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Improving Design of Experiment Skills through a Project Based Fluids Laboratory

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1.0 Introduction

The educational community recognizes that the typical engineering curriculum has steadily decreased the emphasis on the study of experimental techniques for problem solving.[1] Industry partners suggest there is a need to place a greater emphasis on the study and practice of experimentation in the engineering curriculum.[2] These recent trends are supported by results from exit interviews of Mechanical Engineering (ME) seniors at Rochester Institute of Technology (RIT). Students commented that more hands on data acquisition and open ended projects throughout the curriculum would be extremely valuable in preparation for their capstone senior design course.

Laboratory courses, which are often used simply to demonstrate theoretical material, are an excellent opportunity for students to learn and practice problem solving skills. However, we must move away from traditional canned experiments, with step by step instructions and known outcomes, to open ended experiments that challenge students intellectually and encourage creativity. This experience is consistent with the Kolby Learning Cycle,[3] which is completed by asking the questions, *why, what, how,* and *what if*? The traditional canned experiment often gets from *why* and *what* in the lecture portion to *how* in the lab portion, but in many cases does not give the student the opportunity to ask and answer *what if*? Open ended projects require students to not only complete the cycle once, but to make several revolutions before a solution is found.

As a pilot, the ME department at RIT decided to revise a Thermo/Fluids Laboratory from the current theme of theory verification and deviation to an open ended project based experience. The development of the pilot was based on studies which demonstrated that open ended projects are consistent pedagogically with learning cycles and seen by the students as a critical component of their education. For example, students at the University of Pittsburgh, who were enrolled in a special pilot course developed an Automatic Data Collection Laboratory.[4] Waitz (1997)[5] describes an experimental projects lab pilot at Massachusetts Institute of Technology that resulted in excellent student feedback over 3 years. Mahendran (1995)[6] describes the success of a project based civil engineering course at the Queensland University of Technology. Dally and Zhang (1993)[7] from the University of Maryland demonstrated the benefit of students completing a design and redesign cycle for their open ended projects. Results from these studies are consistent with those found in our pilot course.

This paper describes the evolution of a project based Fluid Mechanics Laboratory from an initial evaluation of the traditional laboratory, through four iterations of the pilot course. A complete assessment was performed and improvements made at each stage. The 3rd and 4th iterations of the pilot are described in detail, including a sample list of the students projects. Finally, the survey results are provided and compared to the pilot course goals.

2.0 Original Course Description and Evaluation

The traditional Thermo/Fluids Laboratory at RIT, is a one credit course that supports the prerequisite Thermodynamics course and the co requisite Fluid Mechanics course. The lab meets for a 2 hour lecture on the theory relevant to the experiment one week and 1 hour lab the following week. The course content is shown in Table 1.

Table 1. Original Course Syllabus

Centrifugal Pump (2 weeks)
Reynolds Pipe Flow (2 weeks)
Refrigeration (2 weeks)
Steam Power Plant (4 weeks)

Student evaluations were typically very good, indicating that the instructor was well organized, the labs were well laid out, procedures were easy to follow. However, they complained that too much emphasis was placed on the lab write up and grading on technical writing was too strict. Instructors observed that the students' reports were weak on experimental analysis and critical evaluation of data. They had difficulty identifying and quantifying sources of error. The majority would cite that error was due to old or outdated equipment, not mentioning the assumptions that were made in applying theory to the experiment. In addition, students had difficulty with the theory and objective sections indicating that they had trouble identifying the main purpose of the experiments. Instructors further observed that the labs resulted in a low level of student (and instructor) frustration, but also a low level of student (and instructor) excitement, because the lab work required low level thinking skills.

The hypothesis and motivation for this pilot course was that the reason for these difficulties is that the students had no ownership in the experiments. Students were not asking the questions themselves, but were filling in blanks on a data sheet. They were not involved in setting up the experimental apparatus or measurement devices. Therefore, they had no feel for the physical mechanisms responsible for the measurement and the resulting inherent error. The critical analysis was not attempted until after the students left the lab and began to write up the report. This analysis should have occurred while the experiment was being performed. Some attempts were made to encourage this critical thinking by having the students answer a set of questions before leaving the lab. The questions and answers were often simply repeated in their reports with no integration into the thought process and no indication that the students understood.

The pilot course was designed to give the students ownership in their project and thus give the students responsibility for their own learning. The following specific goals were set for improving the students experience in lab.

