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Lawnmowers and Prospective Engineers: A Recruitment Exercise

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Abstract

Every College of Engineering faces the challenge of recruiting and retaining students in their majors. Midshipmen at the United States Naval Academy face a strict requirement to complete their coursework in four years in addition to myriad other demands on their time and attention, making their selection of major even more consequential. Naval Academy Summer Seminar (NASS) is a week-long, on-campus immersion program designed to provide rising high-school seniors insight into the unique environment and requirements of the Academy to help them make more educated choices with regard to both school and potential major. Candidates get a "week-in-the-life" exposure to the culture of the institution plus structured time with various academic departments-—periods when the departments are actively recruiting future majors as well as educating the potential students about what it means to major in their field. These academic periods also present the future students with the hallmarks of our academic program: small class sizes, teaching-focused faculty, and a significant STEM component to all fields of study.

The Mechanical Engineering Department developed a new disassemble/assemble/analyze (DAA) exercise involving a push lawnmower as its presentation for Naval Academy Summer Seminar. The purpose of the exercise was to get students on their feet, applying what they learned in physics and chemistry to understand how something works, and to give them confidence that they can use these tools on their own to help them understand the physical world around them. The push lawnmower was chosen because it is likely familiar to all students of this age range. They would not have to spend extra time to understand how the device functions. Moreover, it was complex enough that they might have some idea how it worked in general, but had never considered its operation in a detailed way. It also readily demonstrates the three areas of mechanical engineering: structures and materials, thermo-fluid sciences, and engineering design.

The students (who had no particular technical preparation) were divided into small teams and guided through a discussion of what it means to be an engineer and a qualitative overview of design, solid mechanics, material properties, and thermodynamic principles as applied to the construct of a small machine. This paper will describe that project-based learning exercise in detail and propose options for extending and adapting it for use as a module within or as a framework for an introductory course for mechanical engineering majors.

Introduction

Every college of Engineering faces the challenge of recruiting and retaining students in their majors.[1] Midshipmen at the United States Naval Academy (USNA) face additional constraints, opportunities, and challenges in the form of a strict requirement to complete their course work in four years as well as myriad other demands on their time and attention.

The Naval Academy uses an application process to select 2,500 highly qualified rising high school seniors to participate in Naval Academy Summer Seminar (NASS) for a week-long immersion in the unique requirements and academic opportunities available to our students. Their time on the Yard includes athletic, academic, leadership, and cultural activities, some designed to both recruit students to and "de-cruit" students from the school as a whole–the blessing-and-curse of many of our unique opportunities and challenges dictate that it is *not* the right school for everyone. This one week program has been formulated to help some students come to that realization sooner, and prevent their later attrition from denying admission to another, more suitable, worthy candidate.

To select their academic activities, the students prioritize from among twenty-seven workshops and attend eight of them–while their preferences are considered, level loading results in some students attending workshops they had not necessarily chosen. The academic departments craft their respective seventy-five minute presentations to introduce their subject areas and recruit students both to the school and to their discipline. Many of these sessions also demonstrate to future students the hallmarks of our academic program: small class sizes, teaching-focused faculty, and a significant STEM component to all fields of study.

Engineering educators have been exploring and extolling the virtues of active and project-based learning (PBL) throughout their curricula recently. Using ideas first presented by Felder and Silverman[2], Prince's review of the literature indicates that test scores may not be directly improved by incorporating PBL, student attitudes and engagement are positively influenced.[3] More recently Dalrymple, Sears, and Evangelou specifically found that Dissassemble/Assemble/Analyze (DAA) activities–a particular subset of PBL–elicited high levels of motivation for first year engineering students.[4]

In prior years, USNA's Mechanical Engineering Department scavenged the most interesting parts of senior design projects into its Summer Seminar presentation. Alas, too many of these devolved into too much lecture and too little student involvement. Recognizing that our regular curriculum is significantly more project-based and active learning oriented, this lawnmower disassembly/reassembly exercise was developed and first presented in Summer 2014.

