Learning Engineering by Product Dissection

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A new multi-disciplinary course in Product Dissection has been developed, distributed electronically, and implemented at Penn State, the University of Washington and the University of Puerto Rico-Mayaguez. The course examines the way in which products and machines work: their physical operation, the manner in which they are constructed, and the design and societal considerations that determine the difference between success and failure in the marketplace. The primary objectives of this course are to develop a basic aptitude for engineering and engineering design, and to develop mental visualization skills; by examination of the design and manufacture of consumer and industrial products. This course is intended to complement engineering science and mathematics courses and to show freshman or sophomore level students how these fundamentals relate to engineering practice. The course is modular and consists of self-standing dissection modules on: bicycle, electric drill, four stroke engine, Funsaver disposable camera, and telephone. This paper describes the philosophy and content of this course and presents results from two years of development and deployment.


Engine Dissection

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I. Introduction:

1.1 Engineers are tinkerers

A straw poll of engineers who grew up before computers were a fixture in every grade school would probably show that most preceded their technical careers with long hours in the basement or the garage, "fixing" mom's appliances, wiring a radio that could listen to Europe, or keeping a British sports car in running condition. These tinkerers developed an instinctual, common sense feel for engineering; learned about basic hardware and tools and how to use them; and developed a visual way of thinking. With this solid foundation in hand, an engineering education was the next logical step, adding technical depth and theoretical understanding of the underlying physical principles. Previous physical experiences provided real-life examples which reinforce the theory, enhanced its retention and served as a kind of mental "bookmark" for future recall and application. The reason these people went into engineering was primarily because they liked to work with their hands, on machines.

A similar straw poll of current engineering students shows a much different profile. There are still some folks who grew up on a farm and can keep any tractor running, or daughters and sons of engineers who grew up with tools. However, most students today are in engineering because they excelled in math and science in high school, not because of any deep abiding love of engines or ham radios. Their guidance counselors told them that with those skills and an engineering degree, they could get a good job. Without some previous physical experiences or mental pictures of how things work, these students can have great difficulty with the theoretical engineering education predominant at most universities.

A typical engineering curriculum in the first two years is heavily front loaded with "fundamental" lecture courses in Physics, Calculus, Chemistry as well as general education requirements in English and Humanities. Large halls, hundreds of students, and lecture presentation are the rule. As a result, students may not see an engineering application or real hardware until their junior year. All along they are told that these fundamental courses are important and they are expected to learn the material on the faith that they will need it later. However, without some physical experience to give meaning and context to the material, most of it is forgotten the day after the final exam is taken, or it is rarely applied because they have no confidence in its utility.

1.2 What's Wrong with Lectures?

Since its beginnings, engineering education has swung between two extremes; practical, laboratory based technical training; and a theoretical engineering science orientation. International competitive pressures are presently causing schools to re-emphasize engineering practice, including manufacturing techniques. While the content of engineering curricula, as well as the balance between theory and practice has dramatically changed over the decades[1], the predominant delivery method in most engineering schools today - the lecture - is relatively unchanged from that of a century ago. Lecture is a time honored, efficient technique for delivering large quantities of analytical information. In recent years, new findings in cognitive processes[2] and behavioral psychology[3] have demonstrated the limits of lecture, and alternatives to augment its effectiveness have been proposed[4], including laboratories and cooperative learning.

Lectures encourage passivity in students, leading them to expect the instructor to provide all required knowledge. Lectures are geared toward the verbal learner, and do not take into account the varied learning styles of our students. Many engineers are in reality "visual learners", much better served by active, visual and tactile teaching methods[5]. Many students who have the intelligence and creativity to be excellent engineers find little fulfillment or stimulation in the rigid confines of the lecture hall, and drop out of formal engineering programs as a result. They do not see the relevance of their required courses to the actual practice of engineering. Too often these are promising minority or female students, to whom this lack of relevance and stimulation is sometimes "the straw that breaks the camel's back". Just as one cannot learn to drive without getting behind the wheel; or to swim without getting wet; entry into the profession of engineering, particularly in the area of design, requires far more than sitting in a lecture hall.

1.3 Changing Engineering Education

The National Science Foundation has recognized the opportunities to improve engineering education and is providing impetus to change by sponsoring several major education initiatives and coalitions[6]. In the Fall of 1993, one of these partnerships, the Manufacturing Engineering Education Partnership (MEEP[7]) began its existence with the mission of integrating design and manufacturing into the engineering curricula. MEEP consists of three major engineering schools and a national laboratory (Penn State, University of Puerto Rico-Mayaguez, University of Washington, and the Sandia National Labs).

