Facilitating the Transition of a Traditional Engineering Course to a Structured, Active, In-Class Learning Environment as a Teaching Assistant

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Introduction

Active learning techniques, when properly implemented, have been shown to improve learning compared to traditional lecture. A review of active learning by Prince found broad support for active, collaborative, cooperative, and problem-based learning.[1] Specifically, a meta-analysis revealed that small-group work, one form of active learning, promotes enhanced academic achievement, more favorable attitudes toward learning, and increased persistence in STEM fields.[2] Despite the strong evidence, many college engineering courses uphold the status-quo, lecture-only format because changing the structure of a course takes considerable time, planning, and foresight. Particularly, faculty perceptions of institutional rewards for productive research over teaching provide little incentive for course improvement.[3]

Teaching assistants (TAs) can be valuable resources in facilitating the transition of a traditional engineering course to include active learning techniques; however, prior studies indicate that people tend to teach how they were taught,[4] contributing further to this lack of course reform. TA training can help prepare graduate students to teach in this new course structure. Various TA training workshops,[5] courses,[6,7] boot-camps,[8] and certificates[9] have been successful at preparing graduate students to teach; however, few papers have outlined ways in which TAs can work together with instructors to transition a course to an active format.

In this paper, we discuss *tricks of the trade* in how TAs can play a pivotal role alongside instructors in the course restructuring process. We provide a step-by-step outline to create and implement new classroom activities and demonstrate use of this outline through specific application in the recent restructuring of a bioengineering course. This methodology, presented in "Structured, Active, In-Class Learning (SAIL) TA Training" and an "Active Learning in STEM Courses" mini-course, both offered by the University of Pennsylvania's Center for Teaching and Learning (CTL), is used to form the basis of the goals of this paper. Specifically, we address 1) defining and communicating course goals, 2) designing activities to support these goals, 3) facilitating positive student group dynamics, 4) providing student feedback, and 5) reflection. It is important to note that this is a collaborative process between the course instructor and TA, so the steps in this system involve both parties.

Background

The "Active Learning in STEM Courses" mini-course is a series of four 2-hour sessions led by two staff members of the University of Pennsylvania's CTL. The objective of this mini-course is to introduce graduate students and post-docs to active learning techniques and how to create activities that reinforce and strengthen course goals. This objective is different from the "SAIL (Structured Active In-class Learning) TA Training" (also led by the same two staff members of the CTL), which aims to prepare TAs for facilitating (rather than designing) activities already defined by the instructor.

At the University of Pennsylvania, Introduction to Biomechanics is a required course in the bioengineering department. It is typically taken sophomore year and is the students' first core bioengineering course. For reasons described later, the co-instructors aimed to restructure the course during Summer 2014 to include active learning techniques that would be implemented in the Fall 2014 offering. During this restructuring process, the instructors sought the help of a graduate student who had been a recitation TA for the prior three years of the course. In Summer 2014, during the course restructuring process, this TA participated in the "Active Learning in STEM Courses" mini-course and in Fall 2014, during implementation of this new structure, participated in the "SAIL TA Training." This TA is now helping to lead the Spring 2015 "SAIL TA Training." This paper describes the TA's experiences in helping restructure Introduction to Biomechanics by drawing on lessons from both the "Active Learning in STEM Courses" mini-course (defining course goals, creating activities, and providing feedback) and the "SAIL TA Training" (facilitating activities in the classroom).

Each following section describes how TAs were trained to consider these issues in the mini-course and TA training, specific examples of how this was implemented in the Introduction to Biomechanics course, and the importance of the topic learned through experience in restructuring the Biomechanics course. Examples from the Biomechanics course are provided as a model of how this system can be used to restructure a course and are not meant to reflect the only way in which these concepts can be applied. The recommendations posed to TAs in this paper are based on experience, and specific course restructuring decisions were guided by educational literature. The lessons learned through experiences described in this paper may benefit current graduate students who are helping an instructor redesign a course to include more active learning techniques, graduate students who are facilitating courses that already include active learning techniques, and students who hope to pursue a career in teaching and may need to design their own courses in the future.

Defining Course Goals

Goals are the foundation of course reform. Although TAs are typically not responsible for defining the course goals (this is normally the instructor's responsibility), an important aspect emphasized in the "SAIL TA Training" was to ask the TAs to 1) reflect on why it is important to know the goals of the course, 2) articulate what these goals are, and 3) understand why/how the instructor plans to use active learning methods to achieve these goals. This step ensures that instructors and TAs communicate the same goals and expectations to the students.

To model these suggestions made by "SAIL TA Training," the goals were clearly defined by the instructor of the Introduction to Biomechanics course and then communicated to the teaching assistant before beginning the restructuring process. The Biomechanics class is normally 60-90 students and meets for lecture twice a week and recitation (4 sections of 15-25 students) once a week (80 minutes each). This class introduces students to engineering problem solving and the applications of biomechanics. In the prior three years of teaching this course, the instructors noticed that students struggled with adapting their problem solving skills to new contexts and understanding the physical meaning of the equations and concepts. Based on these observations, the instructors had two broad goals for the restructuring of the course: 1) improve students' problem-solving abilities, specifically by developing a flexible framework for solving problems and understanding limitations and assumptions and 2) develop students' intuitive senses of the physical phenomena in biomechanics. More specifically, these course goals led to assignment objectives of 1) building students' skills in estimation and simplification, 2) introducing students to the concepts of design (i.e., how to "think like an engineer"), and 3) providing hands-on experiences for the students to translate equations from a theoretical framework to practical application. Importantly, these goals were clearly established by the instructor and then articulated to the teaching assistant before beginning the semester. As described in the following sections, these goals were also communicated to the students through the design of specific activities, feedback, timing, and verbal announcements. These broad student learning goals led to more specific assignment objectives that helped focus the students during the activities. Rather than trying to accomplish everything in a single activity, each assignment focused on one or two goals to avoid overwhelming the students.

