



Integrating 'Design Challenges' into a Freshman Introduction to Mechanical Engineering Course

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Introduction

It is currently widely recognized that retention of engineering students can be enhanced by including introductory engineering courses into the first-year engineering curriculum in addition to the usual math and science classes¹⁻³. Moreover, the inclusion of engineering design projects within the first-year curriculum, or “cornerstone design projects”, provides students with insight into the differences between engineering and science, and increase students’ motivation and interest in engineering⁴⁻¹¹. One team of researchers has shown that the incorporation of hands-on design projects in the first year provides “experiences of mastery” that enhance feelings of self-efficacy in, and increases the likelihood of, success in engineering¹².

The benefits of integrating design problems into the curriculum during the freshman year are undeniable, however such integration typically requires a heavy commitment in faculty time and in resources^{3,10,11}. At the Virginia Military Institute, a small state supported military college in the south, the amount of design-based project content in the curriculum of its 1-credit introduction to mechanical engineering course, ME-105, has been increased through the introduction of a ‘design challenge’ hovercraft development project. All students are required to take this introductory course during the fall semester of their freshmen year. Design-based projects now constitute about 40% of the current course curriculum, with the remainder of the labs/projects consisting of both standard “follow the procedure and report a result” style of laboratory and skills development labs, such as basic welding and machining. It should be noted that the ‘design challenge’ hovercraft project has been implemented without additional staff or space resources.

The purpose of this paper is to examine the effects of design-based projects referred to as ‘design challenges’, on the retention of students in the Mechanical Engineering program, as well as to explore the preferences of engineering students towards design-based projects versus conventional laboratories. In the first section of the paper, the original lab sequence used in ME-105 is summarized and the design content of the labs is presented. In the next section, a description of the revised laboratory sequence is given, along with results of a survey used to gauge students’ subjective enjoyment of the ‘design challenge’ design projects. Finally, retention results and survey results are discussed and it is shown that students who elect to stay in mechanical engineering demonstrated a statistically significant preference for ‘design challenge’ design-based project versus conventional labs.

Initial Lab Sequence

Prior to the introduction of the ‘design challenge’ hovercraft design-project in the fall semester of 2012, the first-year Mechanical Engineering course, ME-105, included a total of 6 hands-on labs, performed over 10 weeks of the semester. For the balance of the semester students received lectures on such topics as GPA calculation and management, academic standards, and explanations of the various areas of concentration available in Mechanical Engineering and an introduction to ASME. Hands-on labs consisted of:

- Basic Welding
- Introduction to Machine Shop Equipment and Practices
- Thermo-couple lab
- Engine Tear-Down lab
- ‘Design Challenge’ Clock using the LEGO Robotics system
- Materials lab

Of these labs, only the ‘design challenge’, LEGO clock project, involved actual mechanical design activities, making for a total of 15% of class time spent on design oriented content. For this lab project, teams of two or three students designed and built a gear-reduction system to drive the second hand of a clock at 1 revolution per minute using one of the DC motors available in the LEGO Robotics kit as the power input. Students were instructed on the basics of gear train kinematics in a 30 minute lecture and were then set free to try to design and build the most accurate clock in the class. Building the most accurate clock in this case was the goal of the ‘design challenge’, and the winning team received bonus points on their project. In the process of realizing their paper designs students soon discovered the effects of friction and loading of the motor on the performance of their clocks. More often than not student teams were able to find creative engineering solutions for tuning their clocks, and the competitive nature of the task made it one of the more enjoyable labs for students. At the end of the semester, many of the course evaluations specifically mentioned the ‘design challenge’, LEGO Clock project, as the most interesting project in ME-105 and suggested that more labs like it be added to the course.