The new course should create an environment in which students will:

i. become motivated to critically evaluate a problem, be creative, self directed and explore alternative solutions on their own.
ii. gain confidence in their ability to design, build and conduct experiments and to see the project through to completion.
iii. improve their overall project management skills, including team work, time management, technical writing and formal presentation in preparation for coop and senior design.
iv. obtain an overall exposure to a variety of fluid mechanics topics.

3.0 Evolution of the Pilot Course

The course evolved over 4 quarters or sections of the Thermo/Fluids Lab course. In each of the pilots, student teams of 2, 3 or 4 were involved, as in the original course. This section describes the first 2 iterations of the pilot and the following sections detail the final 2 versions.

The first test was to determine how students responded to the exercise of designing their own experimental procedures. Students were given a simple experimental apparatus of a draining tank with interchangeable drain sizes. They were asked to design and conduct an experiment that would answer a question that they choose. This experiment replaced the 4 week steam power plant experiment in Table 1. The positive results were that student reports improved compared to those of the first three labs. The experimental objectives were clear and the conclusions focused on whether these objectives were met. In addition, students required less help from the instructor to determine what to write up. Of course these improvements were due in part to continuous learning through out the quarter from reviewing corrections made to the previous 3 labs. The level of difficulty included in the chosen objectives ranged widely from barely acceptable to outstanding, with the majority being “average”. Students commented that they were not too excited about the draining tank and would like to choose something on their own.

The second test was to allow the students to design and build their own apparatus, once their proposal had been approved by the instructor. Table 2 shows the hand out and schedule for the project. Students presented their proposals to the class in order to inspire weaker students and increase overall project quality. Students commented that they enjoyed the project more than the canned experiment, but they would like more direction in choosing a project. When the students were choosing a project, they were covering conservation equations in lecture but had not yet covered real pipe flow. In some cases, the students commented that when they did cover the material in class, it was clearer and more interesting. Students suggested that more time should be given to building the project, and time allowed after demonstration day to improve their design before final grading. Other comments included - more clarity for how grades were determined and clearer expectations. These observations were incorporated into the 3rd and 4th generations of pilot course.

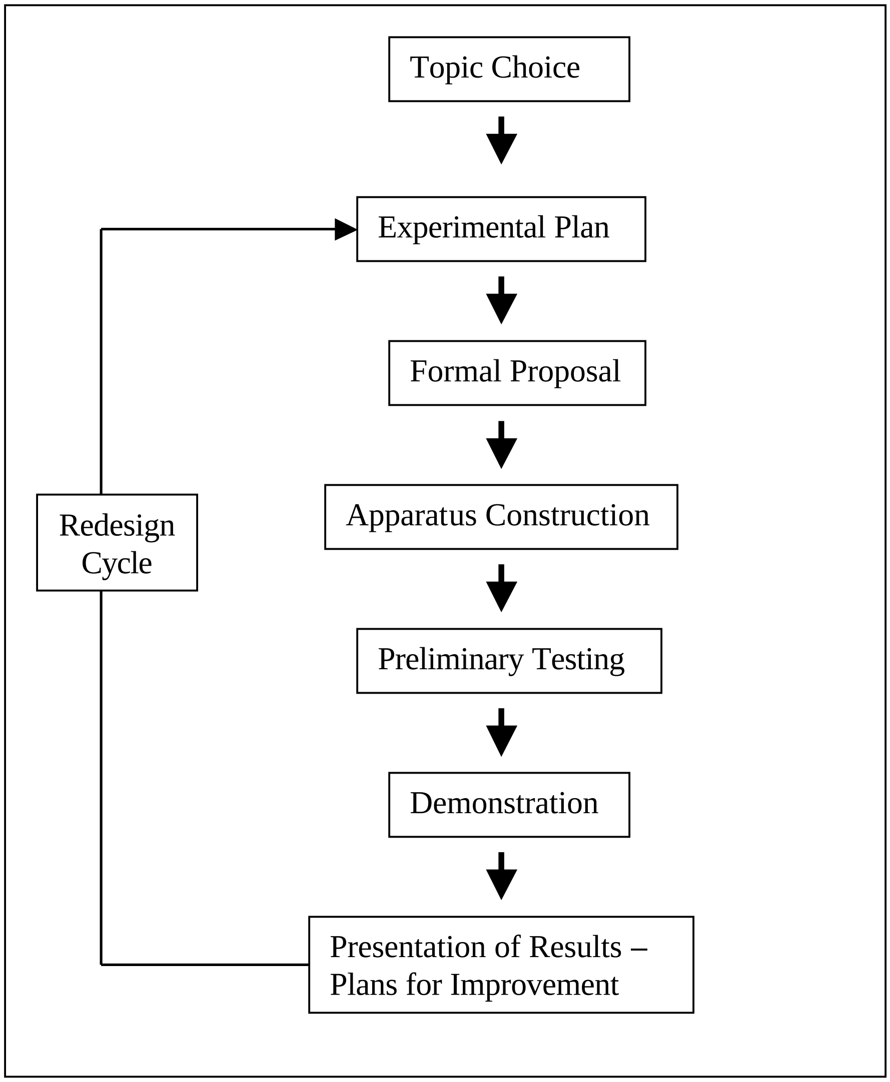
Table 2. Project Description Given to Students - Pilot Iteration 2