One of the accomplishments of this effort is a new curriculum in product realization as shown in Figure 1. This interdisciplinary curriculum is available as a minor or a degree option at the participating universities. Several departments at each school are cooperating in this development, including: Mechanical, Industrial, Chemical, Electrical Engineering and Business. The curricula, consist of a progression of manufacturing/design courses, approximately one per term, and allows students to practice engineering science fundamentals in the solution of real problems.The key element in this approach is ***active learning*** - the combination of curriculum revitalization with coordinated opportunities for application and hands-on experience; thereby erasing the traditional boundaries between lecture and laboratory, academia and industrial practice. Facilities for active learning are provided by the Learning Factory[§] at each school. The curriculum consists of existing courses in Graphics, and Manufacturing Processes, as well as new courses in Product Dissection, Concurrent Engineering and Technology-Based Entrepreneurship. The senior capstone design course has been upgraded to use industry projects almost exclusively. The Product Dissection course is the subject of this paper.

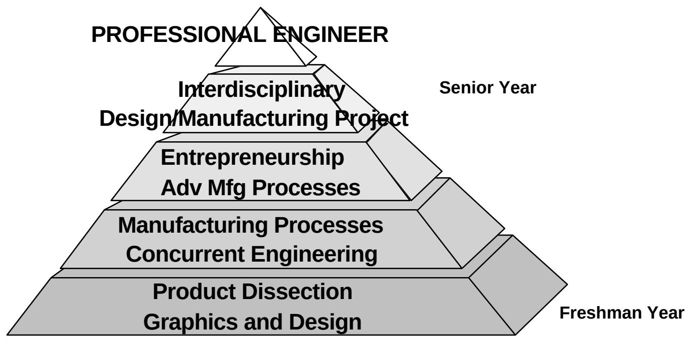


Figure 1. The Product Realization option build a firm foundation for a productive engineering career in manufacturing, design, and product realization

II. Course Design

2.1 Product Dissection Course Overview

A new course in Product Dissection has been developed by the MEEP schools. The product dissection course examines the way in which products and machines work: their physical operation the manner in which they are constructed, and the design and societal considerations that determine the difference between success and failure in the marketplace. This course is intended to complement engineering science and mathematics courses and to show freshman or sophomore level students how these fundamentals relate to engineering practice. The course has five major objectives:

1. Develop visualization skills
2. Introduce basic engineering building blocks (mechanical, electrical, chemical, etc)
3. Show relations between physical principles and real-world hardware
4. Introduce product dissection as a tool for design (reverse engineering and competitive analysis)
5. Motivate students for future learning in engineering

2.2 Course Development

The course (and the other new courses developed by MEEP) was developed by an innovative, four part process designed to take maximum advantage of the strengths and diversity of each school.

1) Planning - coordinators from each school agree on overall course objectives and content and how that course fits into the balance of the curriculum
2) Piloting - one school takes the lead role in developing the course specifics and offering it on a trial basis
3) Publication - The piloting school makes all course materials available in electronic format for use by other schools in the partnership.
4) Deployment - The remaining schools apply the course materials and offer the courses, making whatever modifications are necessary to satisfy unique institutional requirements. The desired end result is a modular, transportable set of course materials, available electronically, which can be of use to a wide audience

A unique aspect of the course development process was the team approach which was followed during the planning and piloting phases. The course developers (one from each school) met regularly over a period of two years to share experiences and information. Considerable time at each meeting was devoted to the issue of how to make the course materials both"flexible" (so they coud be adopted to different local conditions) and "portable" (for a potential wider dissemination of materials). The course also owes a considerable debt to a number of student assistants who did much of the implementation (notably, Beth O'Neill of PSU and John Weller of UW).

Product Dissection was first offered at Penn State on an experimental basis in the Fall of 1994. UW, UPRM and PSU have since offered the course on a regular basis. Based on the experiences gathered, improvements were made and the course materials were exported to each of the universities for regular offering in the Fall of 1996. Export to a fourth university was achieved in January 1996 (University of Turabo, Puerto Rico). For the price of some up-front cooperation and consensus building, each university now has a new course in Product Dissection for a minimal investment in development time. The development of this course was aided by the generous sharing of printed materials from a similar course (ME99 Mechanical Dissection)[9] [10] at Stanford University, developed under the auspices of the Synthesis Coalition. It is the intent of this paper to return the favor and add to this body of knowledge and thereby facilitate the widespread adoption of courses of this type. A major contribution of this work is to make modular course materials available over the Internet.