Revised Lab Sequence

As described above, in the original curriculum for ME-105, the only lab involving mechanical design was the LEGO clock project. In an effort to bring more design and build experiences into ME-105, a leaf-blower powered hovercraft project was introduced in the course in the fall 2012 semester. The hovercraft project took the place of the materials lab and one of the class lecture periods, for a total duration of 3 seventy-five minute class meetings, increasing the design content of ME-105 to about 40%. During the first class meeting, the basic physics of hovercrafts was covered, and the engineering ‘design challenge’ posed. In particular, students were challenged to design a hovercraft capable of carrying a 200 pound payload using a battery powered leaf blower, a 4’x4’ sheet of plywood (cut into any shape) for the hovercraft “deck”, and 6-mil thick plastic sheeting for the hovercraft skirts. Groups of 3 or 4 students were allowed to self-select as a team for the design project, and bonus points were to be awarded for the hovercraft that could glide the furthest. While rough designs exist on the internet for hovercraft, the design teams quickly realize that “the devil is in the details” and a cleverly designed sealing method for the skirt can make the difference between designs that work and almost identical looking designs that don’t. Throughout the process of design and construction, faculty members conversed with the teams, asking them to explain their designs, and, in the case where something didn’t work as planned, helping the students to strategize about how to find the problems with their designs. Through this project, students gained experience in an open-ended engineering design problem, as well as in fabrication techniques and collaborative problem solving.

In addition to the two ‘design challenge’ projects, the thermocouple lab was replaced with a 2-week long Rocket lab to demonstrate thermodynamic principles. The rocket lab was considered

by students to be a “fun” lab, but was conventional in the sense that it included no design activities.

During this introductory semester for the hovercraft ‘design challenge’ and the more conventional rocket lab it was decided to survey the students in the class to determine the students’ subjective enjoyment of both the design-based projects as well as their enjoyment of the conventional labs in the course. In addition, the survey asked students whether they were planning to stay in Mechanical Engineering or were considering a change of major. The survey is shown below.

ME-105 Student Survey

As part of the ME departments ongoing effort to improve our Intro to Mechanical Engineering course, it is important for us to know what’s working and what’s not! Please take a few minutes to rate your enjoyment of the lab exercises listed below:

1. Lego Clock design lab:
 - a. I really enjoyed this lab and wished that there were more like it in the ME-105 curriculum.
 - b. I generally enjoyed this lab exercise
 - c. This lab was OK; not great, not bad.
 - d. I didn’t enjoy this lab
 - e. I strongly disliked this lab and recommend that it is discontinued.

2. The Rocket Lab:
 - a. I really enjoyed this lab and wished that there were more like it in the ME-105 curriculum.
 - b. I generally enjoyed this lab exercise
 - c. This lab was OK; not great, not bad.
 - d. I didn’t enjoy this lab
 - e. I strongly disliked this lab and recommend that it is discontinued.

3. The Engine Tear-Down Lab
 - a. I really enjoyed this lab and wished that there were more like it in the ME-105 curriculum.
 - b. I generally enjoyed this lab exercise
 - c. This lab was OK; not great, not bad.
 - d. I didn’t enjoy this lab
 - e. I strongly disliked this lab and recommend that it is discontinued.

4. The Hover Craft Lab
 - a. I really enjoyed this lab and wished that there were more like it in the ME-105 curriculum.

- b. I generally enjoyed this lab exercise
 - c. This lab was OK; not great, not bad.
 - d. I didn't enjoy this lab
 - e. I strongly disliked this lab and recommend that it is discontinued.
5. Having now completed most of your first semester as an ME at VMI, would you:
- a. Like to stay in the Mechanical Engineering Program
 - b. Like to switch to Civil Engineering
 - c. Like to switch to Economics and Business
 - d. Like to switch to "Other", (some unlisted major)

This survey was administered to students in all sections of ME 105 on the last day of class along with the course evaluation forms.

Results

In order to develop a baseline for the effect of changes in ME 105 design content on retention, the average percentage of students leaving mechanical engineering as a function of semester (i.e., at the end of the semester) was plotted in Figure 1 below for the time period from the beginning of the 2008 academic year through the end of the 2011 academic year.

