A Freshman Seminar: "The Art and Science of Motorcycle Design"

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***Abstract* - This paper describes a Freshman Seminar that has been offered at Princeton University every spring semester since 2009. The course enrolls 15 first-year students and it satisfies Princeton University's Science and Technology Laboratory (STL) requirement. Students are from both liberal arts and engineering programs. The restoration of a vintage motorcycle is the focus of attention. In class students learn about technical ideas important in the design of a motorcycle. In laboratory they disassemble, restore, reassemble, and operate the motorcycle. The book, "Zen and the Art of Motorcycle Maintenance" by Robert Pirsig is one of two books that are read closely to stimulate discussion in bi-weekly classes. Colleagues (experts) in Fluid Mechanics, Material Science, and Combustion Science contribute as guest lecturers. The completed motorcycle is operated during reading period - shortly after the last instructional week of the semester.**

Index Terms – case study, freshman seminar, motorcycle, design.

This academic year marks the sixth time that the author offered a freshman seminar entitled, "The Art and Science of Motorcycle Design". A picture of the class from spring 2013 on our first day is below. This group just graduated as the class of '2016.

The following description of the course paraphrases a letter that the author sent to the donor who sponsors it thanking him for financial support. The Seminar operates with a $10K annual budget.

The class project (in this example, spring 2013) was the restoration of a 1959 Triumph Tiger Cub motorcycle. Tiger Cub was selected in part because of the name – 'Tiger' as in Princeton's mascot and 'Cub' as in freshman. Students were selected to participate in this popular course by our Freshman Seminar office in consultation with me, the instructor. Selection was based on an essay explaining why students want to take the course. We try to achieve a mix of students that includes those from the liberal arts as well as those from engineering, and we try to achieve a balance of women and men.

The course involves a top to bottom restoration of a vintage motorcycle, along with an analysis of the basic elements of its design. The design of a vehicle links structures, machines, networks, and processes. Consider the frame, forks, and wheels as a structural system, the engine, transmission, and chains as a mechanical driving system, the ignition network (battery, generator, plug, and points) as the electrical control system, and the carburetor, valves, cam, and combustion chamber as the chemical power system. All engineering disciplines (which one can group as civil, mechanical, electrical, and chemical engineering) integrate together to produce a functional motorcycle.

In laboratory, students disassemble the motorcycle down to nuts and bolts, and bare metal. We inspect, clean, and repair the engine, frame, wheels, &c. We look for wear and try to understand the reasons for it. Then we re-build the motorcycle, and if all goes well, we will run it. Each year's motorcycle presents new challenges. This year, the fork tubes (stanchions) were badly pitted and required replacement. The clutch basket and plates were heavily rusted and needed some replacement parts – some parts were able to be salvaged. The frame was cracked and required welding. (Q: Why did it crack where it did?) The wheel rims, spokes, and hubs were rusted beyond repair. We purchased new stainless steel rims and spokes and re-built the wheels. The electrical system was missing key parts including a distributor rotor, coils, and battery. Given that we have restored Tiger Cubs in the past, we re-built this year's motorcycle from old parts in our inventory and new

ones that we obtained from various motorcycle parts dealers and from eBay. The engine head this year also had major problems – its valve guides were too loose, and the cylinder was worn and was too large for the original 0.020-over piston. So, we re-bored the cylinder to 0.040-over, obtained a new and larger piston with rings, bought new valves, re-cut the valve seats, and re-built the head.

Funds from Princeton's Dean of the College Office were used to purchase replacement parts and specialty tools needed for restoring and testing the motorcycle and its components. Below are a few pictures of work from this year (spring 2013) on the engine head by our Top End Group (Karen, Kimberly and Frances) as assisted by one of our technical staff members, Jon Prevost. Shown also are pictures of work on one of the wheels by members of the Frame Group (Oren and Nicole) assisted by my volunteer friend and motorcycle restorer, Bill Becker (a retired architect from Philadelphia). Bill Becker also lectured to the students about the wheel as a structural system. Pictures of two students from the Bottom End Group (Alex and Grant) are shown as well assembling the transmission and cams.

