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Confidently Uncomfortable: First-year Student Ambiguity Tolerance and Self-efficacy on Open-ended Design Problems

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Abstract

First year engineering students are generally confident and able to self-direct when working on closed-ended tasks. These students are, however, generally much less confident or self-directed on open-ended problems, such as design challenges. It is naturally uncomfortable to work on open-ended problems, because it feels risky to proceed along an ambiguous solution path. Nevertheless, some students seem to be more *confidently uncomfortable*, ready and willing to begin working on open-ended problems. We sought in this study to understand the factors that make a student better able to begin work on these projects without directed guidance from the instructor. Here, this student ability is ascribed to, in part, a student's ambiguity tolerance and self-efficacy on open-ended problems.

A survey instrument to measure ambiguity tolerance and self-efficacy on open-ended problems was created and subject to internal validation. Students taking a 2-course sequence of required, foundational courses over their first year of engineering were studied using this instrument in pre-, mid-, and end-of-class surveys. The current academic year is the third year of the study, and data from the first two years of the study have been analyzed for presentation here. Several interventions, including the use of improv-theater inspired games, were included in the class with the goal of promoting student growth in the surveyed areas. Survey results show that the course as a whole creates statistically significant positive growth in general engineering project work self-efficacy and in two key metrics of ambiguity tolerance and self-efficacy towards open-ended design problems. Still, while the course overall shows significant positive impacts, results specifically on the improv game intervention are less conclusive. No significant effect of the games specifically on self-efficacy or ambiguity tolerance could be found within the scope of this study. Nevertheless, the instructor and a large majority of students indicated that the games were a positive addition to the course climate.

Introduction

Many first year engineering courses emphasize design principles. Inherent to design work is creativity, implying that there is a significant degree of choice in how to perform the work. This flexibility can be difficult for first year students. Often, the technical and pre-college courses to which these students are accustomed focus on closed-ended problems. As defined by Wood [1], a closed-ended problem is one where these three conditions are all met: 1) the methods to be used are familiar, 2) all needed data are provided, and 3) the desired outcomes are clearly stated. In comparison, design problems are often open-ended, with one or more of the conditions not met.

In this study, we sought to understand why some students seem more able and eager to begin self-directed work on an open-ended design problem without much hesitation or desire for additional scaffolding from the instructor. To borrow a term from Pirsig [2], this quality of a student might be called *gumption*. Particular student qualities that we considered as possible contributors to gumption included: self-efficacy on engineering work, on open-ended problems, or on new tasks in general; risk and/or ambiguity tolerance; preference for creative work; self-regulation; resilience; or openness to experience [3] – [8]. In order to focus this work, we selected from this list two factors to study: self-efficacy on open-ended problems and ambiguity tolerance.

Self-efficacy refers to the belief in one's own ability to perform a certain task, and a student who believes they can perform a task are more motivated to do so [9]. Self-efficacy can be assessed as a general psychometric evaluation of "optimistic self-beliefs", as with the Generalized Self Efficacy Scale (GSES) [10]. A typical item in the GSES is "I can solve most problems if I invest the necessary effort," to which the study participant would give a 4-point Likert-scale response that indicates the level of agreement or disagreement. For application to specific topic areas, the questions in the GSES are often modified. For example, recent work has developed a validated instrument to measure self-efficacy in general engineering and in specific engineering skills, such as experimentation or tinkering [11]. A typical item in the general engineering self-efficacy instrument is "I can do an excellent job on engineering-related problems and tasks assigned this semester," to which the study participants indicated agreement using a 6-point Likert-scale response indicating level of agreement or disagreement. General engineering self-efficacy was found to be a reliable predictor of an engineering student's academic achievement.

Methods

In this study, we examined first year engineering students taking a required pair of foundational engineering courses at Northeastern University, a medium-sized, private, urban, 4-year school. Each of the two courses was 4 credit hours and had content centered on design, programming, and CAD. The coursework included, over the course of the two semesters, three very open-ended, team-based, design-and-build projects. The desire to see students begin working on these projects without significant direction from the instructor was a motivating factor for this study. Some teams wasted time at the start of these projects because, it seemed, they wanted to be told what to create and how to create it. Other teams, in comparison, seemed to be able to self-direct their own creative idea generation and then move from that into the formation of a team work plan.