In our experience, starting the course reform process by articulating our goals was necessary to guide our decision making. Strategies for developing or reforming course goals may include identifying strengths and weaknesses of students in the previous year's class (as done for the Biomechanics restructuring), understanding where the course fits into the department's curriculum to help prioritize skills that students will need as prerequisites for subsequent courses, gauging students' learning expectations, and referring to ABET standards. To ensure a successful transition, we found it to be important for the instructors and TAs to explicitly and implicitly communicate these course goals to the students throughout the semester. Explicit communication may include verbal announcements and written descriptions of what the students should expect to learn on each assignment (learning objectives). Implicit communication occurs through the design of the activities, the type of feedback and assessments provided to the students, repetition, and the amount of time given to a specific task (the more time spent on an activity or objective, the more important this activity or objective is viewed). As described in the subsequent sections, these goals form the foundation of the course restructuring decision-making process.

Creating Activities to Support Course Goals

Once course and assignment goals are identified, they can be translated into structured, in-class activities that support these goals. Creating activities is where the bulk of the workload for restructuring a course resides, making this a particularly fruitful place for TAs to be involved. As described in the "Active Learning in STEM Courses" mini-course, important questions for TAs and instructors to discuss before the TA begins the process of creating activities include the following:

1. *Are these activities giving students practice with application or are the students learning new material through discovery?*
2. *How much emphasis is on learning facts/theories, and how much emphasis is on learning skills?*
3. *What kind of skills are students asked to use?*

The answers to these questions help define which activities are appropriate for the goals. For example, the answer to question 1 determines the type and extent of pre- and post-class work. Students learning new material through discovery may not need to have prepared with a pre-class assignment but instead may need to do post-class follow-up work (e.g., watch a video, read a chapter, or complete an assignment). In contrast, an activity designed to give students practice with application implies that students should already be familiar with the general content and theory, which may require specific pre-class preparation work in order for the students to fully benefit from the in-class assignment. Presentation of new material, compared to material already learned, will require more scaffolding to help guide students through the steps. Learning certain skills (e.g., problem solving) may require additional time or repetition throughout the semester compared to learning facts, theories, and equations (e.g., static equilibrium equations) that could be presented and then practiced in one activity.

With these goals and methods in mind, the TA can begin designing in-class activities. Several resources summarize the variety of active learning techniques, and we refer the reader to these excellent guides.[10-13] Deciding which in-class activities to use depends on the activity goals. Regardless of the technique used, many of the following questions, posed by the "Active Learning in STEM Courses" mini-course, should be considered when designing a new assignment:

1. *Preparation*
    a. *How will students prepare for the in-class work?*
    b. *Will this preparation be sufficient to complete the activity?*
    c. *Is the pre-class assignment the appropriate level of difficulty?*
    d. *How will students be held accountable for the preparation work?*
2. *Groups*
    a. *Will group, pair, or individual work best support the goals?*
    b. *Will groups be defined? If so, how will groups be formed and how many students per group?*
    c. *Is quality group work a skill that will be emphasized and learned through the course or is it simply a tool used to encourage engagement?*
3. *Complexity*
    a. *Is the complexity of the activity appropriate for this type of structure?*
    b. *Is the degree of scaffolding appropriate for this level class/point in the semester?*
4. *Feedback*
    a. *Does this activity have a deliverable?*
    b. *How will students get feedback?*
    c. *How will the instructor get feedback on the students' progress and understanding?*
5. *Accountability*
    a. *How are groups held accountable?*
    b. *How are individuals held accountable to their groups?*
6. *Logistics*
    a. *How will materials be handed out and collected?*
    b. *Is this activity feasible for the time allotted?*
    c. *Is the classroom environment and layout appropriate for this activity?*
    d. *Are there enough instructors/TAs to appropriately facilitate this activity?*

Broadly speaking, active learning methods can be divided into group and individual work. The remainder of this paper focuses on group work because it is commonly used to engage students and requires additional forethought for successful implementation.

For the restructured Biomechanics course, these concepts and questions were applied to develop two categories of activities. Each week of the course had approximately one active-learning class session and one more traditional lecture (enhanced with clicker questions). The first category of in-class activities was hands-on, experiential learning activities, in which students were not expected to have any background or preparation (example in **Appendix A**). Prior educational literature supports use of this style of activity. Discovery-based learning is loosely defined as a method wherein the learner must independently (i.e., not explicitly told by the instructor) arrive at the target information or concept with the supplied materials. Meta-analyses performed on discovery-based instruction showed that unassisted discovery does not benefit learners, but enhanced/assisted-discovery methods lead to greater learning.[14] Specifically, feedback, worked examples, scaffolding, and elicited explanations benefit the learners.[14] Given these previous findings, we sought to create assisted-discovery activity worksheets that would guide students through a set of mini-experiments to arrive at the mechanical concepts. The activity topics (supports/reactions, stress/strain, and bending) were chosen to address concerns that the equations alone were not conveying the physical meaning of these concepts to the students. By presenting this new material through a hands-on activity rather than a blackboard derivation, we hoped students would have a deeper intuitive sense for the mathematical representations they would be using in the course. The first page of each hands-on activity listed any necessary background (a few bullet points), the assignment goals, the materials they would be using, and a sentence summarizing what students should be able to do or understand upon completion of the activity (explicit communication of assignment objectives).

The second type of in-class activity for the Biomechanics course were problem-based activities, in which students were expected to apply concepts learned in a previous lecture to solve one or two biomechanics problems (example in **Appendix B**). Since the goals in the Biomechanics course included improving students' problem-solving abilities, small-group work was chosen for application because it allows students to solve more challenging problems and develop critical thinking skills by bringing together diverse ideas and experiences. As mentioned previously, small-group learning has positive effects on students' learning and attitudes,[2] suggesting that this active-learning technique would be appropriate to implement. Problems were inspired by clinical, industrial, or research scenarios that a bioengineer may be expected to encounter. For the problem-based activities, students were provided an outline as scaffolding. This outline was designed to reinforce the problem-solving method and was kept general enough to allow students to build a flexible problem-solving framework, a course goal. In this problem solving outline, students were led through the process of restating and defining the goal of the problem and identifying the knowns/unknowns and necessary equations prior to numerically solving. This process of starting with the problem goal and delineating a problem-solving plan prior to numerically solving has been described previously.[15] After numerically solving the problem, students were asked to think more in depth about their solutions to, for example, provide a design recommendation or estimate a mode of failure, again reinforcing the course goals.