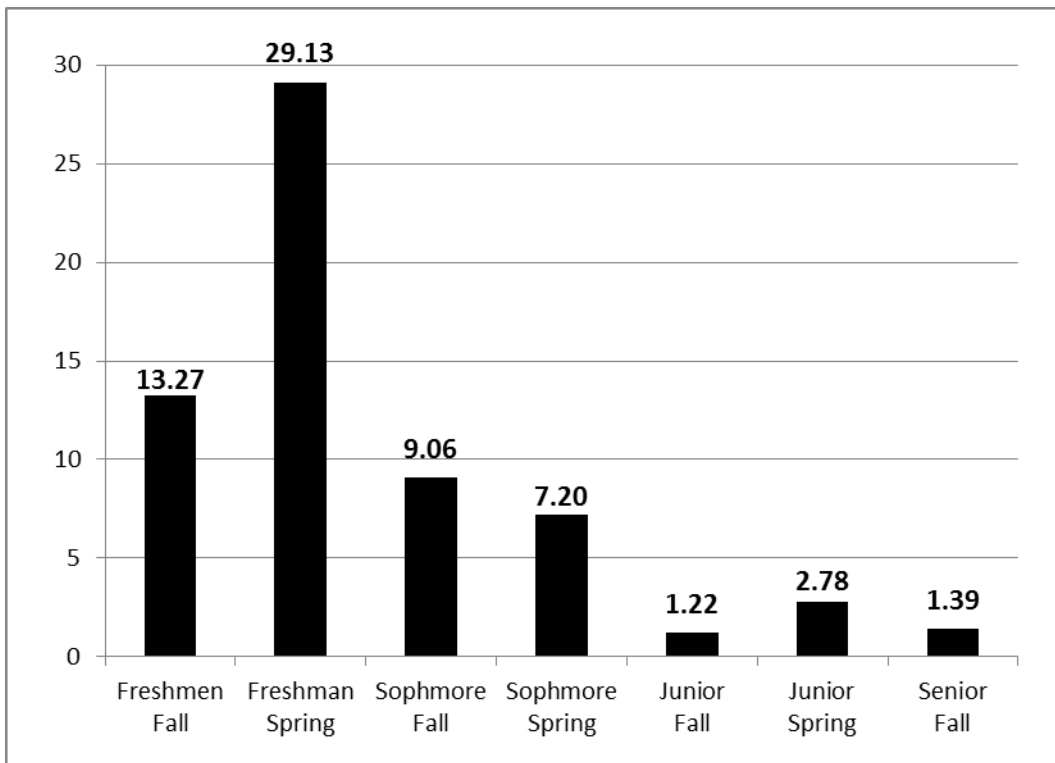


Figure 1: Percentage of Students Leaving Mechanical Engineering vs. Semester

Over this four year period, an average of 13.27% of the students enrolled in mechanical engineering withdrew from mechanical engineering (either by changing majors or leaving the institute) at the end of their first semester. Many students left because of problems in navigating the introductory calculus and chemistry courses while others report that they felt “Mechanical Engineering just wasn’t what they thought it was”. Attrition spikes at 29.1% before students begin the fall semester of their sophomore year. All told, only 36% of the students that started in the mechanical engineering program graduate.

The percentage of students leaving mechanical engineering at the end of their first semester, i.e., after their participation in the ME 105 course, is plotted for each academic class during the past 5 years in Figure 2 below.