A few learning interventions were employed with the goal of promoting students' growth in confidence and ability to work on open-ended problems. One intervention was the use of improv-theater inspired game breaks during class. Improv-inspired games were used because they are easy and fun to implement, and because improvisation is, effectively, an open-ended problem: the players must create something without knowing what the result will be or how they will do it [12]. A number of articles have suggested the use of improv-type games as a way to inspire creativity and positive risk-taking in college classrooms, including engineering and business courses [13] – [17]. Each class session was 100 minutes long, and the game breaks would take approximately 5 minutes at about the midpoint of the class session. A description of a selection of the games used is given in appendix A. In addition to the in-class games, other interventions included repeated practice on solving open-ended problems, ranging from in-class exercises, such as the marshmallow challenge [18], to week-long homework challenges. Finally, the course content itself included an examination of strategies for working on design problems, including those where the design space is broad.

Pre- and post-class surveys were distributed and collected electronically. Each year, approximately 130 first year engineering students took part, split into four class sections of roughly equal size. Survey response rates were nearly 100% for the pre-class surveys and around 80% for the post-class surveys. Data collected included demographic information and prior experience in teamwork, problem solving, written and oral communication, and a few specific skills such as programming. Approximately 25% of the students were women, though the proportion within each section was significantly variable. Each year, one of the four sections was a designated Honors section that had identical coursework but a student population chosen solely from the university's Honors program.

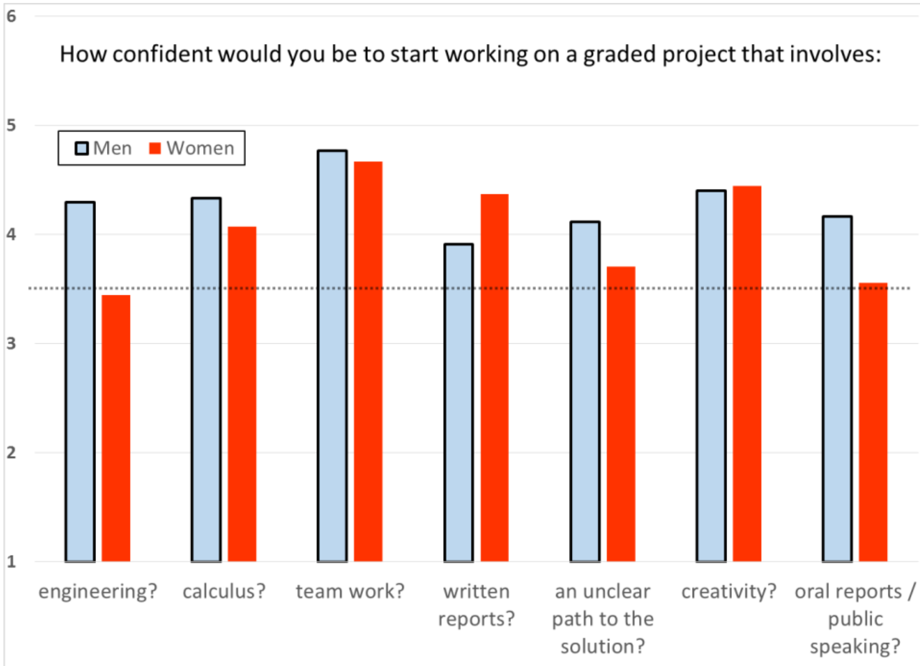
A number of questions regarded self-efficacy along multiple metrics, including in one's ability to begin open-ended problems. These questions were adapted from the validated measure of general engineering self-efficacy provided in [11]. Additional questions in the surveys regarded one's emotional response and opinions towards the various ambiguities inherent to open-ended problems. Likert-scaled responses were used for all of the self-assessment questions. Examples of all of the questions can be found in the results section. A list of the questions is provided in appendix B.

As a specific test of the effectiveness of the improv-game intervention, during the first two years of this study, two sections of the course had an in-class game break during all weeks of the course, while the other two sections only had the games starting at week 5. Surveys to compare these two conditions were additionally collected at the end of week 4, and the questions included student perceptions of the games. The surveys were statistically analyzed for correlations between student characteristics, responses to qualitative questions, and the levels and growth in self-efficacy on open-ended problems over the course of the first semester.

