Bicycle Frame Building for Engineering Undergraduates

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Abstract

The common safety bicycle design first appeared in Brittan in the 1870s. In the 130 years since, engineers and craftsmen have created hundreds of new bicycle designs, fabrication methods, materials and components. However, the simplistic diamond frame design has survived, is still commercially available and fully functional. The bicycle itself provides a rich learning platform in which to illustrate topics such as design, manufacturing process planning, tooling, materials, and the design/build process. This paper gives a status report on the development of a course that teaches engineering undergraduates the process of building a bicycle frame. Learning opportunities are described and methods and equipment are briefly explained. This is a work in progress.

Introduction

The intent of this course is to teach relevant engineering topics through a project-based course[1] that engages and motivates students. Each student enrolled in the course plans, designs, fabricates and inspects a custom-fit bicycle frame. The course was initiated by the authors after a discussion on the benefits to engineering students of the process and skills required to build a bicycle frame.
The course development process was started in January of 2009 by obtaining funding for initial curriculum development, materials and required tooling. The course was designed and developed using backward design.[2] The steps in backward course design are: (1) identify the desired results, (2) determine the acceptable evidence, and (3) plan learning experiences and instruction (See Figure 1.). By focusing on the end results first, course developers can help students to see the importance of what they are learning and make our activities more meaningful and based less on what we have seen others do or how we were taught.

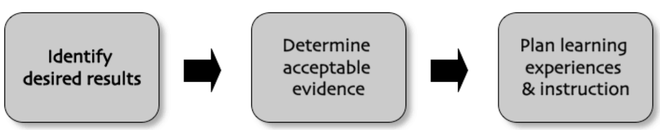

Figure 1. Backward Course Design

While there are many interesting and exciting engineering design and fabrication opportunities possible with bicycles, our experience has been an open-ended project can quickly become complex and difficult to achieve learning outcomes (and completed projects) in a 10-week course: Therefore, we narrowed the objective of this course to design and build a conventional, straight-stay, chromoly bicycle intended for road use. This specificity was established to limit both the simplicity of the fabrication methods and the variety of tooling required to build the frames.

The remainder of this paper describes application of the backward course design process, briefly explains the steps in the design-build process and identifies an inherent challenge with continued offering of this course.

Identify Desired Results

Similar to the importance of establishing a problem statement and set of requirements for any engineering endeavor, the desired results for a course must be explicitly established. This statement then, is the ultimate objective of the course:

Each enrolled student shall deliver a custom-designed, chromoly tube road bike frame of sufficient quality to perform as well as a commercially-purchased steel bicycle frame.

In terms of student learning, the authors have developed the following list of learning objectives that we suggest would be beneficial to the education of engineering undergraduates:

- *The ability to define and use relevant vocabulary*
- *The ability to translate anthropometric data into a design*
- *The ability to create a dimensioned drawing with all required information*
- *The ability to understand the interrelatedness of design and manufacture*
- *The ability to apply tolerancing concepts to an assembly*
- *The ability to inspect and rework to meet a tolerance specification*
- *The ability to evaluate acceptable overall quality*
- *The ability to work closely in a resource-limited environment*
- *Experience the challenges and complexity of manufacturing*

While it could be argued that these learning objectives are manufacturing or mechanical engineering-specific, at Cal Poly, we strongly believe all engineering graduates should have practical, hands-on experience with fabrication techniques. ABET assessment criteria suggest students would benefit from experience with concepts such as tolerancing, creating engineering drawings, evaluation of quality and working together in a resource-limited environment.[3] These are universal engineering concepts, applicable to all engineering majors. In this project-based learning experience, we have selected a topic (bike frame manufacture) that interests students, yet provides a rich milieu to accomplish the list of learning objectives above.

Determine Acceptable Evidence

Following the backward course design process, the next step is to determine acceptable evidence that the learning objectives have been achieved. In this case, to achieve the ultimate objective of this course (*deliver a usable bicycle frame)* all of the learning objectives must be met with at least acceptable evidence. One of the advantages of project-based learning experiences is that achievement of the learning outcomes is inherent in the definition of the project.[4,5] In other words, it is virtually impossible to complete the objectives of the course without achieving the intermittent learning outcomes.

Since each student enrolled in the course is required to build their own frame, it ensures that each student is held accountable for achieving each of the identified learning outcomes. For example, if a student generates a drawing missing a critical dimension for fabrication, he cannot continue until the omission is rectified and the drawing corrected. As instructors our assessment activities are well-defined, objective and readily accomplished.

Learning Experiences and Instruction

Finally, the last step in the backward course design process is to develop the learning experiences and instruction to achieve the desired results. The following sections briefly describe the distinct activities required to achieve the learning objectives. They are outlined here to give a general sense of the course activities. These lessons equate to the ten, 5-hour lab meetings of the course.

1. Bicycle frame building terminology, processes and skills
Students are introduced to the history of the bicycle, frame and component terminology, joining methods, basic machining and shop safety.