Generalizing our experiences, we found it to be important to ensure that in-class activities align with the course goals. Different goals may result in the creation of different kinds of activities, as in the development of the hands-on and problem-solving activities created for the Biomechanics course. Furthermore, we suggest focusing on 1 or 2 goals per activity rather than trying to accomplish everything in one assignment. By limiting the focus of each assignment, explicitly noting the assignment goals, and repeating these goals multiple times throughout the semester (implicit communication of goals), we felt that students had a greater sense of what skills they should value as important.

Student Group Dynamics

After designing a group activity, the next challenge is successful implementation. It is important for TAs to prepare for working with groups by thinking about and even practicing how to interact with such groups. During the first SAIL TA training session, different group scenarios were considered: groups with members working independently instead of together, groups that are stuck, groups with especially dominant or passive members, groups looking for the "right answer" without regard to the process, groups too embarrassed to acknowledge their confusion, and groups that are "done" much earlier than others. During the TA training session, reasons why groups may be acting in these ways and strategies to approach and redirect the group dynamics were brainstormed (**Appendix C**). In the second SAIL TA training session, these group dynamics were role-played to give TAs experience in how to handle these different scenarios and confidence to approach groups in their real classrooms (**Appendix D**). In the role-play feedback, fostering discussions between students and "exit strategies" (i.e., how to remove oneself from a group) were emphasized.

Using the skills learned from the SAIL TA training sessions and prior literature on applying active learning in STEM courses, several steps were taken to promote positive group dynamics in the Introduction to Biomechanics course. For both kinds of activities (hands-on and group problems), students (60 in the class) were assigned into groups of 2-4 (normally 3 students per group) and given a role: manager, recorder, checker, or skeptic. The small group sizes and assigned roles were applied to encourage participation from all members. We noticed that, apart from "recorder," students did not adhere to these roles. Since this was not a course goal and the groups generally worked well together, we did not try to enforce these roles. During the class period, 3-4 instructors/TAs (for ~20 student groups) circulated the classroom to answer questions, reinforce positive group dynamics, and help students navigate the problem solving process. These group sizes and student-to-instructor ratios have been used successfully in previous active learning (or "flipped") classes (2-4 instructors for 50-120 students with small groups of 3-4 students).[16] Groups were rotated three times during the semester, but roles were rotated for each assignment (so that a single person did not get assigned the role of "recorder" every time). One handout was provided to each group (to encourage group instead of individual work) and expected to be turned in at the end of class (to maintain accountability).

A flag system was used to notify instructors/TAs when groups were struggling; red flags required immediate attention and meant a group was stuck and had no way to move forward with the problem, yellow flags meant the group was struggling and had a question but could still keep working together, and green flags meant the group had completed the problem and was ready for it to be reviewed by an instructor/TA. During this time (~1 hour) students and instructors received immediate feedback on the assignment by circulating the classroom. If an instructor/TA noticed trends with a common issue, he/she would bring it to the attention of the other instructors/TAs. Partway through the semester, the instructor began re-grouping the entire class midway through the class to ensure proper pacing and to address any common issues noticed by the circulating instructors/TAs, which was helpful for the students.

In our experience with the Biomechanics course, small group work was an important aspect of upholding student engagement. Group work is often a component of active learning, but dysfunctional groups can impair the learning process. The very same reasons group work can be so beneficial (e.g., combining people with different backgrounds and knowledge to solve a problem) can contribute to detrimental group dynamics (e.g., frustration with knowledge asymmetries).[17] Examples include “blockers” (students who discourage others’ contributions) and “constant pupils” (students who habitually take on the pupil role instead of contributing to teaching fellow group members).[17] These interactional problems can be minimized and remedied through appropriate facilitation by instructors and TAs. During in-class activities, the TA and instructors can circulate the classroom to interact with each group and provide support as needed. Because detrimental group dynamics can be hard to detect without interacting with a group, it was our experience that instructors and TAs should be proactive in approaching groups, even when the groups do not express need for immediate help.

Feedback and Assessment

Finally, a method should be chosen to provide feedback and accountability on the in-class activities. Example methods for grading include grading schemes or rubrics, checks for completion, individual grades, quizzes, or no grades (**Table 1**). These may be in addition to posted solutions. Emphasis should be placed on aligning feedback and grades with the course and assignment goals.[18] Grading is one important way that students can gain a sense of what the instructor values and prioritizes in the course.

Importantly, from our experience we suggest giving much consideration to how class activities fit into the course as a whole. One common form of summative assessment is an exam. As described in the “Active Learning in STEM Courses” mini-course one strategy for ensuring that all aspects of the course align is to begin by forming an exam question that assesses a course objective. Then ask,

1. *What would students need to know/be able to do in order to answer this question? How do class activities support that understanding?*
2. *How do these things relate to the course goals?*

With the answers to these questions in mind, the TA and instructor can think about the purpose of other class assignments (pre-class and post-class homework/projects) that will prepare students with these skills. Questions to consider while creating these assignments, as discussed in the “Active Learning in STEM Courses” mini-course, are as follows:

1. *What kind of questions are being asked in these different categories (pre-, in-, and post-class)?*

2. *How do these questions compare across categories and to the exam questions? How do the formats compare? How does feedback on these assignments compare?*
3. *As students complete these assignments, how will they know how to prepare for the exam?*

Table 1. Grading method pros and cons.