ThermoFluids Lab I Project Objective Design, build and conduct an experiment that investigates an area of fluid mechanics. Time Line Week 7 In class, brainstorm and decide on a project. Turn in a page with the name of the experiment, the objective of the experiment and a rough sketch. Include your team name and members. Week 8 Meet in the lecture room during the two hour scheduled time. Give a formal presentation of your proposal. Include one page each of the following: Title page, Objective, Theory, Apparatus, Procedures (what will be measured and what will be calculated) Materials List and budget. 6 pages total. The presentation should take 5-7 minutes max. I encourage you to use power point. Week 9 Meet in lab during 1 hour time. Demonstrate your experimental apparatus. Week 10 No class meeting. Final report due Friday May 12. Facilities If your team needs space to store equipment or work on the design of your experiment, let me know. There are rooms available. The main purpose is for you to explore an area of Fluids that interests you and to gain some experience in experimental design and set up. I want you to have fun with this. *Good Luck*!!

4.0 Pilot Course Description

This section describes the 3rd and 4th versions of the pilot course. Student teams completed a design, evaluation and redesign cycle as illustrated in Figure 3. Students were encouraged to determine ways to improve their designs and to set their own goals. The instructors role was to aid the students in evaluating these goals and to determine if they were realistic yet challenging enough for the allotted timeline.

Figure 3. Design, Redesign Cycle for Experimental Project
Pilot Iterations 3 and 4



The draw back of allowing time for the design redesign cycle, is that the majority of the course is taken up with the project. In fact, one argument against project based labs is that the students are focused on their own topic, which limits their exposure to the areas typically covered in traditional lab courses. To maximize students exposure to a wide range of topics, we scheduled alternating weeks of meeting as a class and meeting as individual sections.

Figure 4 shows the project schedule, in which the last 7 weeks of a 10 week quarter were allotted for the project. In Figure 4, "All Teams" means the entire class (25 and 50 students for trials 3 and 4, respectively) would meet together. These times were intended to allow students to benefit from seeing presentations of a variety of team project topics and experimental methods.

"Individual Sections" indicates that students sections (holding 2-4 teams with an average of 3 students each) meet with the instructor outside of class. This allowed the instructor more time with each team for project advising. More one-on-one instructor time was incorporated in the 4^{th} trial, as a result of student feedback from trial the 3.

In response to student comments concerning grades and expectations, students were given a list of the deliverables for each week, as shown in Figure 4, and a brief explanation of how the team grade was determined each week. In addition, students were a given a detailed deliverables explanation sheet which can be found on our website[8]. Once a week, each student team was given a grade out of 10 that indicated how well they met that weeks deliverables. At the end of the quarter, each team member was asked to divide 100 points between their teammates, including themselves, based on how much each had contributed to the success of the project. The instructor used this information to adjust the individual student's final grades if necessary.