Results

First we looked at some general self-efficacy measures of the students pre-and post-class. The pre-class surveys suggested a cohort of students that were, on average, confident in their placement in the program. In the first year of this study, additional questions in the survey asked students to rank themselves relative to other incoming first year engineering students in ability to solve math problems, to be creative, to work collaboratively on a team, to understand science, and to perform a few other abilities. For every ability, the average student ranked themselves above average relative to peers.

Data on incoming student self-efficacy towards general project-related tasks is shown in figure 1a, with results split by self-identified gender (a non-binary gender option was given, but surveys that selected that response were too few to create a meaningful average). Differences between genders were generally statistically insignificant except for the most general question of a)



b)

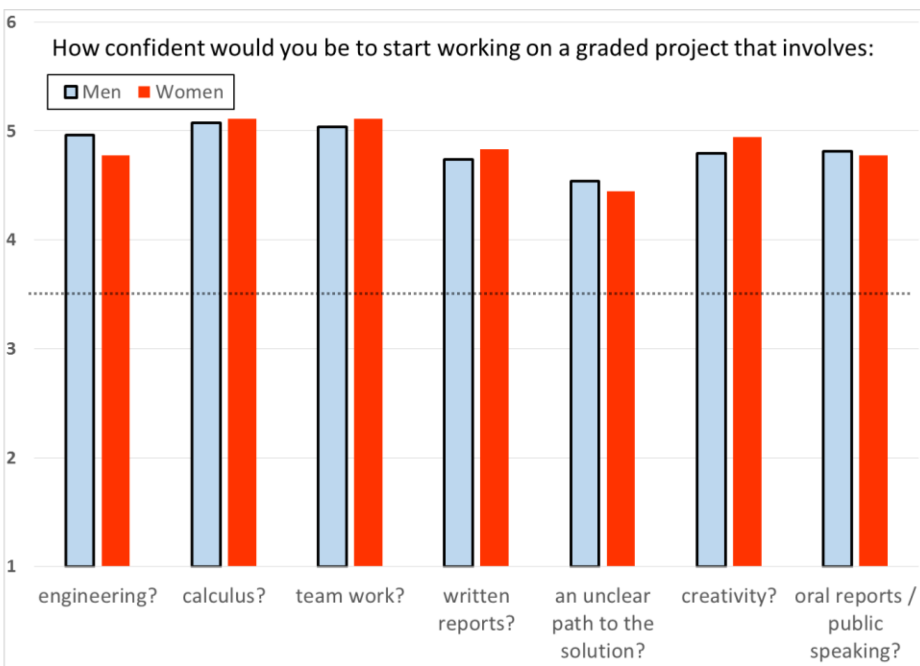


Figure 1. Responses to the (a) pre-class and (b) post-class survey questions on general engineering project self-efficacy, averaged separately for men (light blue/dark outline) and women (red/solid). A response of 1 indicated a feeling of very nervous and a response of 6 indicated a feeling of very confident. The dashed line indicates a hypothetical neutral response (respondents had to choose at least 3-slightly nervous or 4-slightly confident).

self-efficacy towards a project that involves "engineering," where men reported significantly greater self-efficacy than women. This trend was found in every year of this study. Figure 1b shows the same data but collected in the post-class survey. Self-efficacy significantly increased across all metrics, and no significant gender differences in self-efficacy remained.

In order to provide internal validation to the survey responses, correlations were made between a few survey items and students' prior experience. Figure 2 shows, for example, the positive correlation expected between a student's self-efficacy on projects that involve programming and the student's prior experience with writing computer programs. Before the class began, students who had never programmed before reported, on average, very low self-efficacy on this metric, while students with significant experience reported high self-efficacy. By the end of the class, average self-efficacy in this metric increased for students with all levels of incoming programming experience, and especially for those for whom this class was their first programming experience. Similar positive correlation trends were found relating self-efficacy in completing projects that involved electronics with the students' past experience with circuitry as well as self-efficacy in completing projects that involved calculus with the students' current math course (which ranged from one student in a pre-calculus course to multiple students taking post-calculus III coursework). It should be noted that this internal validation applies to the questions of self-efficacy to perform specific tasks, and not the specific questions of ambiguity tolerance and self-efficacy on open-ended questions that are most unique to the survey instrument developed in this work. Additional means to validate those questions are desirable, but remain the focus of future work.