Grading Method	Pros	Cons
Rubrics/schemes	Systematic approach guarantees more objective grading; Grading emphasis and feedback to students can align with course goals	Takes time to develop and use a rubric/scheme
Completion/Participation	Quick and easy; Promotes attendance and efficient use of class time	Does not enforce correctness, so students may be quick to answer without providing much thought; Provides no feedback to students
Individual Grades	Individuals are held accountable for the material	Does not enforce positive group dynamics
Post-Activity Quizzes	Individuals are held accountable for the material	Takes additional class time; Does not enforce positive group dynamics; Students may not prioritize in-class activity time if no deliverable is expected
No grades	No effort required	No group or individual accountability

For the Introduction to Biomechanics course, we wanted to give the students written feedback, in addition to the immediate feedback they received during class, as this was often a more systematic form of feedback than what could be done in class. Group activities were graded on a 10-point scale for process, correctness, and completion, and returned within a week. Complete solutions were posted online. One assignment was handed in per group and all members received the same score to encourage teamwork during these in-class activities. Since one course goal was to improve students' problem-solving abilities, the grading emphasized process over final answer by attributing the majority of the points to creating a solution outline; identifying the knowns, unknowns, and relevant equations; and setting up the equations using variables before plugging in numbers. Common errors were collected by the TA and communicated to the instructors to reinforce in the next lecture.

The Biomechanics course incorporated several assignments in addition to the in-class activities: conceptual clicker questions during lectures,[19] homework assignments that involved solving biomechanics problems, recitation small-group problem solving, and online 15-minute videos prepared by the instructors with short quizzes. All of these assignments were used to provide feedback to students to help them prepare for the three exams they had during the semester. The exams were created by the course instructors to test students' individual knowledge of biomechanics concepts in addition to biomechanics problem solving. The exam questions were formatted to be similar to questions the students came across during these various assignments.

Our experience with the Biomechanics course supported the value of aligning course goals with assessment. After the first in-class activity at the beginning of the semester, before a grading rubric had been created, students expressed concern and anxiety about not knowing how they were going to be assessed. They were unsure what they should prioritize when working on the group problems and how important completion of the activity and getting the "right" final answer was compared to the overall process. With this feedback, we created a rubric reflecting the instructor's goals for the assignments, which seemed to assuage their concerns. We learned that being explicit about expectations can improve the learning process by reducing student stress.

Reflection on Introduction to Biomechanics Course

Restructuring a college course is an iterative process, requiring continuous reflection and alteration. To comply with ABET criteria, course development is a three-pronged effort: defining the learning objectives, creating the instructional techniques (which may include active learning), and measuring learning gains through assessment; these stages may not be sequential and often rely on feedback from the other stages for continuous improvement.[20] The outline presented here and in the CTL courses provided the foundation for the restructuring of the Biomechanics course; however, we also found it to be necessary to have realistic expectations and to be open to feedback throughout the semester. Several changes were made throughout the semester in the Introduction to Biomechanics course as we and the students saw areas for improvement. Although the instructors spent some time at the beginning of the semester explaining why this course had been reformed to include in-class activities, we found that the students began questioning the purpose of these assignments; therefore, midway through the semester, one of the instructors took extra time to reiterate the goals of these activities and why we expect the students will benefit from them. We learned that repeating the course goals and purpose of each assignment helps the students understand why they are being asked to complete the activities, reducing push-back. Further, we learned that the amount of time spent on a particular topic/activity should correlate to how highly the instructor values that skill. For example, in a first draft of an in-class group problem-solving activity, one problem asked students to calculate multiple integrals. In revising this problem, we realized that the goal of having students predict a loading scheme within a bone was lost to the amount of time they were going to spend calculating integrals; therefore, the problem was revised to make the math easier so that the assignment objective would not be overshadowed. Along similar lines, we found that students really struggled with pacing, which led to unnecessarily high levels of stress and anxiety at the beginning of the semester, so the assignments were revised to include suggested time stamps for each section of the activity to keep students on track and help them realize which portions should be emphasized in their problem solving process. Finally, partway through the semester, the instructor began to regroup the class midway through a session to review solutions, address common issues, and ensure students were pacing themselves appropriately. We were happily surprised by the amount of student participation when the class was brought back together as a whole, which we believe is because they had already worked through the problem in their groups and received feedback from the circulating instructors/TAs. The first semester of a restructured course is a learning experience for the instructor(s), TA(s), and students; however, by staying open to feedback, improvements can be made along the way. Our final in-class activity was certainly the smoothest of the semester, with fewer groups stuck without a way to move forward in solving the problem, positive group dynamics, and appropriate timing.

In our experience, feedback can come from the students, fellow instructors/TAs, outside observers, assessment results (e.g., exams), or personal reflection. Pre-, mid-, and post-surveys of the students (separate from course/instructor evaluations) can be useful in identifying their expectations, prior experiences, confidence levels, and opinions. Sometimes just asking students during recitations or office hours what they think can provide quick insight (though one must keep in mind that these are the opinions of a few students, not necessarily representative of the collective body). Personal reflection on what stresses the instructor/TA most and what stresses the students can help identify areas of improvement to reduce anxiety and improve student engagement and learning.

Conclusion

Training teaching assistants specifically for active-learning based classes aids in their utility in restructuring the course and facilitating activities. With clear communication between the instructor and TA, teaching assistants can play a pivotal role in creating in-class activities, managing group dynamics, providing student feedback and assessment, and aiding in the continual evaluation and modification of the course. When teaching assistants help instructors transition a class from a traditional lecture format to a more active format, the TAs receive valuable experience in course design, assignment development, and small group facilitation. This also allows the instructor to offload some of the work and stress associated with course restructuring and, importantly, benefits the students through enhanced engagement and deeper learning.