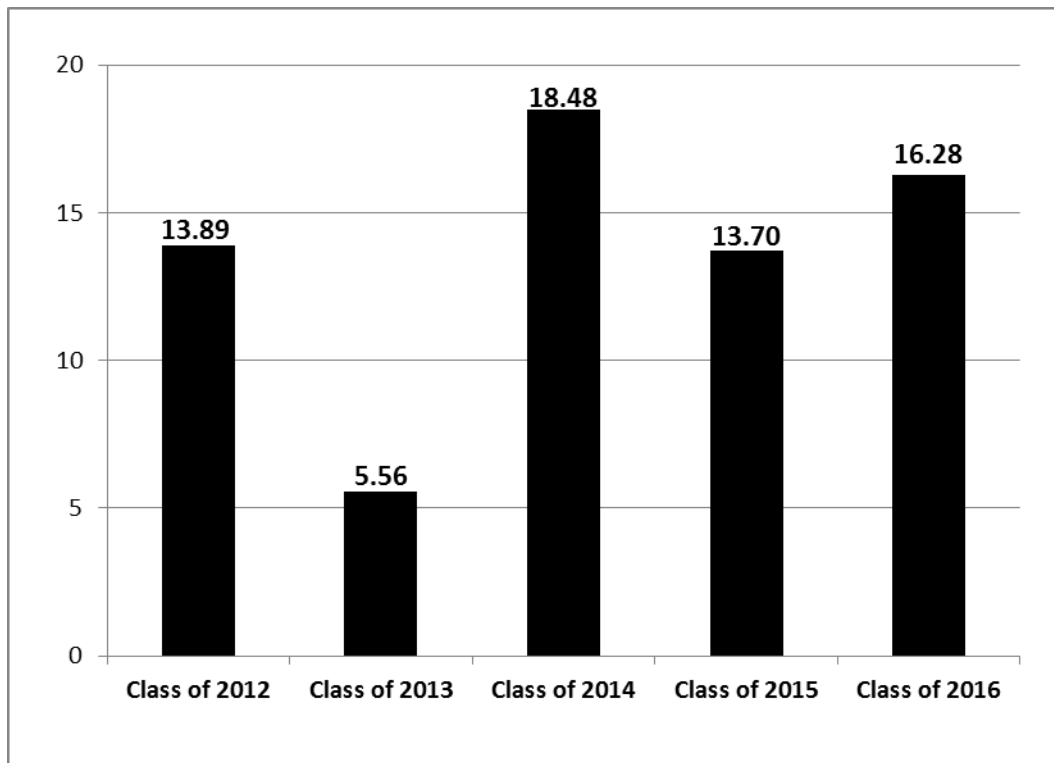


Figure 2: Percentage of Students Leaving Mechanical Engineering Immediately after the First Semester vs. Academic Class

The most notable feature of this data is that the Class of 2016, which was the first class to have taken the ME-105 course with enhanced design content, experienced a 16.28% attrition rate as of the completion of the fall 2012 semester. This is noticeably larger than the average 13.27% of students leaving mechanical engineering after their first semester over the previous four academic years, (2008-2011) shown in Figure 1. Given the reported benefits of first year design experiences at other universities, it was anticipated that an immediate reduction in the percentage of students leaving mechanical engineering would be observed at the end of the fall 2012 semester. In order to check on the statistical significance of this apparent difference a one tailed hypothesis test was performed comparing the proportion of students leaving Mechanical engineering between 2008 and 2011, (sample size $N_1=309$), and the students leaving Mechanical engineering after the fall semester of 2012, (sample size $N_2=86$). A significance level on the one

tailed test of $p=.063$ was obtained so it could not be concluded that there was any real difference in the proportion of students leaving Mechanical Engineering before and after more design content was added to the ME-105 course. While this result is somewhat surprising, it remains to be seen whether the change in design content in ME-105 will have an effect on future attrition from the mechanical engineering program for this particular cohort of students.