Figure 4. Project Schedule Given to Students - Pilot Iterations 3 and 4

	Team Deliverables	Class Meeting Place 3^{rd} Trial	 4^{th} Trial	Team Grades	
Week 4	Choose a Topic and Prepare an Initial Project Proposal	All teams	Individual Sections	Completeness, Level of Difficulty	
Week 5	Work on project as a team and Design Experiment	No class*	Individual Sections**	No Grade*	Class Prep and Participation**
Week 6	Presentation: Formal Proposal	All teams	All teams	Presentation Format and Plan Organization	
Week 7	Experimental Set Up and Calculations	Individual Sections	Individual Sections	Completed Calculations and Working Experimental Set-Up	
Week 8	Presentation: Experimental Results, Plans for Redesign	All teams	All teams	Presentation Format, Plans for Improvement	
Week 9	Redesigned Set-up and Improved Calculations	Individual Sections	Individual Sections	Completed Calculations and Working Experimental Set-Up	
Week 10	Presentation: Final Project Results	All teams	Individual Sections	Presentation Format, Overall Project Success	

4.1 Student Projects

Results from earlier pilot trials indicated that some students would like more direction in choosing a project. In response to this request, we provided students with a project definition and a list of optional topics, shown in Figure 5. Most students developed their own ideas or a variation from the list. In many cases, the project ideas were more difficult and imaginative than those provided.

By allowing students to choose their own topic, we give the exceptional students the opportunity to reach their highest potential without being limited by the instructors imagination.

Project topics ranged from demonstration of a homework problem, to incorporating projects from ASME Formula Team, to solving problems from local family business to designing novel measuring devices. In terms of quality, the projects varied from poor to exceptional, with the majority being in the "good" range.

Figure 5. Pilot Course Project Description Given to Students

Project Description

Choose an area of fluid mechanics that interests you. Define a problem to solve, question to answer, phenomena to demonstrate or task to accomplish. Your project should include a comparison between an analytical solution and experimental results. Your final apparatus should include a working, repeatable experiment that agrees with your analytical or numerical solution or a device that performs according to design calculations. The idea is to have FUN! So choose something that gets you EXCITED!

Ideas for Device Designs

1. Miniature Jet Ski
2. Small Water Supply System Model
3. Model of a Heated Swimming Pool or Jacuzzi
4. Power Generation System
5. Miniature Fire Boat
6. Model of a Sprinkler System for Irrigation or Fire Control
7. Power Washer (includes a mixing chamber for surfactant)
8. Tropical Fish Tank Water Supply, Filtration, Level Control and Turnover Rate
9. Choose device that requires calculation of pressure, flow rate, heat transfer etc.

Ideas for Experimental Apparatus

1. Head Loss, Major and Minor Apparatus
2. Demonstrate different methods to measure flow rate
3. Apparatus to demonstrate the Bernoulli Equation
4. Apparatus to demonstrate the Momentum Equation
5. Apparatus to demonstrate the Energy Equation
6. Flow visualization apparatus; streamlines, streak lines, timelines, path lines
7. Choose a homework problem in Chapters 2, 3, 4, 6, 8, 10 to verify.

Figure 6 gives a representative list of projects chosen by the teams. Also shown are the corresponding topic areas in fluid mechanics that are required to solve their chosen problem. In many cases a wide range was covered, and overall the class was exposed to all topic areas. An additional benefit which is evident from the chart, is that for any given topic area the students were exposed to a large array of applications requiring this knowledge. This repetition is beneficial for long term memory and assimilation of theory.

Figure 6. Student Project List and Corresponding Coverage of Fluid Mechanics Topic Areas

Project Title	Conservation Laws			Fluid Properties (density, viscosity...)	Pitot Tube, Pressure, Hydrostatics	Drag and Lift	Viscous Flow and Head Loss
	Mass	Momentum	Energy				
Fire Boat	X	X	X		X		
Jet Ski Propulsion	X	X			X	X	
Momentum Bus	X	X				X	
CO_2 Air Powered Rocket	X	X (transient)	X	X	X	X	
Sprinkler System	X				X		
Air Powered Water Jet	X		X		X		X
Draining Tank - Head Loss	X				X		X
Power Washer - Mixer	X	X		X			
Road Vehicle Accelerometer	X			X	X		
Concentric Viscometer				X			X
Cavitation of Tree Sap			X	X	X		
Pressure on Airfoil					X	X	
Hydrofoil Lift				X	X	X	
Optimizing Boat Hull		X			X	X	
Drag Force Comparison on Model Cars					X	X	
Comparison of Honda Air Intake Design					X		X
Air Foil Effect on Pressure Loss in Throttle Body					X		X
Solar Heater			X	X			
Optimum flow Rate for Formula Car Radiator	X		X	X	X		X
Temperature Effect on Velocity and Flow Rate	X		X	X	X		
Project Ski Fast - novel method for testing friction on ski surface			X		X		X

4.2 Course Assessment

The purpose of the assessment was to determine the students impression of the effect this class had on each of the following areas: (1) Motivation and life long learning (2) Preparation for future and (3) Basic skills. In addition, a survey was used to monitor the appropriateness of class procedures and logistics. The results were compared against the goals and hypotheses of the study as described earlier.