Through our experiences in restructuring an Introduction to Biomechanics course, we recommend the following:

1. Clearly define and then articulate (explicitly and implicitly) to the TA and students the course goals that lead to assignment objectives.
2. Together the TA and instructor should be able to answer the provided questions *italicized* in the body of the paper to establish a course vision and help identify the appropriate activities to match with the course goals.
3. Create a portfolio of activities that will support the course/assignment goals. The portfolio (not necessarily a single activity) should address all goals. TAs can be especially useful in creating activities, but in order to do so successfully, communication between the TA and instructor during this planning phase should be emphasized.
4. If possible, complete a draft of all of these activities before the semester begins and review as the semester commences. This upfront work will allow the instructor and TA to develop a cohesive course by ensuring all course goals have been addressed in the portfolio of activities.
5. For group work, TAs can practice facilitating student group interactions through role-playing. We suggest interacting with and approaching groups even when they do not have a specific question.

6. Decide upon an assessment/feedback method that reinforces the course goals and student (group and/or individual) accountability while being practical given TA/instructor constraints.
7. Maintain flexibility and be open to feedback and reflection throughout the semester. Incorporate improvements to the activities and in-class sessions as the semester progresses. Allow your course to be dynamic instead of static.

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References

1. Prince, M. J. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, *93*(3), 223-231.
2. Springer, L., Stanne, M.E., & Donovan, S.S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research*, *69*(1), 21-51.
3. Fairweather, J. (2008). Linking evidence and promising practices in science, technology, engineering, and mathematics (STEM) undergraduate education. *A Status Report for The National Academies National Research Council Board of Science Education*.
4. Linenberger, K., Slade, M.C., Addis, E.A., Elliott, E.R., Mynhardt, G., & Raker, J.R. (2014). Training the foot soldiers of inquiry: Development and evaluation of a graduate teaching assistant learning community. *Journal of College Science Teaching, 44*(1), 97-107.
5. Bohrer, K., Ferrier, A., Johnson, D., & Miller, K. (2007). TA training workshops. In K.L. Chase (Ed.), *Association for Biology Laboratory Education (ABLE) Proceedings, 29,* 67-126.
6. Baumgartner, E. (2007). A professional development teaching course for science graduate students. *Journal of College Science Teaching, 36*(6), 16-21.
7. Marbach-Ad, G., Schaefer, K.L., Kumi, B.C., Friedman, L.A., Thompson, K.V., & Doyle, M.P. (2012). Development and evaluation of a prep course for chemistry graduate teaching assistants at a research university. *Journal of Chemical Education, 89*, 865-872.
8. Petrinjak, L. (2010, April 20). TA boot camp improves freshman chemistry. *NSTA Reports.* Available at http://www.nsta.org/publications/news/story.aspx?id=57302&print=true
9. Addy, T.M., & Blanchard, M.R. (2010). The problem with reform from the bottom up: Instructional practises and teacher beliefs of graduate teaching assistants following a reform-minded university teacher certificate programme. *International Journal of Science Education, 32*, 1045-1071.
10. Paulson, D.R., & Faust, J.L. (accessed January 2015). Active Learning for the College Classroom. http://web.calstatela.edu/dept/chem/chem2/Active/
11. O'Neal, C. & Pinder-Grover, T. (accessed January 2015). Active Learning Strategies. PDF available at http://www.crlt.umich.edu/sites/default/files/resource_files/Active%20Learning%20Continuum.pdf
12. University of Minnesota, Center for Teaching and Learning. (accessed January 2015). Active Learning. PDF available at http://www1.umn.edu/ohr/teachlearn/resources/active/index.html
13. Florida State University, A Guide to Teaching & Learning Practices. (accessed January 2015). Chapter 8: Using Active Learning in the Classroom. PDF available at http://distance.fsu.edu/instructors/instruction-fsu-guide-teaching-learning-practices
14. Alfieri, L., Brooks, P.J., & Aldrich, N.J. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology*, *103*, 1-18.
15. Wales, C.E. & Stager, R.A. (1990). *Thinking with Equations: Problem Solving in Math and Science*. Center for Guided Design, West Virginia University, Morganstown, WV.

16. Beichner, R.J. & Saul, J.M. (2003). Introduction to the SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) Project. *Proceeding of the International School of Physics*.
17. Haller, C.R., Gallagher, V.J., Weldon, T.L., & Felder, R.M. (2000). Dynamics of peer education in cooperative learning groups. *Journal of Engineering Education*, *89*(3), 285-293.
18. Biggs, J. & Tang, C. (2011). *Teaching for quality learning at university* (4th ed). Berkshire, England: Open University Press, McGraw-Hill Education (UK).
19. Lopez, J.A., Love, C., & Watters, D. (2014). Clickers in biosciences: Do they improve academic performance? *International Journal of Innovation in Science and Mathematics Education*, *22*, 26-41.
20. Felder, R.M. & Brent, R. (2003). Designing and teaching courses to satisfy the ABET engineering criteria. *Journal of Engineering Education*, *92*, 7-25.

Appendix A: Annotated Example Hands-On Activity Created for Introduction to Biomechanics

Groups of 3 members and roles were assigned to encourage equal participation. We noticed that students only used the "recorder" role.

Group Member Names/Roles:

	Name (printed)	**Name (signed)**
Manager	__________________________	__________________________
Recorder/Checker	__________________________	__________________________
Skeptic	__________________________	__________________________

Hands-on activities were used to help students deduce engineering concepts through experimentation and understand the physical meaning of the equations/concepts

HANDS-ON ACTIVITY: STRESS-STRAIN

Goals

1) Understand why stress and strain are important engineering calculations
2) Deduce the strain equation
3) Deduce the stress equation

Assignment goals were explicitly communicated to students

Materials

Elastic
Ruler
Spring scale
Safety pins

In these discovery-based, hands-on activities, students were not expected to have prepared by learning certain material; therefore, we briefly provided the necessary background to ensure students had the same starting point.