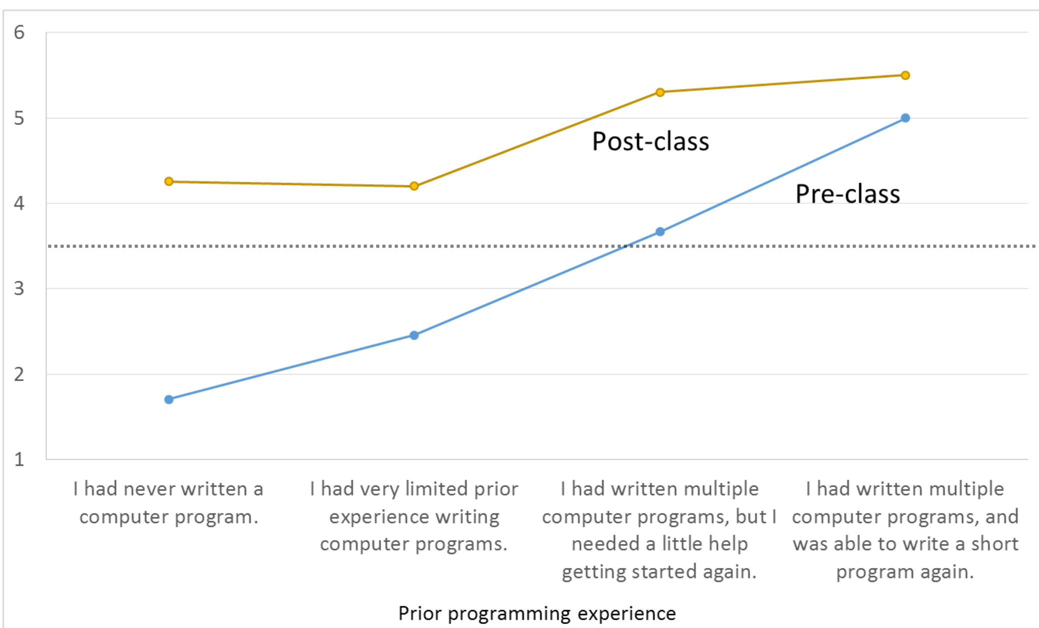


Figure 2. Average response to: "How confident would you be to start working on a graded project that involves programming?" for all students with where a response of 1 indicated very nervous and a response of 6 indicated very confident.

Next, we looked at survey responses for the more specific questions of ambiguity tolerance and self-efficacy on open-ended problems. Using a paired sample t-test, students had statistically significant growth in two of the metrics from pre-class to post-class. These results are shown in table 1. Besides these two metrics, the other metrics studied showed no statistically significant change. For completeness, these other metrics are listed in Appendix B. As an example of a metric with no significant change, self-efficacy in the ability to teach oneself new skills is shown in table 1. It may be that there was little growth in this metric because students began the semester already at a high level of self-efficacy. Further analysis of the other metrics that showed no average growth over the semester is ongoing.

Table 1. Average student self-assessment to questions about self-efficacy towards open-ended problems and ambiguity tolerance. Student responses were collected before the class began and after the class completed; the p-value indicates statistical significance of the difference in pre-class and post-class measurements. Responses used a 6-level Likert scale indicating the degree of agreement or disagreement with the statement. To account for differences in question phrasing, some questions used a reverse encoding of the numerical values. A numerical encoding of 6 always indicates the most positive response of increased self-efficacy and ambiguity tolerance and 1 always indicates the opposite, most negative response. Thus, an increase in numerical score is always the desired direction of student growth.