2. Design frame and create frame drawing
Students learn how to properly take body measurements to fit an individual to a custom frame. After they have gathered the appropriate measurements, a short lecture on the geometry of a standard road frames is presented. Once the anthropometric measurements have been translated into a basic design, the students create a frame drawing.

3. Seat tube subassembly preparation and welding
The seat tube is rough cut to length then mitered to fit the bottom bracket shell and fully welded.

4. Front triangle preparation
The remaining front triangle tubes (head tube, top tube and down tube) are issued. Required machining processes are performed. Every dimension is verified as any errors at this stage translate to poor fit-up once the tubes are fixtured for welding.

5. Front triangle fixture, tack and weld
The front triangle tubes are now dressed, sanded, degreased and fixtured in preparation for welding. If any joints have out of tolerance gaps, the tubes are hand-filed to improve the fit. Once the tubes fit properly in the fixture, the tubes get a final cleaning and are tack welded. The main triangle is then removed from the fixture and fully welded.

6. Rough cut and miter chainstays
The rear triangle (dropouts, chainstays and seatstays) of the frame is built as separate subassembly. The chainstays are prepared and mitered. This is a delicate and time-consuming process.

7. Rough cut and miter seatstays
The seatstays are dealt with similarly.

8. Fixture, tack and weld rear triangle
Once all the rear end members are mitered, sanded and cleaned, the front triangle is put back into the main frame fixture along with the rear triangle tubes. Once all joints are tacked on their centerlines,

the frame is removed from the fixture. The alignment of the frame is checked and corrected if necessary. The rear triangle is then fully welded on a bench and the alignment checked for a final time.

9. Select, prepare and braze on small fittings and bridges
The rear brake bridge is machined, prepared and brazed. Shift bosses and cable stops are installed. Fittings to attach racks and fenders can also be integrated, if desired.

10. Prepare frame surfaces for components and painting
The final stage is to prepare the frame to accept all of the components. The frame gets a final quality inspection and any rework is completed before it is sent to be powder coated.

Course Development and Continued Offering

Course Development
The course was designed to accommodate ten students with two instructors. The low instructor-student ratio is necessary to assist students with intricate tooling, fixturing and welding tasks. There is also significant equipment setup and tear down time, as our labs are not dedicated to frame building and have many other classes being taught throughout the academic term.

Our costs to develop the course were roughly $10,000 ($6,000 in tooling and $4,000 in salary). This does not include the following required equipment used in the course that was already present in our manufacturing engineering labs:

- 10 TIG welders
- 3 milling machines
- 1 engine lathe
- 1 drill press
- 1 belt sander
- 1 oxygen-fuel torch cart

Continued Course Offering
We have designed the course to be offered in weekly 5-hour lab sessions over a 10 week academic quarter. The 50 in-class hours are roughly divided into 30 hours of instruction and practice and 20 hours of build time.

The costs to offer the course to 10 students per term on a reoccurring basis would be approximately $9,500 per term, broken down as follows:

• 10 Bike frame building kits:	$1,000
• Outsourced powder coat of 10 finished frames:	$ 500
• Miscellaneous supplies and expenses:	$ 500
• Two instructors (2 x $75/hr x 50 hrs)	$7,500
Total:	$9,500

The bike frame class has been offered twice at Cal Poly: First, funded by college-based student fees (which are no longer available) and a second time by a large fee assessed on the enrolled students. We find these options neither attractive nor sustainable. The course is not scheduled to be offered again.

Conclusion

The construction of a simple conventional bicycle frame provides a rich learning opportunity for engineering undergraduates and the students are tremendously enthusiastic about the course. It develops very specific building skills (i.e., welding and machining) and more generalized engineering skills (i.e., design, common manufacturing processes and quality assessment). Further, it fosters a team-based atmosphere and the students' enthusiasm for the project builds quickly. It has been a unique teaching experience for the authors. Finally, as educators, we've found the nature of the project-based learning makes assessment of the learning objectives inherent in the students' work. The students understand from the first day of class that success in this course is defined by delivering a usable bicycle frame by the end of the course.

In the two offerings of this course, all 20 students have completed their frames to at least an acceptable quality level. The informal student feedback has been overwhelming. All report having achieved the ultimate objective of completing of their frame. Word of the bike frame building class has spread among the students and we have weekly inquiries about how and when the course will be offered again. Many inquiries come from non-engineering students.

While this is an expensive course to offer, we feel it has a legitimate set of learning objectives that are beneficial to engineering undergraduate students. It closely follows Cal Poly's learn by doing philosophy and it is a very enjoyable experience for both the students and instructors.

In conclusion, about half of the students have invested their own money to purchase components (forks, wheels, brakes, etc.) to complete their bicycles. Several times we have encountered students on campus riding their hand-built bicycle. It is very apparent how proud they are to have built their own bicycle.

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