The push lawnmower was chosen because it is likely familiar to the target audience, and discussion of all areas of mechanical engineering: design, thermo-fluids, and structures and materials can be directly incorporated into the exercise.

This paper will describe the necessary preparation and materials required; outline a guided dis-assembly and subsequent re-assembly sequence, both designed to be accomplished within a seventy-five minute class sessions; relay student feedback from the exercise; and discuss possibilities for expanding the exercise for inclusion within an introductory engineering course.

Finally, a detailed script for an instructor or facilitator is provided as an appendix.

Set-up and Execution

Students, Classroom, & Tools

Each session was attended by twenty-four students escorted by a rising sophomore. At the Naval Academy rising sophomores have recently declared their majors, but have not yet taken any classes in the discipline. The escorts were part of the Naval Academy Summer Seminar team, not necessarily engineers or even technical majors. Each session was conducted by a primary instructor/facilitator plus at least one assistant. The escort was usually drafted to help. While a script was provided for each instructor, they were encouraged to complete the disassembly and subsequent reassembly themselves before presenting in order to familiarize themselves with the idiosyncrasies of these machines. The students were divided into fairly arbitrary groups of four to five students. Facilitators circulated to assist and ensure that every student participated and that no one student dominated any group.

The classroom was arranged with five workstations in a circle about a center table on which a sixth lawnmower was used for demonstration. Each workstation was comprised of two tables (approximately 2 ft x 5 ft), one holding a lawnmower, the other holding a tool set, a sheet of paper on which to stage parts, a six inch square foam block, and a small plastic cup. These latter two items were designated for use as engine stand and shear pin receptacle, respectively. The classroom itself also contained an ample supply of paper towels and hand cleaner. Each mower had been disassembled at least once before the first group of students encountered them, and all fasteners were merely hand tight; students were directed to return them to that state as well, so no excessive force was required for any of their actions.

The tools sets provided were 154-piece mechanics tool sets. They were more than sufficient for the exercise at hand, but also provided another learning opportunity. The head bolts of these lawnmowers were 10mm, and were the only metric fasteners on the assembly. For the various USCS size fittings the students had a choice of socket, combination wrench, and nut bits to loosen or tighten. Many of the students had never wielded such tools themselves, but quickly understood the advantages and disadvantages of each for various purposes. A great majority of the students had heard of the right-hand-rule; considerably fewer were familiar with its application to threaded fasteners.

Lawnmowers

The particular model push lawnmower used was an MTD 20 in, 125 cc Gas Walk-Behind Lawn Mower, available at a national retailer for approximately $150 each. It was advertised as “easy setup” for its usual purpose. For our purpose(s) some adaptation was required. The upper, lower, and blade control handles and emergency stop cable were assembled as directed. The starter rope was not threaded to the handle to simplify cowling removal. No gasoline or lubricating oil were added to the engines, and their blades had never come into contact with actual grass. The key preparation measures were removal of the piston rings, removal of all gaskets (save the head gasket), removal of crankcase oil, and dulling of the cutting blade (accomplished with a bench grinder). These enabled the students to easily cycle and remove the pistons as directed during their exercise and minimized their exposure to lubricating oil. They were also informed of this configuration change should they be inspired to dissect their parents' lawnmower.

The Main Event

Beginning with the Ralph J. Smith quote "Engineering is the professional art of applying science to the optimum conversion of natural resources to the benefit of man," the facilitator(s) lead the students through an overview of the discipline of mechanical engineering to ensure a common understanding. Specifically, they described and explained the three broad divisions of mechanical engineering: thermofluids, mechanics and materials, and design.

This exercise definitely falls on the "expose" section of Ogot and Kremer's Framework for these activities: it assumed little prior knowledge and featured maximum instructor guidance.[5]

The design specifications of a push lawnmower such as uniform cutting height, endurance, and fuel capacity were elicited; then ground rules and their rationale were discussed. Each step of the procedure was a directed action accompanied by some discussion of the features of, physics behind, or design considerations that resulted in the system as revealed. While a fair amount of discussion focused on the internal combustion cycle, the students were lead through an observational sequence to deduce the cycle rather than just telling them what happens. Another point of emphasis was that every observation they were drawn to was something they already knew, with a slightly different perspective applied.