	Pre-class	Post-class	p
I would be nervous to start working on a problem that I haven't been taught how to solve.	2.09	2.44	< 0.01
I get frustrated or find it annoying when instructions are unclear and/or I don't know how to start a problem.	1.40	1.80	< 0.01
I am able to teach myself new skills.	4.12	4.08	0.6

Next, we examine the effects of the improv-inspired games. The Honors sections have been excluded from this analysis, since they were found to have significantly different average survey responses relative to the other sections, starting as soon as the pre-class surveys. Out of all of the questions included in the survey, only one had a statistically different response between the games and no games sections. This question was the ambiguity tolerance metric “I prefer working on problems that have an exact or single best answer.” Table 2 shows that students in the games sections did indeed indicate greater ambiguity tolerance (i.e., disagreement with the statement), though the difference from the no games section was found in the pre-class surveys, too, and no significant change in response was found in either group during the 4 week time period of the game intervention. All other survey metrics showed statistically insignificant difference between the games and non-games sections. The reason for the difference in pre-class surveys between the games and non-games sections was certainly unexpected and begs for further investigation.

Table 2. Average student response to "I prefer working on problems that have an exact or single best answer". Student responses were collected before the class began and after 4 weeks, when the "games" sections already had started including game breaks in class but the "no games" sections had not. This question was encoded so that a larger number indicates the more positive response of disagreement.

	Pre-class	Post-games intervention
Games	4.35	4.38
No Games	3.86	3.89
p	< 0.05	< 0.05

One of the shortcomings of this examination of the effects of the games is that only 4 weeks—8 class meetings—of the intervention was studied. This may simply have been not enough time to have a measurable impact. Alternatively, though students were somewhat randomly assigned to the different course sections, there were some statistically significant differences in student population between the sections. The signal-to-noise difficulties exemplified by the pre-class difference shown in table 2 may have interfered with the ability to find significant effects of the games.

While no statistically significant growth in either self-efficacy or ambiguity tolerance was found when comparing sections that did or did not play games for the first four weeks of the course, overall response to the games was positive. When asked "Do you think the games, in general, were a waste of class time or a good use of class time?", figure 4 shows that a large majority perceived them as a good use. Interestingly, students who did not find the games favorable reported generally lower self-efficacy across the varied metrics. Students with more negative perceptions of the games also were more likely to be non-native speakers of English, suggesting that perhaps nervousness in communication or non-familiarity with a less-structured learning environment may play a role.

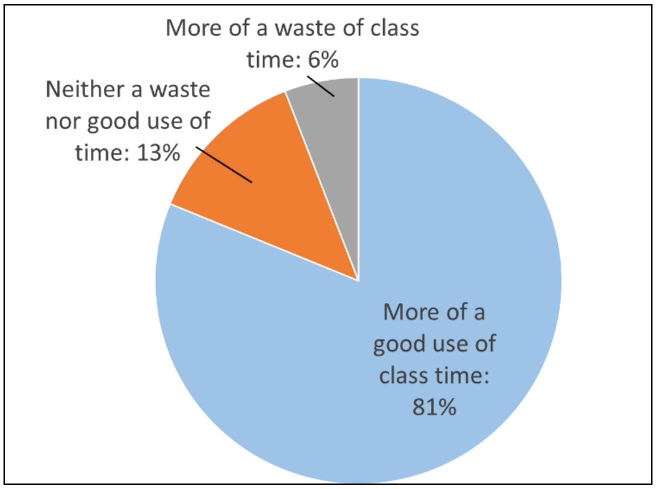


Figure 4. Response to survey question: "Do you think the games, in general, were a waste of class time or a good use of class time?"

In addition to the quantitative measure of students' perceptions of the games, an open response question requested comments, suggestions, or other feedback regarding the game breaks. A selection from the comments received is given below, grouped into comments received by those who indicated the games were a good use of class time (“Positive”), neither a waste nor a good use (“Neutral”), or more of a waste of class time (“Negative”). A consistent theme of the comments is that the games were fun and suggested a net benefit to course climate. Students largely reported an appreciation of the mental break the games create within the 100 minute class sessions. For the instructor as well, the game break was perceived as a nice break from defined instructional time and a helpful way to maintain a supportive, relaxed course climate.