Background

- So far, we have been doing rigid body mechanics; however, we know that in reality, all materials undergo some finite amount of deformation when loaded. Now, we will learn about deformable bodies and mechanics of materials.
- The length of an unloaded material is known as the original or "gauge" length, L_o.
- The term "load" can mean an applied force or moment. If you are talking about deformation along an axis, the "load" is a force.
- Reminder: To reduce error, repeated measurements are needed

Reiterating what students should take away from this activity

At the end of this hands-on activity, you should be able to 1) understand how material geometry may play an important role in mechanics and 2) write the equations for stress and strain.

PART 1: STRAIN (30 minutes allotted)
"Strain" is an engineering term used to describe how much a material deforms.

We learned that students worked better (and had less anxiety) when they were given pacing guidelines

Using the materials in front of you, explore how the length of the material influences the amount of axial deformation when a load is applied. You will develop a relationship between length and deformation.

The goal of this section was defined

1. In front of you, you will find 4 pieces of elastic cut to different gauge lengths. Apply **2N** of load to each piece of elastic and measure the corresponding deformation. The length of the material should be measured from the pins. Record your findings in a table. Note any sources of error in your measurements.
2. Using the provided graph paper or your computer, create a graph that demonstrates the relationship between the deformation of the elastic (change in length, ΔL, y-axis) and the gauge length (L_o, x-axis). Determine the linear relationship.
3. **Fact: All of these materials underwent the same amount of strain. The symbol for strain is ε.** Using your graph, discuss what this must mean and use your observations to write the equation for strain in terms of ΔL and L_o. How much strain did your specimens undergo?
4. What are the units of strain?
5. For the same strain as this experiment, use your equation to predict the axial deformation of a piece of elastic that is the length around the equator of the earth (40075 km). What is the total length of the stretched elastic?

Record answers to all the above questions to turn in. Raise your green flag when you are finished and begin Part 2. When the entire class has completed Part 1, we will momentarily pause to discuss your results as a class.

We learned that re-grouping the whole class midway through a session allows the instructor to address any common issues and reinforce the main take-aways of a section of the assignment.

PART 2: STRESS (20 minutes allotted)
"Stress" is an engineering term used to describe the load a material experiences when it is deformed.
Using the materials in front of you, you will explore how the cross-sectional area of the material influences the amount of load that can be applied to achieve the same deformation. You will develop a relationship between area and load.

The goal of this section was defined

1. In front of you, you will find 3 pieces of elastic that are the same gauge length safety-pinned together. What is the cross-sectional area of your material? Given the small thickness of your elastic and the limited resolution of your ruler, what can you do to increase the thickness dimension to reduce error in your measurement? Determine the amount of load required to deform the material by 1 cm. Record your findings in a table. Note any sources of error in your measurements.

2. Now, **without changing the gauge length of the material**, remove one piece of elastic. What is the new cross-sectional area of your material? Determine the amount of load required to deform the material by 1 cm. Add your findings to your table.
3. Finally, repeat the above steps with a single piece of elastic. What is the cross-sectional area? What is the load required to deform the material by 1 cm? Add your findings to your table.
4. Using the provided graph paper or your computer, create a graph that demonstrates the relationship between the cross-sectional area of the elastic (x-axis) and the load required to achieve the same change in length (y-axis). Determine the linear relationship.
5. **Fact: All of these samples experienced the same amount of stress. The symbol for stress is σ.** Using your graph, discuss what this must mean and use your observations to write the equation for stress. How much stress did your specimens experience?
6. What are the units of stress?
7. Using your equation, predict the load required to deform 1 cm a piece of elastic the same length as you tested in this section of the assignment with the same cross-sectional area as the earth (~1.275×10^{14} m^2).

Record answers to all the above questions to turn in. Raise your green flag when you are finished and begin Part 3.

After identifying relationships, students were asked to think more deeply about their discoveries and expand the applications, one of the course goals.

PART 3: SUMMARY QUESTIONS (15 minutes allotted)

1. In part 2, were your 3 samples experiencing the same amount of strain? Explain.
2. In part 1, were your 4 samples experiencing the same amount of stress? Explain.
3. You know from experience and physics that load and deformation are related, often linearly as in the case of a linear spring. The term relating force and deformation is called stiffness, k. Recall Hooke's Law: $F = k * \Delta L$. A similar relationship between stress and strain exists, and when linear, is called the Modulus of Elasticity, E. $\sigma = E * \varepsilon$.
   a. Consider a piece of steel and a piece of elastic with **the same amount of load** applied to each. Using what you know about the difference between steel and elastic, describe in relative terms (not numbers) what the **geometry** of these two materials must be to experience the **same amount of strain under the same amount of load**.
   b. Describe the relative **geometry** of the two materials when they experience the **same amount of stress** as they are undergoing the **same amount of deformation**.
4. Explain why stress and strain are important engineering concepts in addition to load and deformation. To aid in your discussion, consider describing to a fellow engineer the failure stress, failure strain, failure load and failure deformation of a specific piece of hair (geometry known) versus hair in general.

This final summary question addresses the main goal of the assignment.

Record answers to all the above questions to turn in.

Appendix B: Annotated Example Group Problem-Solving Activity Created for Introduction to Biomechanics

	Name (printed)	**Name (signed)**
Manager:	____________	
Recorder/Checker:	____________	____________
Skeptic:	____________	____________

> Groups of 3 members and roles were assigned to encourage equal participation. We noticed that students only used the "recorder" role.