The survey conducted at the end of the ME-105 course concerning the students' subjective enjoyment of the labs/projects provides some possible insight as to why there were no observed improvements in the retention rate at the conclusion of the fall 2012 semester. In order to analyze the survey, a Likert scale was used to convert students' multiple choice selections for questions 1 through 4, to a numerical value between 1 and 5. The most positive opinions of a given lab, choice "a", was converted to a 5, while the most negative opinion, choice "e", was converted to a 1. Notice that skills labs such as the Basic Welding and Machine Shop were not included in the survey. Results for the LEGO Clock Lab and the Hovercraft lab were added up to give a score between 2 and 10 for labs with design content. Similarly results for the rocket lab and the engine tear-down lab were added to give a score between 2 and 10 for the conventional labs. These survey results are shown below for the students who have elected to stay in mechanical engineering and for those who have elected to leave mechanical engineering at the end of the fall 2012 semester. The results for the 'design challenge' projects (LEGO Clock and Hovercraft projects) are shown in Figure 3 while Figure 4 shows the results for the conventional labs (Engine tear-down and Rocket labs).

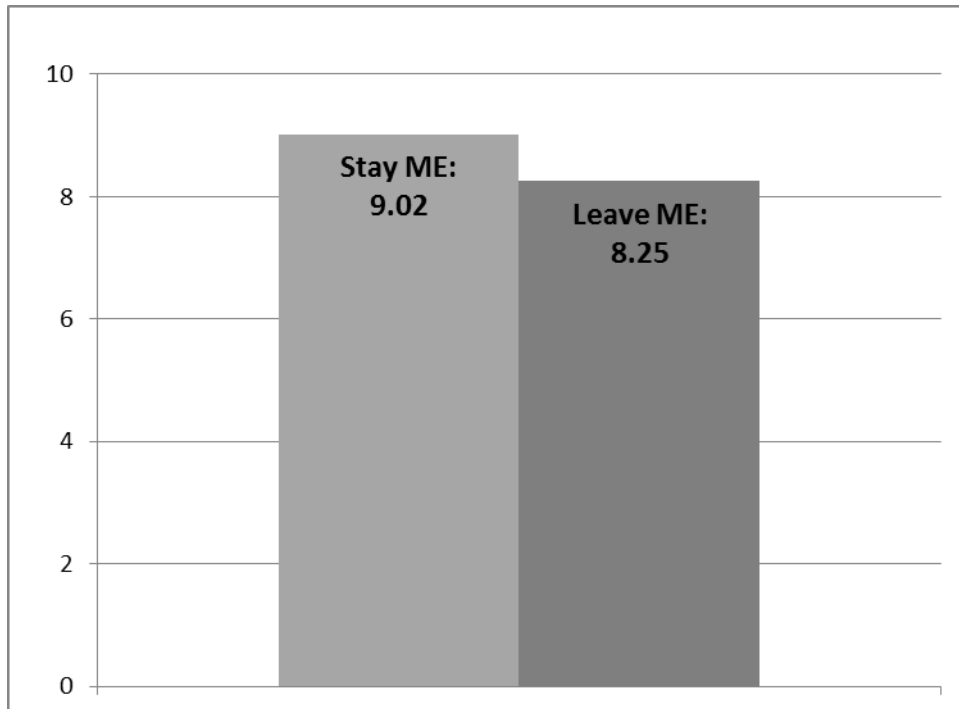


Figure 3: Student 'Design Challenge' Projects Satisfaction (10 = most positive opinion): Comparison of results for students planning to stay in ME or to leave ME