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The students were asked to compare this type of project based lab with traditional labs, in which objectives, procedures and apparatus are provided. The comparison was based on the Centrifugal pump and Reynolds pipe flow experiment which students completed in the first 2 weeks. The total percent of responses that agreed or strongly agreed with the statement, are shown in Figures 7, 8 and 9 for each of the 3 categories.

Figure 7 shows that 34% more students enjoyed the project format more compared to the traditional course. 27% more were motivated to learn about fluids during the project based course than the traditional canned experiments. Figure 8 shows that 22% and 52% more students consider the project format to benefit coop performance and senior design, respectively. In terms of understanding lecture material, the students did not see much advantage of the project based course over the traditional. Figure 9 shows the basic skills comparison, in which 68% more students consider the project experience to improve their skills in designing and conducting experiments, and 76% more to improve their problem solving skills. The results shown in Figures 7, 8 and 9 indicate that the goals listed for the pilot course were met.

Figure 7. Assessment Results – Motivation and Life Long Learning
(traditional = white, pilot = diagonal)

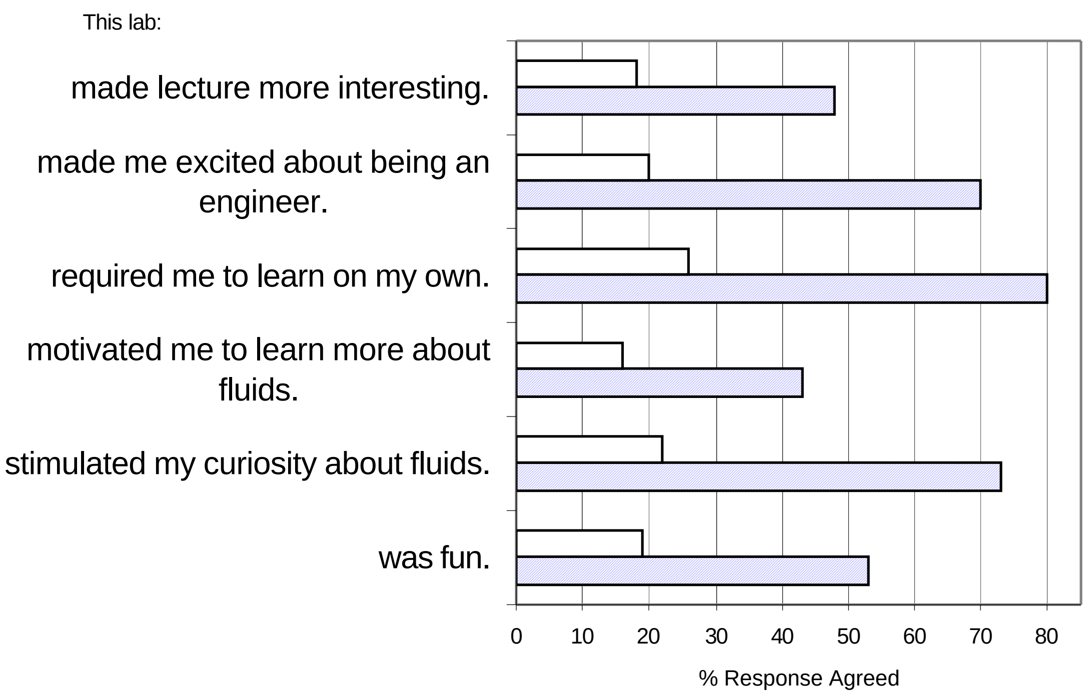


Figure 8. Assessment Results – Preparation for Future
(traditional = white, pilot = diagonal)