The importance of following along with directed actions and organizing the various pieces and parts on the tool table were stressed.

Detailed scripts for each process (disassembly and reassembly) are provided in an Appendix.

Student feedback

Student feedback for this exercise was exceptional. A full 9% of the students listed it as their favorite activity of the week (out of 27 possibilities). Some specific comments follow:

> Hands on applications that coincide with the major were fun and entertaining. This class alone shifted my potential major from computer science to mechanical engineering.
>
> This workshop was not like the others I participated in. The mechanical engineering workshop was hands on and very informative. In addition I was also educated on the mechanics of a lawn mower.

> This was the only workshop that was "hands on." Though all the other workshops were interesting in their own way relative to the subject, mechanical engineering was the only workshop in which I was given the opportunity to be an active participant whereas the other workshops were more passive.

> We put together a lawn mower - by far the most fun I've ever had learning about an engine.

> We took apart a lawnmower which I had never done before in my life. I used tools that I had only seen my Dad use in the garage, and never actually used myself. I learned so much in such a short period while having fun at the same time.

> The Mechanical engineering applications workshop was a great way to receive some hands-on experiences with some of the basis of thinking of mechanical engineers. The workshop was entertaining, constructive and allowed for learning.

> It was fun being able to do something really hands on with mechanical engineering. Instead of being lectured about the basics we were able to take apart a lawn mower engine.

> It involved some incredible hands-on applications that included putting a lawn mower back together. I enjoyed everything about this workshop from the instructors to the activities and there was not a moment which I found myself to be bored or uninterested. Admittedly I was not magnificent at putting the machine back together, but the mistakes were worked through by other classmates and the instructors.

> This workshop was very hands-on, and made me realize that mechanical engineering could be a serious future major for me.

Summer 2014 was the first time the new exercise was presented to rising high school seniors who may apply to the Naval Academy. If they are admitted and matriculate, they will declare their majors in March, 2016. As such, no immediate quantitative data is available and future follow-up surveys (ala Genau[6]) will be necessary to determine the long-term efficacy of this exercise as a recruiting tool.

Lessons learned

This exercise was originally designed to have each group of students accomplish both the disassembly and reassembly of their lawnmowers. That proved to be too ambitious for the time allotted, so the first adaptation was to have each group complete only one half of the process. Fortunately, an even number of sessions were scheduled each day.

When dealing with the individual groups (as opposed to addressing the entire class), the facilitators and assistants spent a fair bit of their time explaining the advantages and disadvantages of various tools for their disparate tasks. Ensuring that every student played an active role in the exercise was also a point of emphasis. Not only did we want to ensure that all had an opportunity to try some of the tasks, we wanted to ensure that the car-or-engine enthusiasts did not dominate. Many students had never used tools themselves; in fact, a number of students were completely unfamiliar with the concept of "righty-tighty, lefty-loosey."

Related possibilities

This exercise was designed as an orientation and recruitment event, but possibilities abound for a more rigorous investigation into various aspects of mechanical engineering through the vehicle of a simple yet inclusive machine. A slightly longer time period would have enabled one team to both disassemble and reassemble the mower in the same session. Disassembling one mower and rotating groups to reassemble another might provide insight into the value of standardization and organization.

An extended dissection of the mower could form the basis for a module in an introduction to mechanical engineering course. Deeper analysis of design decisions, material selection, the Otto cycle, and even tool selection(s) are just the beginning of other avenues of investigation. Given the fairly straightforward model lawnmower presented, students could be given design challenges to improve functionality or user convenience, by say, adding cupholders and propulsion assist. Perhaps after a thorough analysis of the machine as is, students could be given leave to use it to create something else altogether: repurposing the engine to drive a go-kart, pump, or generator.