Drill Dissection

Bicycle Dissection

2.3 Desired Student Outcomes

The desired student outcomes from this course, i.e. the skills and knowledge we wish to impart to students, are listed in Table 1.

Table 1. Product Dissection Course Outcomes

Course Outcomes - skills and knowledge	Level of Understanding
Engineering Science Fundamentals (basic physics, graphics)	P
The Design Process and Product Life Cycle	B
Materials (Selection, Non-Traditional)	B
Basic Manufacturing Processes	B
Concurrent Engineering	B
Communication Skills (graphical, verbal, written, electronic)	A
Team Skills	A
Problem Solving Skills	B
Business Concerns	O
Customer awareness, ergonomics, marketing	B
Green engineering	B

Legend: O=Overview B=Basic A=Advanced P=Prerequisite

2.4 Modular Course Structure

In order to achieve the desired student outcomes, a number of modules were designed and constructed. These modules consist of 5 dissection exercises and a team training workshop generously provided by D. Evans and D. Linder of Arizona State University[11]. A modular course structure was chosen to accommodate many possible uses for this material. These modules may be used together as a 15 week semester course, or a subset may be used for a 10 week quarter. Alternatively, a module may be used to add practical relevance to an existing course. Each dissection module consists of:

- Laboratory instructions and worksheets
- Instructor's guide
- Expected outcomes and deliverables from this module
- Lab preparation assignment handout for students
- Associate lecture materials
- Reading assignments
- List of references for further exploration
- Assessment tools for student feedback

The currently available dissection modules are: bicycles, electric hand drills, four stroke engines, the Kodak Funsaver disposable camera and a rotary dial telephone. These products are obtained at local discount stores (drills, cameras), or second hand shops (bicycles). Engines were either purchased new, or obtained used from small engine repair shops. The rotary dial phones were former dormitory phones rescued from the dumpster and donated by Penn State's campus phone service. More modules, following the same format, are being developed to provide a large selection of possibilities. An instructor can then choose the most appropriate module or modules to accomplish the desired educational goals. As an aid in selecting the most appropriate module, the content of each module is shown in Table 2. As an example, the dissection instructions from the engine dissection module are included as an Appendix. A multimedia package to assist the students in the engine dissection has also been developed using Macromedia Authorware.

Table 2. Content of Individual Dissection Modules

Topic	bicycle	drill	engine	phone	camera
metrology	x		x		
CAD drawing	x		x		
sketching	x	x	x	x	x
journal record	x	x	x	x	x
team skills	x	x	x	x	x
manufacturing processes	x	x	x	x	x
materials selection	x	x	x	x	x
electric/electronic machines		x	x	x	x
mechanical hardware	x	x	x	x	x
chemical processes	x		x		x
analysis	x	x	x		x
history of technology	x		x	x	x
green design					x
design for manufacture/assembly		x	x	x	x
ergonomics	x	x		x	x
business concerns, marketing	x			x	x
design process	x			x	x
competitive analysis	x	x		x	x

2.5 Assessment of Student Performance

Student performance is measured by a variety of metrics including:

- Dissection journals - a detailed record kept by each student of their dissection activities, sketches, reflections, calculations, etc. These are periodically collected and graded for completeness and accuracy.
- Oral Presentation - each student is individually required to give at least one oral, computer assisted (Powerpoint) presentation
- Final Project - students in groups study a product or process of their own choosing and prepare a poster and/or multimedia presentation to demonstrate to a non-technical person (or a high school student) how that device works.
- Class Participation

III. Implementation

3.1 Course Offering

The course has been offered three times at Penn State (Fall 94, Spring 95 and Spring 96), three times at UW (Winter 95, Spring 95 and Fall 95) and twice at UPRM (Spring 95 and Fall 95). Enrollments have been limited to 30 students per section during the development stage. External to MEEP, The University of Turabo, Puerto Rico will be a beta test site for the course materials, beginning in September 1996.

3.2 Course Dissemination

All course materials are available in electronic format over the World Wide Web at address http://jsl.meche.psu.edu/pdiss.htm/. The materials consist of text files in Microsoft Word 6.0 and Powerpoint 4.0, chosen for their wide availability and ease of editing. Additionally, a CDROM is available upon request, at nominal cost, containing multimedia elements and animations to supplement the dissection exercises.

