of the assignments and exams…I spent so much time studying for the mid-term…I just don’t understand what I did wrong.” Later he remembered, “I was so upset that I began to get emotional. I felt worthless. I felt as if I couldn’t do anything to improve my grades because I simply wasn’t capable.”

If you were the professor, what would you say to this student? What kind of questions might you ask?

Professor Peterson proceeded to ask several questions. Then she said something that took Mark by surprise. “Maybe you’re having a difficult time grasping the material that we are learning in class because you are of a different background. How long have your parents been in the United States?”

What do you think Professor Peterson was thinking or trying to accomplish by asking this question?

What are some different ways the student might interpret Professor Peterson’s remarks?

CASE 2

(Adapted from Sanders, Jo, Janice Koch, and Josephine Urso. Gender Equity Sources and Resources for Education Students. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 1997.)

You are teaching in a well-equipped computer lab. Each student has his or her own computer and is working alone. You notice that many of the women in the class seem to be bored. You have read educational research suggesting that women are often happier working in groups, so you assign all your students to mixed-gender groups and ask them to continue to work collaboratively.
Is this approach likely to be successful? Why or why not?

You now notice that the women in the groups you have assigned are the secretaries and errand-runners, while the men are making the decisions and doing the hands-on work at the computers.

Consider the consequences, for the women and men in the class, of various courses of action open to you. What do you do?

CASE 3

(Adapted from Sanders, Koch, and Urso, Gender Equity Sources and Resources for Education Students.)

You are teaching a class and you have just called on Junie to answer a question. She looks confused. Before she has a chance to say anything, Mark mutters to a friend, but loudly enough for everyone to hear, “She’ll never get it - don’t bother.”

You could:

- Ignore the comment
- Disagree, saying Junie may be able to answer the question
- Agree, saying that after all, Junie is trying hard
- Reprimand Mark mildly
- Reprimand Mark harshly
- Tell Mark to leave your class and return only when he can be civil
- Hold a class discussion on insulting behavior

Consider the consequences for Junie, Mark, and the rest of the class of various courses of action open to you. What is the best thing you can do?

Would your response be any different if you knew that Junie felt isolated being the only Latina student in the class? Why/why not? If so, how?