Conclusion

This paper describes a lawnmower disassembly/reassembly exercise developed as a recruiting tool for potential applicants to the Naval Academy. The exercise as developed is aimed at rising high school seniors on campus for a week-long immersion program, but has potential to be expanded to allow the same students restore the machines to its initial condition or for incorporation into a project-based introduction to engineering course for major students. Initial qualitative feedback was quite positive, but follow-up surveys will be necessary to quantitatively assess the exercise's merit as a recruiting tool.

References

[1] National Science Board. Science and engineering indicators 2014. Technical report, National Science Foundation, Arlington VA, 2014. (NSB 14-01).

[2] R. M. Felder and L. K. Silverman. Learning and teaching styles in engineering education. *Engineering Education*, pages 674–681, 1988.

[3] M. Prince. Does active learning work? a review of the research. *Engineering Education*, pages 223–231, 2004.

[4] O. Dalrymple, D. Sears, and D. Evangelou. Evaluating the motivational and learning potential of an instructional practice for use with first year engineering students. In *Proceedings of the 2010 American Society for Engineering Education Annual Conference &Exposition*, 2010.

[5] M. Ogot and G. Kremer. Developing a framework for disassemble/assemble/analyze (daa) activities in engineering education. In *Proceedings of the 2006 American Society for Engineering Education Annual Conference & Exposition*, 2006.

[6] A. L. Genau. Initiation of summer camp program as outreach and recruiting tool. In *Proceedings of the 2014 American Society for Engineering Education Annual Conference & Exposition*, 2014.

Appendix–Handout for Instructors

Script prepared for any instructor to deliver – most here have their Master of Science plus about five years fleet (non-academic) experience. Instructor guidance:

- Be sure to emphasize that they follow along with you. Watch that they don't take things apart that aren't part of the discussion (e.g. the mower handle, the muffler cowling, etc.)
- For each stage, determine which group is moving the fastest. When they're complete with the previous task, show them the next one and have them explain it to the class. Once they are finished with this next task, have them go and help the other groups. This is especially useful when there is only one instructor.
- Even though they're only disassembling or reassembling, not both in a single session, there is still a real tendency to cut it close timewise. There are a million questions you could ask. Try to pick the ones you think are the most interesting and keep it moving. You could even ask the squad leader to give you a heads up when there are 15 minutes left.
- Discuss right-hand-rule (righty-tighty-lefty-loosey)
- Consider discussing tool kits and recommend the driver as the primary for this exercise. Small socket wrench and/or 5/16" box wrench are optimal for re/disconnecting the connecting rod.
- Piston rings, crankcase seals, crankcase oil were removed to expedite this exercise – be prepared if you are trying this on your parents' mower.
- Keep the escort Midshipman in the room and gainfully employed. Summer 2014 had the same Midshipman for two consecutive sessions – even a liberal arts major can be helpful during their second session (reassembly)

Introduction and Ground rules

Guidance for the instructors: introduce yourself and discuss the field of mechanical engineering – here are some talking points:

a) Your name and a brief description of your educational and work experience

b) What do mechanical engineers study?
  - thermofluids
  - structures and materials
  - design

c) Everything that is not designed and created by nature had to be designed and created by man to serve some function.

d) What specific functions must a lawnmower accomplish?
  - Holds the rotating blades at some desired distance and parallel to the ground
  - Counteracts the torque created by the engine
  - Transports the fuel required to run the engine for approximately 1 hour

Ground rules: make these clear to all students:

- Please don't remove anything until I tell you. Not only do I want to point things out as we go, but there's an order here that will prevent damage to the equipment
- Everything should be "finger tight" meaning you should use the tools, but nothing should take a lot of effort to unbolt. If it does, please raise your hand.

- When you take something off, place it in order, with its fasteners, from left to right on the table. That way when the next group comes in to reassemble, they can pick up the parts and replace them from right to left.