IN-CLASS GROUP PROBLEMS: STRESS ON INCLINED PLANE + AXIAL LOADING

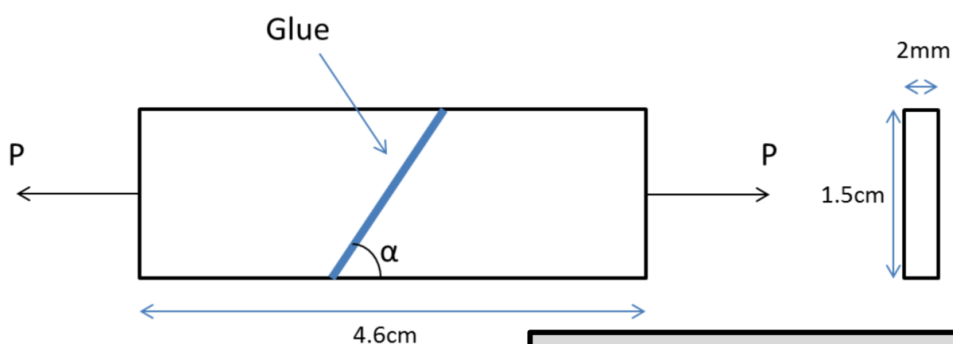
> In group problem-solving activities, students applied a concept learned in the previous lecture to solve a biomechanics problem. This particular activity had two biomechanics problems; only the first one (loading on an inclined plane) is shown here as an example.

Problem 1: Skin Wound (read and discuss problem statement 2 minutes)

When the hand is open, the distance between two collinear points is 40 mm. When the hand is closed, the distance between those same two points is 46 mm. E_{skin} = 4 MPa

A small wound at an angle α on the back of someone's hand requires skin adhesive. Mechanical tests have shown that the adhesive can withstand a normal stress of 0.5 MPa and a shear stress of 0.25 MPa **on the plane of the adhesive** before failing.

In this example, we will assume the force (P) stretching the skin is only in one direction (axially), allowing us to construct the following diagram for equilibrium:



> After the problem statement, the question (goal of the assignment) was asked.

Question you are trying to answer:

At what angles α is the skin adhesive no longer effective in keeping the wound sealed when the hand is in a closed equilibrium position?

Note: Depending on how fancy your calculator is, you may need 2cos(x)sin(x) = sin(2x)

Since the goal of this assignment was to reinforce the concept of axial loading on an inclined plane (not trigonometry), we provided a trig identity to simplify the math and communicate where students should spend their efforts.

This outline was used as scaffolding to walk students through the steps of problem solving and was included in every assignment. The outline was kept general enough that it could be applied to a variety of problems to help students develop a flexible framework for problem solving (course goal).

Each step of the problem included recommended times to keep students pacing properly. We found that this reduced the students' anxiety and helped reinforce where students should focus their efforts.

I. Estimate (2 minutes)

How will the angle α of the wound impact the stresses experienced by the glue?

The "estimate" step was included to help students think about the problem before solving so that they could evaluate the practicality of their numerical solutions at the end. This step was meant to help build students' intuitive understanding of the physical concepts.

II. Focus the Problem (3 minutes)

Outline the approach to be taken.
State any intermediate problems that must be solved before obtaining the final answer.

III. Describe the Mechanics (5 minutes)

Draw the appropriate FBD of the cut.
Identify and state the knowns and unknowns.
State any assumptions.
State which mechanics principles/equations you can use.

Students had to "solve" the problem in terms of variables before inputting numbers. This step was to help students develop a flexible problem-solving framework (course goal).

IV. Do the Math (10 minutes)

Translate your mechanics descriptions into equations with variables.
Combine these equations to get the equation(s) for your target variable(s) (don't substitute in your numbers yet!).

V. Put in the Numbers (5 minutes)

Put real numbers into your equations and determine numerical values for your target quantities.

VI. Evaluate the Answer (2 minutes)

Are the units correct?
Is the answer unreasonable? Justify.
Compare your answer to your estimates.

Students were asked to evaluate and justify their answers and compare to their original "estimate." This step was included to promote reflection and help students "think like an engineer" (course goal).

VII. Answer the Question (3 minutes)

At what angles α is the skin adhesive no longer effective in keeping the wound sealed when the hand is in a closed equilibrium position?

Appendix C: SAIL TA Training Handout on Group Dynamics (*italicized are brainstormed responses)*

Group work- Looking back on your experiences with group work, what do you think the pros and cons of group work are? In your groups, compare your list of pros and cons and think about strategies to manage group work so that you maximize the pros and minimize the cons?

Pros	**Cons**	**Strategies to Manage Group Work**
• *Learn to communicate* • *Learn to work in groups* • *Can tackle harder problems* • *Get to see range of viewpoints/ways to think* • *Get a range of background knowledge* • *Enhanced reasoning skills (via explanations with peers)* • *Social skills*	• *Lack of structure* • *Students understanding the purpose of activities* • *Motivating individuals ("social loafer")* • *Motivating groups* • *Social dynamics are tricky* • *Grading is challenging* • *Disparate skill levels* • *Time consuming*	• *Break larger tasks into smaller, give time constraints, give guidance* • *Be explicit, have them reflect, ask them the purpose as circulating* • *Have individuals hand something in, make questions similar to exam to make it feel more relevant* • *Have them hand in answer before giving answer, have groups present answers, have friendly competitions* • *Think about how to group individuals, have groups reflect on their practices, give groups feedback on how they function* • *Grade individual contributions, keep grade small* • *Discuss benefits of teaching others, vary difficulty level, give prep work to even baseline knowledge, mix groups* • *Only use when appropriate*

Group dynamics- Below are some observations of group dynamics that you might encounter. Think about why the group may be behaving in this way.

Observation	**Why might the group be acting this way?**
All members of the group are working on the problem, but they are working on it independently.	• *All feeling confident* • *Division of labor* • *Temporary, all thinking as individuals/taking notes*
The members of the group are getting nowhere.	• *No one knows what to do* • *Shy people* • *Distracted*
The group says they are "done" before any other groups are even close.	• *Done poorly/incorrectly* • *Really smart* • *Cheated*

Approaching different groups- Pick at least one reason for each group observation and think of a stock phrase that you might use to begin a discussion with that group.