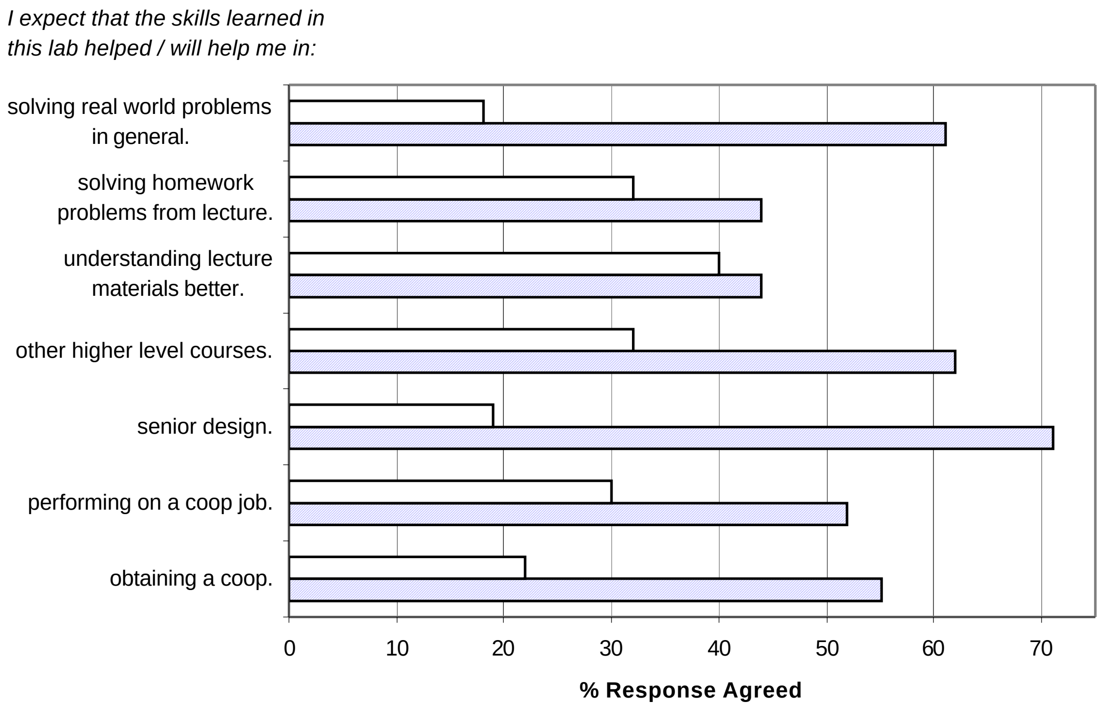
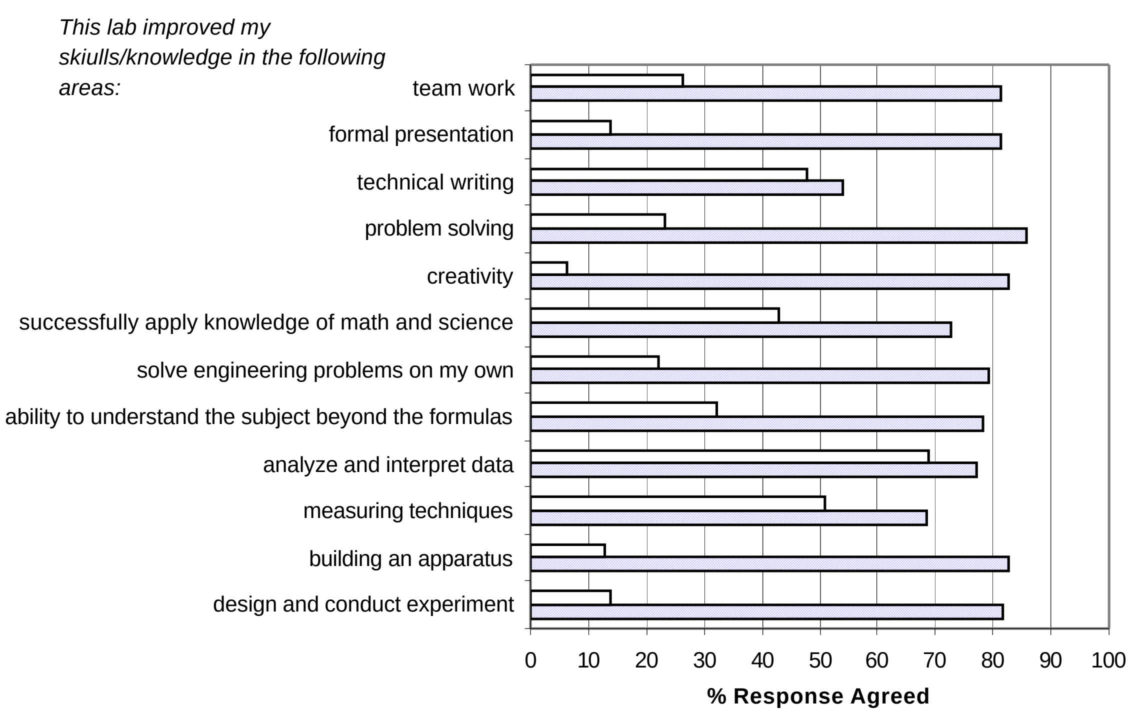