Guided Disassembly

1. Squeezing the emergency stop handle, gently pull the starter cord. Note which way the blade, and thus the engine, spins.
2. Remove the engine cowling (the black plastic part that covers the important stuff)

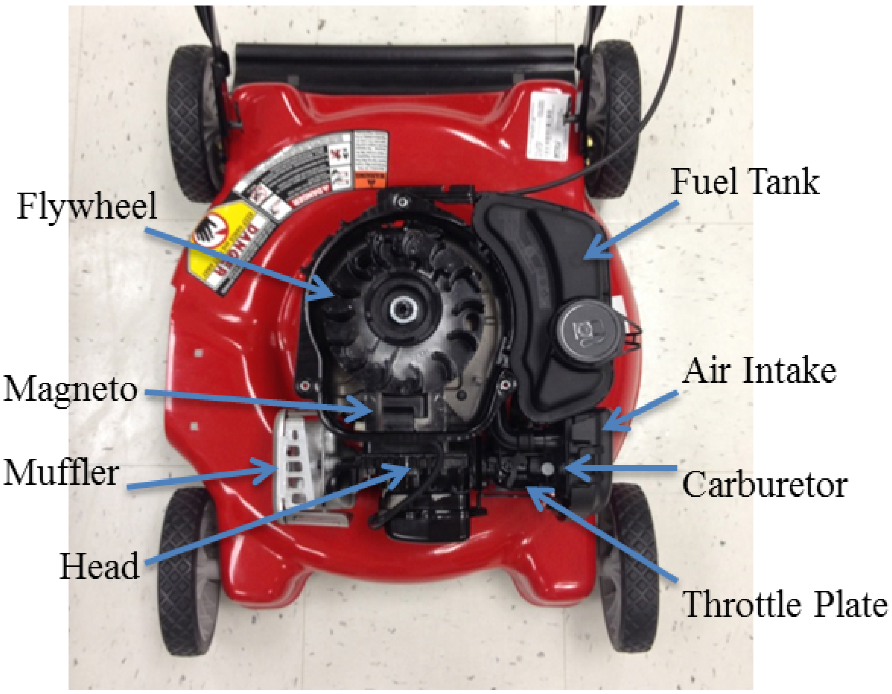

Figure 1: top view with cowling removed

Discussion points Identify the intake manifold, the fuel tank, the carburetor, the throttle plate, the motorhead, the engine, and the exhaust manifold (muffler) See Figure 1.

a) In general, how does an engine (in this case a reciprocating internal combustion engine) work? What comes in? What goes out?
   - Air and fuel goes in, gas, heat, and work come out.

b) How does air get into the engine?
   - Through the intake manifold, into the carburetor, then into the cylinder through the intake valve.

c) How does fuel get into the engine?
   - From the gas tank into the carburetor where it is mixed with air.

d) How does exhaust get out of the engine?
   - The exhaust valve opens and the piston pushes the exhaust out through the muffler

3. Locate the emergency stop handle on the mower push handle; squeeze it and watch what happens. (Figure 2)

Discussion points In order to start the mower, you must squeeze the emergency stop handle against the push handle. What two things happen when you release then handle?