Positive:
- *“…allowed for a break in class which was usually fun and also slightly educational…”*
- *“They were a fun activity and a good break from class. However, standing up in front of the class is always stressful for me…”*
- *“…I was able to laugh and learn at the same time…”*
- *“The games were a fun break from coding and other work. I enjoyed the ones that were team-centered…”*

Neutral:
- *“Great way to build relationships in class and make us all more comfortable with each other, but obviously doesn't teach us that much other than speaking skills.”*

Negative:
- *“Spending more time on teaching…would really help…students next semester.”*

Conclusions

In this work, a survey instrument was created with the goal of measuring engineering student ambiguity tolerance and self-efficacy on open-ended problems. It was believed that these two personal qualities lead to a student that had gumption and felt confidently uncomfortable, ready and willing to begin work on open-ended problems without extensive scaffolding or multiple reassurances from the instructor. The instrument included a number of questions about general project self-efficacy, and those were found to increase among women and men students taking our foundational engineering curriculum in their first year at university. Two metrics of ambiguity tolerance and self-efficacy on open-ended problems increased as well during this semester. While improv-inspired game breaks were found to be a useful addition to the course for reasons of improved course climate, they provided no measurable benefit to ambiguity tolerance or self-efficacy within the scope of this research.

In this work, we have assumed that gumption is a property of an individual student. An interesting consideration for future work is whether instead or in addition, the team dynamic plays a role. The teams for the design projects in this class were formed in a somewhat randomized manner, with all students working with different teammates on each project. Future analysis will track students from team-to-team through the three projects to examine the dependence of a student’s growth on their teammate’s characteristics.

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Appendix A-Description of a selection of improv-inspired games used in the class

1. No-Um Speech

Purpose - Requires active listening to teammates, using their ideas without hesitation; requires that students begin giving a solution without forethought to the outcome.

Gameplay- A team stands in a line in front of class and gives a speech on an impromptu topic. The topic could be related to course content. One person from the team begins speaking, and must continue talking without pause or saying a crutch word like um, uh, like, etc. As soon as the player says one of these words or pauses for > 1 s, a bell is rung and the next teammate must immediately pick up where the previous teammate left off. The answer must continue, as if a single person was saying the answer.

2. One Word at a Time

Purpose - Similar to No-Um Speech, but with greater emphasis on active listening to teammates; unlike No-Um Speech, no teammate can dominate the team's response.

Rules - A team stands in a line in front of class and gives an answer to an impromptu question. The topic could be related to course content. The answer is given from the entire team, with each teammate only giving one word at a time. The answer must continue quickly from each teammate in order, restarting with the first teammate after the last one, as if a single person was saying the answer.

3. Dice Stacking

Purpose - a fast-paced team exercise about collaboration, prototyping, hand-eye coordination, spatial skills, and visualization.

Rules - Student teams are given some time (~ 5 minutes) and 20-30 dice to prototype. Then, to demonstrate, each team is given access to all of the dice (~100) and exactly 60 seconds to build the tallest structure they can using just the dice. The dice tower must be free-standing, that is, it may not lean against or be on top of anything else. A good score is 11 dice high from the tabletop. A great score is 16 dice high. An amazing score is 21 dice high.

4. Complete the Drawings

Purpose - An exercise in creativity, sketching/drawing,

Rules - Developed as part of the Torrance Test of Creative Thinking (TTCT). Each student is given a sheet like [adobe99u.files.wordpress.com/2012/04/1278620722846.jpg] and then asked to complete the image(s). After 3-4 minutes, everyone puts their drawings in the front to make an "art gallery". Typically, I find undergraduates make drawings involving food and/or animals. A similar, more team-related concept is the game Exquisite Corpse.

5. **Fill 30 Circles**

Purpose - An exercise in creativity, sketching/drawing, idea generation

Rules - Each student is given a sheet of paper with 30 circles on it (Google “30 circles sheet” to download a printable copy) and asked to decorate and transform each circle. The goal is to make objects of out of all thirty circles by the end of a three-minute time frame.

6. **Office Supply Olympics**

Purpose - A team-building, creativity exercise that requires use of objects in non-standard ways

Rules - Teams are given bags with a collection of random office supply closet-type objects. By the end of ~7 minutes, each team must present a game that they have created using these objects (and, if you allow, other supplies that they may happen to have with them). The class can vote on a winning, “best” game.