Group Behavior	What will you say to the group?
All feeling confident	*Ask individuals what they are doing/have done, Ask how their answers compare to their peers in the group, If all on the same page, make problem more complex*
Division of labor	*Ask others if they can do the task that another person is doing (mention that they'll need to do it alone on the exam)*
No one knows what to do	*Guide students through questions* • *Get them to talk about what they do know* • *Help students formulate questions* • *Break down ideas into smaller tasks/questions* • *Don't get stuck! Have an exit strategy! Don't give answers!*
Shy people	*Get them to talk to you, then to teach other (by sharing/comparing answers), then extract yourself from the conversation*
Done crudely/incorrectly	*Have them explain what they did, ask pointed questions about errors/sloppiness*
Smart group	*Make sure everyone understands the answer, then complicate it or see if they will help a nearby group*

Appendix D: SAIL TA Training Group Dynamics Role Playing

SAIL TAs were split into groups of 4, and one TA from each group volunteered to role play the TA while the other 3 role played students. Everyone was provided the role play problem with the pre-class reading (below). "Students" were provided a description of their roles, while "TAs" approached the acting group and attempted to resolve their group dynamics without knowing the backstory. Feedback was given to the "TAs" by the observers (other participants in the SAIL TA Training) and "students" in the role play.

Pre-class reading:

Students were expected to be familiar with this material, and come prepared to use this information in class

When different outcomes of an event are equally likely, you can use the following formula to calculate the probability of outcomes:

$$P(A) = \frac{\text{number of ways outcome A can occur}}{\text{total number of ways any outcome can occur}}$$

For example, getting a head when you toss a coin has a ½ chance because there are two possible outcomes that are equally likely (heads or tails) and a heads is just one of the possible outcomes.

*When you want to calculate the probability that multiple independent events will occur, you calculate them by multiplying the probabilities of each independent event. For example, the chance of throwing a heads four times in a row is ½ * ½ * ½ * ½ = 1/16*

In-class problem:

1. What is the probability that you roll the same number on a six-sided die three times in a row?
   *A: 1/36 because the first time you roll the die you are not constrained by which number you roll, so your chances of rolling any number are 6/6, or 100%. The second and third roll, though, you need to roll the same number as the first and therefore your chances on each of those rolls is 1/6. To determine the overall chance of rolling the same number 3 times, you just need to multiply all three of these probabilities together, 1 * 1/6 *1/6 = 1/36*

Scenario 1: Domineering Student

Student 1: The problem seems pretty straightforward to you, based on the reading and what you remember from previous courses. You explained it quickly to the other students in your group as you wrote it down, so it should be fine.
Note: for this scenario, you have come to the correct answer of 1/36, using the correct reasoning.

Student 2: The first student seems pretty confident, and the answer makes sense to you, so you're fine with just letting him or her fill out the answer.

Student 3: The first student seems really convinced that 1/36 is the right answer. However, that just doesn't make sense to you. Why would the probability of rolling one out of six numbers ever be 1? However, you didn't do the reading and you don't want to slow the group down. It's probably better just to let him or her fill out the answers and try to figure this out later.
Note: for this scenario, you would have come to the wrong answer of 1/ 216, because you think the probability of rolling the first specific number is 1/6, not 1.

Scenario 2: Needy Group
You are flagging down the TA in the hopes that you will be able to get the answer.

Student 1: You're just taking this to fulfill the Quantitative Data Analysis requirement. You just want to get through class with as little effort as possible. You didn't do the reading because you were up late studying for your other classes, but based on what you've seen of probability you think the answer might be (1/6)(1/6)(1/6).

Student 2: You are a freshman and you are really excited about this class. However, you haven't quite figured out how to study in college yet. You like getting correct answers, but you don't have much patience for thinking through the process of problem solving. You did the reading, but you didn't take any notes and now you forget most of what you read. But the TA is supposed to teach you anyway, right, so you are flagging the TA down, expecting to get the answer.

Student 3: You don't feel confident at all in this class. You've always hated math. You try to memorize equations when you study. You've memorized how to calculate the probability of a single event, but you don't understand why you calculate probability that way- it seems very arbitrary to you. You can't remember if you add or multiply the probability of single events to get the probability of multiple events occurring.

Scenario 3: Working in Parallel
You are all working on the problem separately on your own pieces of paper.

Student 1: You don't like working in groups. You know how to get the answers, and you don't see why you need to be slowed down by explaining the answers to others. It's 1(1/6)(1/6), obviously.

Student 2: You tried to prepare, but you just didn't quite get it. You don't want your other group members to know that you don't understand, so you are happy to work on your own. You'll read through the chapter again after class, and are confident it will click for you by then. You just have to fake your way through class.

Student 3: You don't mind working in groups and in fact have tried a couple of times to work with the other members in your group, but they don't seem interested in engaging in conversation. You've prepared for class and you've gotten far enough to realize that it's not going to be (1/6)(1/6)(1/6) because that would be if you knew what number you wanted to have rolled. You haven't quite figured out, though, how to take into account the fact that the problem is asking for the probability that you will roll ANY number three times.

Scenario 4: Wrong but Agree
For this scenario, you're pretty confident about your answer and the reasoning. It makes total sense to you.

Your group is in complete agreement. The answer seems obvious to you: (1/6)(1/6)(1/6), just like the reading. The probability of rolling any specific number is 1/6, and you would need to do that 3 times. Since everyone agrees, you were able to finish pretty quickly, and now you're waiting for the next step.

Scenario 5: Confused and Embarrassed

Student 1: You think the answer is (1/6)(1/6)(1/6) based on the reading, but you're still not sure you understand the reasoning why. One of the other group members disagrees on the answer, but you don't want to bother the TA with this. This should be easy, and you're embarrassed about possibly being wrong.

Student 2: You think the answer is 1(1/6)(1/6), because the probability of rolling any number first is 1, but you're having a hard time explaining this to the rest of your group. This makes you feel less confident about your answer and reasoning. You'd like to know who is right, but you don't want to be wrong in front of the TA.

Student 3: You find this pretty confusing right now. The explanations from both of your group-mates seem reasonable, and you're not sure which one is right. You're worried that if you talk to the TA, he or she will know how unprepared you are.