Figure 9. Assessment Results – Basic Skills Improvement
(traditional = white, pilot = diagonal)



Further assessment was completed using the questions listed in Figure 10. For a complete list of comments, see our website.[8] Here we will give some quotes that are representative of the majority. In response to the question "What did you like most about the projects?" students replied, "It allowed us to study an area of fluids that seemed interesting and exciting. This made it much easier to understand the concepts behind the experiment." "We had complete control over the design, from concepts, to equations, to building the device, to redesigning it, exactly what would happen in the real world." "Traditional labs are just plug and chug and the purpose gets lost." These comments seem to confirm the hypothesis stated earlier, that in the traditional lab format, lack of excitement and motivation to think on a higher level was due to lack of ownership in the experiment.

The majority considered the grading and team deliverables to be clear and reasonable. Most team sizes were 3, which was considered appropriate. However, team sizes of 2 were too small for the amount of work required. Average time spent varied from 2 to 10 hours/week, with the majority spending an average of 4 hours/week. At RIT, a 1 credit hour lab is equivalent to 3 hours in class, and therefore this amount of time seems appropriate. Although 55% of the students (all from trial 4) considered this too much time compared to 23% for the traditional format. This was also a common complaint from student evaluations of the traditional lab. Students found the machine shop and personnel valuable and easily accessible. Suggestions for improvement pertained mainly to supplies and equipment "provide updated equipment for measuring data points and collecting information" and "need more high resolution measuring equipment." "provide tubing…don't make us go to the hardware store." Although some students mentioned that going to the hardware store was an excellent learning experience and that it "helped them come up with ideas."

Figure 10. Open ended Survey questions for Pilot Trials 3 and 4.

1. What did you like about the projects?
2. Your suggestions to improve the projects.
3. Were the RIT facilities adequate? If not what did you need?
4. Was the grading appropriate?
5. Were team deliverable clear?
6. Were team deliverables appropriate? Any suggestions?
7. How many students were on your team? Team size OK? Or do you recommend a change?
8. How much did the project cost your team?
9. How much time (total) did you spend on your project in 7 weeks?
10. Would you recommend that the experimental project format be adopted for Fluid Mechanics?

5.0 Conclusions

This paper describes the evolution of a pilot course in Experimental Projects which was taught in place of the traditional Thermo/Fluids Laboratory. The purpose of the new course was to give students ownership and responsibility for their own learning, and to determine if this experience improved their ability to critically solve problems. In addition, we wanted to give them an opportunity to develop overall project management skills in preparation for future projects in senior design and coop. Course assessment indicates that these pilot goals were well met.

Survey results show that students considered the project experience to be more beneficial in the areas of basic skills improvement, motivation to learn and preparation for the future, compared to the traditional canned experiments. Perhaps the most striking argument in favor of project based labs is that 68% more students, compared to traditional format, considered the project experience to improve their skill in designing and conducting experiments, and 76% more to improve their problem solving skills. In addition, students discovered that they could learn things on their own through experimentation, providing a foundation for life long learning. These results indicate that project based labs satisfy ABET 2000 criteria better than the traditional lab format.

The challenge in changing to a project based lab is that labs were traditionally meant to support lecture, and with a project based format students are focused on a smaller topic area. In this pilot, we show that students were exposed to a wide array of topics by attending presentations of other students. They saw how a single topic area can be applied to a variety of problems. In addition, students learned how to solve a single problem on their own, giving them the confidence and skills necessary to repeat the process for other problems they might encounter.

The results of this pilot raise the debate as to what should be the purpose of laboratory experience. Should the goal of the lab simply be to support lecture material and demonstrate theory? Perhaps the time would be better used by solving an open ended problem, in which students become very acquainted with a few aspects of the subject, while developing the confidence, experimental techniques, project management and critical thinking skills necessary to solve real world problems.

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