7. **Fermi Problems**

Purpose - Teaches number and unit fluency; requires students to make assumptions and estimates and ultimately give answers that they know are incorrect, or at least of poor precision. Nevertheless, they see that their answer isn’t “bad”, and in fact is similar to what other smart people would derive and can still be useful to begin a discussion.

Rules – A good ‘go-to’ game, asks teams to come up with a reasonable value for a quantitative question whose answer is unknowable to precision. Plenty of lists of example Fermi problems exist on-line. Each team may use pencil, paper, and calculator, but not Google or other resources. After ~2 minutes, each team reports to the class their numeric answer as well as a list of assumptions/estimates used in forming the answer. Following this, the class quickly discusses the results.

8. **Blind Orthography**

Purpose - Practice with orthographic projection, reinforcing the skill through connecting visual and oral representations

Rules - One student holds an object with her back to the chalkboard, facing the class and holding an object that both she and the class can see and identify. She describes in words the shape of the orthographic projection of the object. A second student, who does not know what the object is, faces the board and draws on the board the orthographic projection based on the oral description from the first student. The goal of the game is for the second student to guess what the object is.

9. **Who's the Client?**

Purpose - A team-building exercise that reinforces active listening skills; practice with product design principles

Rules - Team A leaves the room. While they are out, Team B decides on a product that Team A must design and announces it to the class. Then, Team C decides on a specific client for that product and announces that to the class (the instructor might need to step in to make sure that the combination will work). Team A is then brought in to the classroom and Team B tells them the product they must design. In turn, each member of team A must then announce a feature, objective, or function for the product, with the first teammate starting again after the last teammate. If Team C agrees that the client would want that objective or function, they ring a bell. The goal is for Team A to get more and more bell rings until finally they can guess who the client is. No member of Team A can negate a previously mentioned feature, objective, or function, but only can build upon the list. It helps for the instructor to write down each thing as it is given, putting a star next to those that get bell rings.

10. **Random Slides**

Purpose – Learn to rely on the material on a slide to guide your speech, as opposed to memorizing a script; learn to describe images fully and talk an audience through complicated figures

Rules – Students line up, each one in turn must fill 1 minute talking about a random slide being projected on the screen that they've never before seen. Especially useful to give intro slides, a graph slide, an outline slide, conclusions slide.

Appendix B-Self-efficacy and ambiguity tolerance questions included in student surveys

For all items, a six point Likert scale response was collected: 1 – Strongly Disagree, 2 – Disagree, 3 – Slightly Disagree, 4 – Slightly Agree, 5 – Agree, 6 – Strongly Agree. The question order was scrambled for each survey, and questions about demographics and past experience were presented after these questions so as to avoid survey priming.

	Year(s) in survey
General Engineering Self-Efficacy (used for internal validation)	
I would be confident to start working on a graded project that involves engineering.	1, 2, 3
I would be confident to start working on a graded project that involves calculus.	1, 2
I would be confident to start working on a graded project that involves team work.	1, 2
I would be confident to start working on a graded project that involves written reports.	1, 2
I would be confident to start working on a graded project that involves computer programming.	1, 2
I would be confident to start working on a graded project that involves electronics (basic circuitry).	1, 2
I would be confident to start working on a graded project that involves oral reports / public speaking.	1, 2
I work well on my own.	1, 2, 3
I work well in a group setting	1, 2, 3
Self-Efficacy on Open-Ended Problems	
I am able to teach myself new skills.	1, 2, 3
I would be confident to start working on a graded project that involves creativity.	1, 2, 3
I would be confident to start working on a graded project that involves an unclear path to the solution.	1, 2, 3
I would be nervous to start working on a problem that I haven't been taught how to solve. *[reverse encoding]*	1, 2, 3

Ambiguity Tolerance	
I prefer working on problems that have an exact or single best answer. *[reverse encoding]*	1, 2, 3
I get frustrated or find it annoying when instructions are unclear and/or I don't know how to start a problem. *[reverse encoding]*	1, 2, 3
I prefer when someone approves of my decisions before I act. *[reverse encoding]*	1, 2, 3
It's important to me to know whether my answers are correct. *[reverse encoding]*	1, 2, 3