In class students read and discuss "Zen and the Art of Motorcycle Maintenance", by Robert Pirsig,[1] and "Shop Class as Soulcraft", by Mathew Crawford [2]. Both books use motorcycle maintenance and design to make points about philosophy and the value of manual labor. I make certain that the students understand all the motorcycle references, and we use these books to explore a range of topics. For example in one class was a discussion of chapter 15 of Zen -- the discussion was centered about the definition of Quality (capitalized in the Zen book) and serves to introduce a key idea that Pirsig uses later in his book to examine aesthetics in art and rhetoric. The Crawford book was recommended to me by my friend, colleague, and motorcycle enthusiast, Hank Farber, a faculty member in our economics department. This book is an inquiry into the value of work. I have some favorite observations - Crawford states, "The surgeon's judgement is simultaneously technical and deliberative, and that mix is a source of power. This could be said of any manual skill that is diagnostic, including motorcycle repair.". Crawford quotes Princeton faculty member, Alan Blinder, in an important and relevant observation about jobs that are prone to 'offshoring' – for example, Blinder (and Crawford) note that the radiologist who main role is to read X-rays has the kind of job that can easily be handled remotely.

The class also has its technical core. Sometimes, I bring in demonstration devices that I have developed in other classes to help freshman understand the Otto Cycle (four-stroke) engine. For example during one week, I brought in a small dynamometer to show students how to measure engine torque and brake-horse-power (bhp). I also brought in a clutch demonstrator that we constructed for this Seminar to help students understand the role of slip-stick friction in clutch design. This device highlights why so many clutch plates and surfaces are needed – it also explains the role of the clutch springs. In the last few weeks of the Seminar student groups will be making their own presentations about their assigned portion of the motorcycle.

I also use our Department's 1921 Model T Ford to help with the Seminar. This vehicle was restored by engineering students in a summer program that I ran about a decade ago. I gave the freshman an opportunity to drive the T in low gear. I am the old guy in the passenger's seat – the young one is Henry. The others alongside of the car are students waiting their turn to drive the T.

The course has been well received by students and colleagues. In some cases, it has helped students choose their major, and in a small number of cases it has resulted in a student switching into engineering from the liberal arts. The 'hands on' nature of the course is universally appreciated by the students as well as the instructor and his helpers.

The above paraphrased letter to the donor, did not mention the author's colleagues from the Mechanical and Aerospace Engineering Department, who offered opportunities to 'question the experts" in the areas of combustion (Prof. Yiguang Ju), material science (Prof. Craig Arnold), and fluid mechanics (Prof. Alexander Smits). The Seminar is presented at this meeting as a 'case study' of one method that has had some success in interesting students about engineering.

Student response to the course has been very positive, both in terms of evaluations and in terms of applications for limited spaces. This past year (academic year 2015-16), there were more than 50 applications for 15 spaces. The course meets for 12 weeks with 6 hours per week of contact time. Twice weekly meetings with students start with a 1 hour class which is then followed by a 2 hour lab.

What are some of the basic organizing principles and lessons learned from this course?

The course is predicated on looking at a whole engineering system and understanding how it evolved over time. The course involves repairing and remaking a previously working engineering object. It allows for a deeper analysis of why the designers chose the designs that they did. For example, what sets the specifications on the diameter of the wheel spokes – tensile strength of steel and the magnitude and variety of forces applied to each wheel spoke. Students are paired and given a responsibility for one aspect of the restoration. Success in this activity requires all student pairs to meet their objectives.

The course requires many helpers. Here the author had volunteers from various groups to assist in the restoration. There were 3 helpers available during each laboratory session. The subject matter was of sufficient interest that volunteers were easy to find. One of the volunteers was a retired engineer alumnus – others were technicians that made time to help.

Students in the class were asked to make a bi-weekly report of their progress in laboratory and to share what they learned. At the end of the course, they made a power-point presentation and web posting summarizing their final contribution. Perhaps the most important aspect of the activity is that it comes together at the end with a working device. The sense of completion and satisfaction is an important elixir.

REFERENCES

[1] Pirsig, Robert M., Zen and the Art of Motorcycle Maintenance, HarperCollins Publishers, NY (1974).

[2] Crawford, Mathew B., Shop Class as Soulcraft, Penguin Press, NY (2009)

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