3.3 Student and Faculty Response

Student response is very positive and the course objectives meets with their approval. About 80% of the students have never before taken a device apart, hence, the realization of what goes into a commercial product to provide the intended performance is an eye-opening, unforgettable experience. A typical comment from a freshman female Industrial Engineering student at Penn State was:

> *"As a freshman in engineering, I had several ideas of what it would be like to take freshman engineering courses. Unfortunately, I was immediately bombarded with too much calculus, physics, and chemistry. I, just like many other engineering students, began to lose faith in my major. Product dissection came at just the right time for me. It is a class which combines mechanical and computer aided drawing, physical formulas and principles with actual hands-on learning. I can't imagine I would have as much interest in engineering as I do now if I had not taken the class"*

A Junior ME student at the University of Washington wrote:

> *"... good hands-on experience, all of our courses are just theory, this was an important change. It was good to break down and understand a complicated system. I saw how all the parts are optimized and work together. It was great to hear the engine start up again! It gave me a lot of confidence. "*

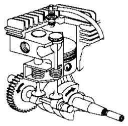
Students fill out a detailed evaluation and feedback form after each dissection exercise. This information is used to refine and continuously improve the dissection activities and course materials. A post-course assessment is currently being developed to ascertain the effectiveness of the course in meeting its educational goals.

Faculty response has been generally positive. Most faculty (particularly those who are actively involved in design or who have had industrial experience) agree that a course of this nature is needed in the curriculum to allow students to gain practical skills. However, there is wide divergence on how to fit this experience into an already full curriculum. Other contentious issues include; the "proper" balance between practical and theoretical content, teaching methodology and level, and the cost-to-benefit ratio for an instructor-intensive course such as this. In a diverse academic community, there will always be some faculty, who have a more theoretical, research inclination, and who do not understand how this course will make better graduate students. These discussions are neither unexpected, nor disheartening. They are a natural occurrence in the long process of improving the way we think about, teach, and practice design at the undergraduate level.

IV. Concluding Remarks

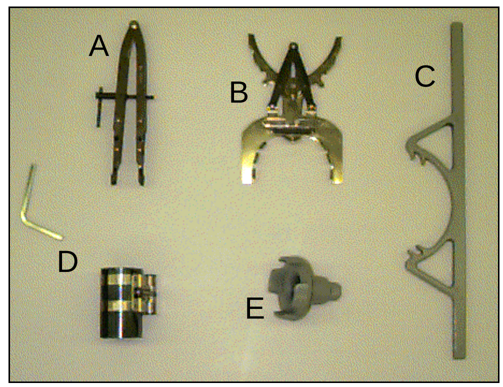
A new course has been developed and deployed that addresses some major shortcomings in current Mechanical Engineering curricula: the lack of visualization skill development, and the lack of a basic common sense aptitude for engineering. Student feedback at all universities where this course has been offered has confirmed the hypothesis that we started with: that engineering students desperately need exposure to actual devices and tools in order to make the conceptual leap from theory to design. The increased exposure to "real devices" has increased the students' awareness of design and its relationship to engineering science and provides us with a means for vertical integration in the curriculum since we can constantly refer back to these experiences in later engineering science courses (such as materials, systems dynamics, thermodynamics etc.)

If our nation's competitive position depends on improved productivity of the product realization cycle, then it is imperative that the engineering curriculum of the future include a course such as that described in this paper. Product dissection may be an excellent teaching tool, however in its current implementation, it is both resource and faculty intensive. The real challenge is how to deliver "hands-on" experience to a large number of students. We must attempt to take advantage of new delivery methods, such as multimedia computer technology and undergraduate mentors, to make this concept educationally and operationally successful.



Engine Dissection

Purpose: To understand the function and manufacture of the four-cycle internal combustion engine
Background and reference materials:
Briggs & Stratton Service and Repair Instructions, Briggs & Stratton Corporation, Milwaukee, WI, 1992
Internal Combustion Engine Fundamentals, J. B. Heywood, McGraw-Hill
Why Internal Combustion, Rudi Volti, Invention and Technology, vol. 6, no. 2, Fall 1990, pp 42-47
Physical principles involved: Bernoulli's principle, combustion, magnetic fields and induction, static and dynamic forces, heat transfer, lubrication
Mechanisms involved: carburetor, flywheel, magneto, journal bearings, crank-slider (piston, connecting rod, crank shaft), cams, valves
Manufacturing processes introduced: casting, machining, molding
Activities: dissection, sketching, dimensioned CAD drawing of the piston,
Associated Lecture Material: (engine.ppt) engine types, history, theory of operation
Required tools: basic toolbox, parts bin, calipers, starter clutch wrench (E), flywheel wrench set (C), ring expander (B), ring compressor (D), valve spring compressor (A), torque wrench