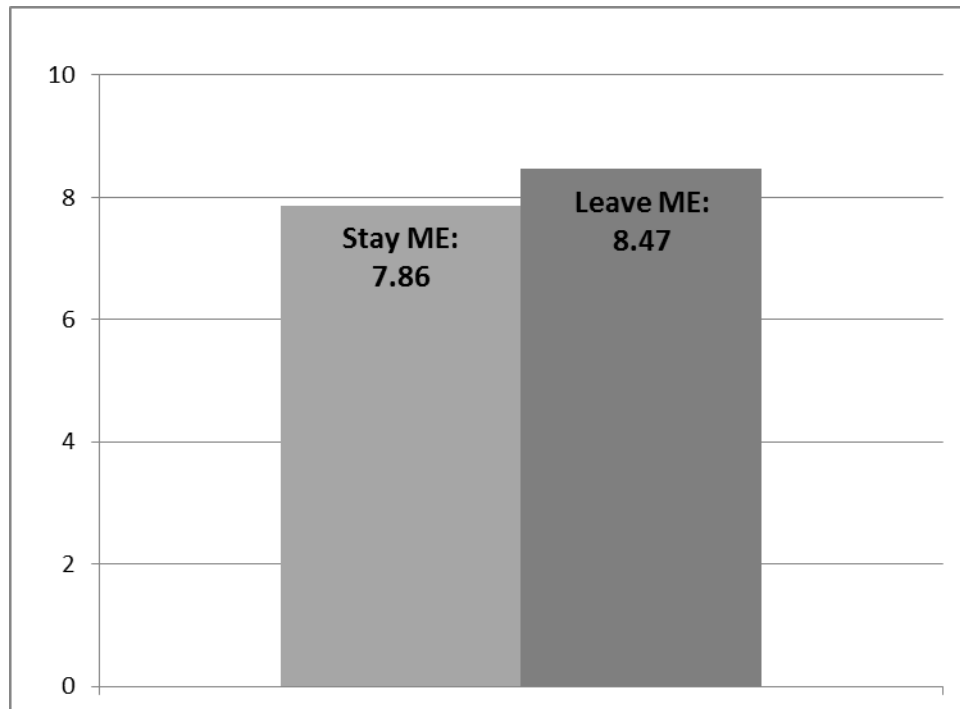


Figure 4: Student Conventional Lab Satisfaction (10 = most positive opinion): Comparison of results for students planning to stay in ME or to leave ME

Examination of the results presented in these two figures shows a clear preference by students who elect to stay in mechanical engineering for ‘design challenge’ design-based projects over conventional labs (9.02 vs. 7.86). In the case of students who decided to leave mechanical engineering after the first semester, the results are reversed (8.25 vs. 8.47). These students prefer the well-defined procedures of conventional labs versus the uncertainties and vagaries of design-based projects. Formal hypothesis testing bears this observation out.

A one tailed t-test performed on the data indicates that students staying in mechanical engineering prefer the ‘design challenge’ design-based projects more than students leaving mechanical engineering with a statistical significance of $p=.0034$. Furthermore, it was found that students staying in mechanical engineering after the first semester have a statistically significant preference for design-based projects compared to conventional labs with a measured p value less than .001 from the one tailed t-test performed on the data.

Conclusion

Based on the survey results one possible interpretation of the higher than expected attrition from mechanical engineering at the end of the fall 2012 semester is that students who are not comfortable with, or interested in, design-based projects, are discovering this early on, due to the integration of more design-based projects into the ME 105 introduction course, and are, therefore, seeking more appropriate majors earlier than in the past. Since the survey data seems to indicate a possible correlation between preference for design-based projects and a student’s decision to stay or leave mechanical engineering, this preference may provide an indicator for retention. Therefore, it is feasible, although not yet certain, that an increase in retention after the

freshman year, and subsequent increase in graduation rates will be observed for those students who elected to stay in mechanical engineering at the end of the ME 105 course. The authors plan to follow these retention and graduation rates over the next 5 years.

Based on the survey results, the authors also plan to integrate more ‘design challenge’, design-based projects into the ME 105 Introduction to Mechanical Engineering course since the clear satisfaction for these types of projects by students electing to stay in mechanical engineering may provide greater motivation for those students to continue on in mechanical engineering beyond the freshman year.