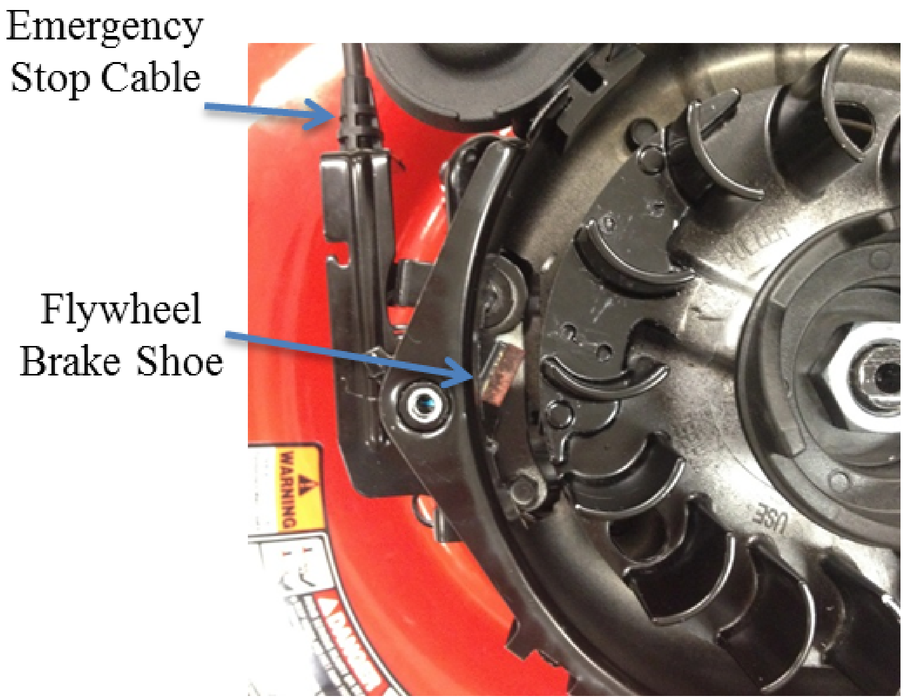

Figure 2: the emergency cable connects to the flywheel cowling and supports the flywheel brake shoe. There is also an electrical connection that stops the spark plug from firing when the handle is released.

- Squeezing the handle releases the brake shoe from the flywheel, allowing the flywheel, (connected to) the crankshaft to rotate.
- An electrical connection is made in the same mechanism that connects via a small wire that runs beneath the flywheel cowling to the magneto, enabling the spark plug to fire.

4. Remove the magneto.
5. Squeeze the emergency handle and turn the flywheel one full revolution, holding a socket close to the flywheel in approximately the same place the magneto was. There is a magnet inside the flywheel that will attract the socket as it passes.

   Discussion point What happened? From this and looking at what the magneto is connected to, can you guess what it does?

   - There is a magnet in the flywheel. When the magnetic field of the flywheel magnet cuts through (moves past) a conductor (coils of copper wire inside the magneto itself) a flow of electrons is created and thus an electric field. As the magnet moves quickly past the conductor, the electric field collapses. This creates a voltage of more than 20,000 V which is enough to cause a spark to jump across the air gap, igniting the fuel at just the right time.

6. Remove the muffler

   Discussion point The intake manifold is made of plastic. The muffler is made of aluminum. Why?

   - The exhaust gasses are much hotter than the intake air and the muffler must be able to withstand the high temperatures.

7. Unscrew the cap and open the gas tank.

   Discussion point Look in the bottom of the gas tank. What's down there? What does it do?

- It's a fuel filter screen. It keeps stuff that might have fallen into the tank or gas can from clogging the fuel system.

8. Lift the gas tank up off of the flywheel cowling but don't disconnect the hose between it and the carburetor. Just let it hang loose.

9. Identify the carburetor

   Discussion point How does a carburetor work? What feeds into it and where do the inputs go from there?

   - Air and fuel feed into the carburetor. As you may know, Bernoulli's equation says that as the velocity of a fluid increases, the pressure decreases. This draws the fuel into the air and is metered by the throttling valve, a butterfly valve that controls how much fuel and air mixture are metered into the cylinder.

10. Locate the cover that is stamped OHV

    Discussion point What do you think OHV stands for?

    - Overhead valve.

11. Remove the cover.

12. Squeeze the emergency stop handle and spin the flywheel. Note what happens to the pushrods, rocker arms, and valve springs.

13. Remove the cylinder head/carburetor/and gas tank by removing the four head bolts, which are shown in Figure 3. These bolts are 10mm and are the only metric fasteners on this mower.