Deliverables:
1. assembled, working, well adjusted engine
2. computer generated drawing of the piston
3. detailed journal record of activities:
    a) record all procedures followed
    b) answer all questions posed below
    c) sketches of parts and assemblies
    d) all other pertinent information

Schedule:

Session #	Date	Approx Duration	Activity	Reading Material	Objectives
0		1/2 hour	Preparation	Briggs manual, sections 1,13,14	Introduction, getting ready for dissection
1		2 hours	Ignition and carburetor	Briggs manual sections 2,3,4	Understand ignition and carburetor systems
2		2 hours	Engine block	Briggs manual sections 6,8,9,10	Understand internal elements, metrology, CAD drawing
3		2 hours	Reassembly and test	Briggs manual section 12	A smooth running engine
			Hand in Journal		

Session 0: Getting the Patient Ready

Readings: from Briggs and Stratton Repair and Service Manual

Section 14 - Theories of Operation   Section 1 - General Information
Section 13 - Tools

Objectives: a) Understanding how to use a factory service manual
b) Assignment of lab partners, tool boxes, and engines
c) Determining engine type and its specifications

Procedures: perform the following and answer all questions in your journal:

1. Note the manufacturer, model, and serial number of your engine
2. What is the maximum RPM for this engine
3. How much torque and horsepower does it develop
4. Check that there is no fuel and oil in the engine
5. Determine if the engine has compression
6. Check to see if ignition system is functioning and explain how you did this
7. Explain the four cycles
8. Draw an overall diagram of your engine (external view of assembled engine) , label all important parts

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Session 1: Ignition and Carburetor

Readings: Section 2 - Ignition   Section 3 - Carburetion
Section 4 - Governor Controls & Carburetor Linkage

Objectives: Troubleshoot, disassemble and inspect the ignition and carburetor systems

Procedure:

A. Ignition System

1. Remove the flywheel shroud
2. Identify the type of ignition system your engine uses
3. What materials are used in the flywheel?
4. Remove the flywheel using the proper tools
5. What is the purpose of the starter clutch? Notice how it does not work in some orientations.
6. How much does the flywheel weigh and what is its function? What would be the advantages and disadvantages of making it heavier?
7. Why does the flywheel have one section made from a different material?
8. Sketch the ignition system identifying all its components
9. Describe how the magneto system works
10. What is ignition timing and why is it important?
11. Remove the rest of the ignition system components

B. Carburetor

1. Remove the air cleaner and identify the type used
2. Why is the air cleaner important?
3. Identify the carburetor style (pages 4 - 5 Section 3)
4. Remove the carburetor
5. What materials are used in the carburetor?
6. Describe how the venturi works.
7. How many jets are used and what is their function?
8. How does the choke work?
9. What type of governor system does this carburetor use? How does it work?
10. Completely dissect the carburetor assembly
11. Sketch the components of the carburetor
12. Reassemble and adjust the carburetor according to the factory specifications

Note: Do not re-mount the carburetor to the engine block, this is to be done in the last engine dissection lab!

Session 2: Engine Block Dissection

Readings: Section 6 - Compression; Section 8 - Lubrication; Section 9 - Pistons, Rings, Rods; Section 10 - Crankshafts & Cam Gears

Objectives:

a) Disassemble, inspect and document the internal mechanisms of an I.C. engine
b) Generate a CAD drawing of the piston
c) Calculate the displacement and compression ratio of the engine

Procedure:

1. Remove the cylinder head
2. Locate the intake and exhaust valves. Are there any differences between them? Explain the differences and the reasons for them.
3. Sketch the top view of the cylinder (include the valves)
4. Rotate the engine through its four cycles. Note what happens if you turn it the wrong way
5. Calculate the displacement of the engine ___ cubic inches = _____________cc
6. Determine the compression ratio by two different methods (analytically and experimentally) and compare the results. Explain how it was determined.
7. Remove the valves (use your safety glasses!!)
8. Remove the crankcase cover, being careful not to damage the gasket. (do not pry off with a screwdriver, it will tear!)
9. Remove the camshaft and crankshaft.
10. What materials are used for the camshaft?
11. What is the significance of cam timing and how is it set?
12. What are tappets and what function do they serve?
13. What type of lubrication system does your engine have and how does it work?
14. Sketch the camshaft assembly
15. Remove the piston
16. Measure and sketch the piston assembly. Produce a fully dimensioned 2-D CAD drawing the machined surfaces of the piston, making all necessary physical measurements.
17. Remove the rings (**using the ring expander)** and identify them
18. Remove the wrist pin and connecting rod
19. What manufacturing processes do you think are used to produce the crankshaft, camshaft, connecting rod, wrist pin, and piston?
20. Remove the crankshaft. What type of bearings does it use?
21. What material is used for the crankshaft?

This completes the engine disassembly

Session 3: Reassembly

Readings: Section 12 - Synchro-Balance

Objectives:
a) Reassemble the engine (with no parts left over)
b) Adjust it to factory specifications
b) Run the engine

Procedure:

Note: Use small amounts of engine oil to lubricate mating parts (bearings, rings etc.). **The service manual must be followed during reassembly.**

1. Reassemble your engine. Install parts in the reverse order which you disassembled them (this is a test of your memory, journal completeness, and common sense).
2. Use the ring compressor
3. **Torque all bolts to the factory specification** Write in the required torque values (and the correct units!) here:
   Crank bolts _____________ Head Bolts:_________________
   Flywheel _______________
4. What grade bolts are used for the connecting rod?
5. Why is it important to torque the bolts to a certain value? How is this value determined?
6. Why are the bolts torqued in a certain pattern?
7. What is the purpose of the head gasket?

8. Prepare to run you engine!
9. Fill the engine with oil and gas (only enough gas to run the engine for a minute or two)
10. While it is running you should adjust the air/fuel mixture, idle speed, and governor speed. Know these procedures before you start!
11. After running the engines, the fuel and oil must be drained. (Let the engine cool first.)
12. What happened when you changed the air fuel mixture?
13. Did your engine operate smoothly? If not, you must make whatever adjustments are needed to satisfy the instructor that the engine is running properly.

Engine Dissection Feedback:

Please comment on this lab experience. Fill out this form and submit it to the instructor within one week of the completion of the dissection exercise.

Your Major________________________________ Semester Standing_______

A. Would you rather have seen more/less:

	less	about right	more
instructions concerning assembly/dis-assembly			
questions relating to the dissection			
written assignments			
lectures (if so, on what topics)			
time allotted for lab			
open lab time			
help during open lab time			
other			

B. How would you rate the difficulty of this dissection?

Trivial		About right		Too difficult
1	2	3	4	5

C. How would you rate the overall value of the this dissection as a learning experience?

Worthless	Mediocre	OK	Good	Excellent
1	2	3	4	5

D. How could the learning experience be improved?

Notes to Instructors

Format for lab: 2 persons per group is best (3 is OK if necessary)
Total time for dissection: Four periods, 2 hours each
Associated lecture material: (2 or 3 fifty minute lectures)
4 stroke engine fundamentals (engine.ppt)
"Why internal combustion engines" - discussion of Invention and Technology article
Facilities needed: Workbenches (each group needs a bench approximately 4 x 6 feet)
Supplies needed: (available from any small engine repair shop)

Specialty engine tools and parts:	**part number**	**cost $**
engine (3.5HP Briggs and Stratton, horizontal shaft)	91232-0035	180.00
starter clutch wrench	19244	5.15
flywheel wrench set	19167	6.65
ring expander	19340	7.20
ring compressor and wrench	19230	7.10
valve spring compressor	19076	11.15
Briggs and Stratton repair and service manual	270962	10.95
Spare rings (in case of stupidity)	298982	12.80

General Purpose Tools: socket wrenches (1/4" and 3/8" drive), screw drivers, pliers, nut drivers, etc. (need both English and metric sizes for Briggs engines), Safety glasses, Torque wrench (1/4 or 3/8" drive, maximum torque needed is 140 in-lbs), Vernier caliper,
Miscellaneous supplies and materials: Shop rags, Hand cleaner, Funnel, Oil pan, Clear contact paper - to cover and protect the Briggs and Stratton repair manual, Gasoline, 30W oil, Engine mount- a plywood board with 1/4" bolts is fine (C-clamp it to a rigid base), Exhaust tubing - to duct exhaust out a window or vent if running engines inside (but it's better to run them outside)

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