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Appendix: Description of Hovercraft Design Challenge

1. **Week-1:** Begin the lab by showing the students a YouTube clip of an LCAC military hovercraft, (<http://www.youtube.com/watch?v=PmCcik8BQQY>). This craft is capable of moving a 60 ton Abrams tank at 40 knots over water, 6 knots over land, and easily grabs the interest of students through its brute strength and heavy duty design. After viewing the video clip and discussing specs for the LCAC, students are asked to estimate the weight of the hover craft as well as the pressure required to lift it. Typically, students overestimate the pressure required, guessing values on the order of 100psi possibly as a consequence of seeing the massive engines that are required to drive the craft. It is at this point where the concept of pressure as a force distributed over an area is reviewed, and it is shown that even very small pressures are capable of lifting the large craft. Students are then queried as to the purpose of the hovercraft skirt; in particular why can't the craft simply propel itself off of the surface without a skirt. The importance of the pressure seal maintained by the skirt as well as the generation of lubricating film of air flowing between the skirt and the surface is emphasized. At the conclusion of this introductory discussion, the students have a fairly good understanding of the physics behind the operation of a hover craft as well as some of the design features that they would need to include in a hovercraft if they were setting out to build their own hovercraft.

Next, students are presented with the hovercraft design challenge for which they are allotted a total of three 75 minute lab sessions. The specifications for the design challenge are given as follows:

- a. Must build a hovercraft that can lift 200 pounds and using a small battery powered leaf blower. Measurements of the static pressure generated by the leaf blower show that it is capable of sustaining about .4 psi
- b. The “deck” of the hover craft must be built from a 4'x4'x.75” sheet of OSB plywood, however, students are free to cut this sheet into any shape they want or even divide it into multiple platforms.
- c. 6 mil plastic sheet is provided as the default skirt material, although students may opt to use other materials if they want. Inner tubes, rigid insulating foam and flexible plastic edging used in landscaping are examples of materials students have adapted to the hover craft design application in the past.
- d. Student design teams are limited to 3-4 members

During the first laboratory session students are given the assignment to develop an initial design for their hovercraft based on the introductory lecture, and resources that they find on the internet and/or in the library. Within 3 days after the first lab session, each design team is required to provide the instructor with rough drawings and explanations of their design. The intent is to provide the instructor with enough time to critique designs and make suggestions to the student design teams before the next lab session.

2. **Week-2:** Construction of the hovercrafts. During this session students fabricate the deck and skirts they designed and assemble them. Often students are unfamiliar with the tools available in the shop and a fair amount of effort on the part of the instructor is devoted to

making sure students use tools safely and for the appropriate job. Depending on the complexity of their designs, students are able to perform their first trial “float” during week-2 of the lab. This is where paper designs and the real world diverge. Typical problems/malfunctions include:

- a. Poor sealing of the skirt to the deck
- b. Skirts that do not uniformly seal against the floor
- c. Hover craft designs that pressurize successfully but do not provide enough flow under the skirt to create a lubricating film underneath the craft.

At this point in the process instructors try to facilitate the trouble shooting process, asking questions about the design and trying to get the students to observe the source of problems rather than jumping to presumed solutions. Designs that “almost work” but which are fundamentally flawed are particularly frustrating to students, (for example plastic skirt stapled to the plywood deck may seal better as more staples are added, but never well enough for the hovercraft to float and glide), and the instructor may have to subtly guide the students to think about alternate ways to solve the problem, possibly using other materials around the shop to seed new ideas or brainstorming sessions. Probably the most difficult part of the hovercraft design challenge for instructors is to help students see the problems in their designs without giving them solutions outright. For the students, the realization that small details in a design can be the difference between something that works and something that doesn’t is an extremely valuable lesson which cannot be learned if instructors are involved too directly in their design.

Week-3: Complete construction and test: In the third and final week of the design challenge, students make any final adjustments to their hovercraft that are needed, (Note: students are encouraged to work on their hovercraft outside of class time so that the third lab session should not involve major amounts of construction), and then submit their design for a test run. One student from the design team kneels on the deck of the hovercraft while the rest of the team pushes the craft down a hallway. Hovercraft trials always attract a crowd, and collisions with the walls as well as “tippy” designs make for a crash filled spectacle reminiscent of NASCAR racing. In the spirit of competition, the team that glides the furthest is awarded with bonus points. All teams submit a final report that describes their initial design concept, and then presents the adaptations/innovations that the team incorporated to create a functioning design.