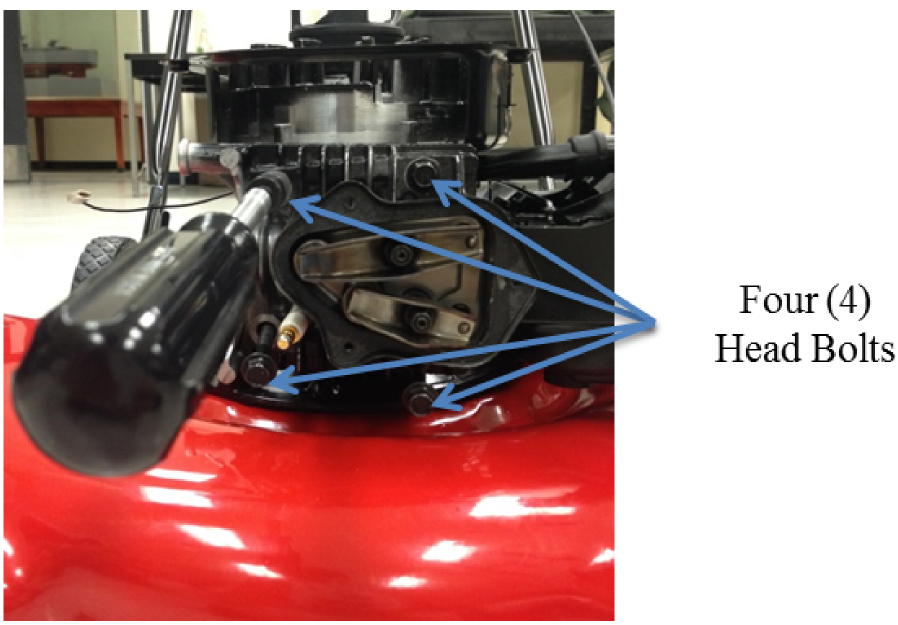

Figure 3: The four cylinder head bolts

14. Also remove pushrods, valve spring caps (see Figure 4), and head gasket.

15. Carefully turn the head/carburetor assembly to disconnect the thin rod between the throttle plate and crank case.

16. Remove the connecting rod.

17. Push on the valve springs and note the movement of the valves.

    Discussion points Which is the intake valve and which is the exhaust valve?

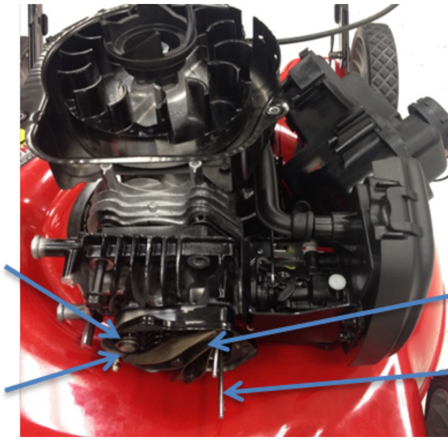

Figure 4: valve springs, rocker arms, and pushrods

- The exhaust valve is on top, the intake valve is on the bottom

Squeeze the emergency stop handle and rotate the flywheel through several revolutions – in the direction it would turn if running (clockwise). When the piston is all the way out, this is the minimum cylinder volume (called top dead center or TDC. You'll see why they're called this in a couple minutes). Wait, if the piston is all the way out it fills the cylinder. What can we mean by 'minimum volume'? There is no volume! Or is there? Hint: check the cylinder head.

Squeeze the emergency stop handle and rotate the flywheel clockwise 180°. When the piston is all the way in the cylinder, this is the maximum cylinder volume (called bottom dead center or BDC).

18. Squeeze the emergency stop handle and rotate the flywheel clockwise another 180°. The piston will be back in the starting (TDC) position.

Discussion point How many times does the piston transit the cylinder, either out or in for one complete revolution of the flywheel?

- 2

Follow along by turning the flywheel as you talk through it. A reciprocating piston engine works like this:

a) As the piston moves from TDC to BDC (moves from out to in over 180° of flywheel rotation), the cylinder volume increases, lowering the pressure inside the cylinder and drawing in air from outside. This is called the *intake stroke*.

   Which valve must be open in order for air to get into the cylinder?

   - Intake

b) As the piston moves from BDC to TDC (moves from in to out), the cylinder volume decreases, increasing the pressure and temperature inside the cylinder. This is called the *compression stroke*.

   What configuration is the intake valve in: open or closed?

   - closed

   What configuration is the exhaust valve in: open or closed?

   - closed

   How do we know the temperature increases when the pressure increases?

   - The ideal gas law

c) When the piston reaches TDC, the spark plug fires, timed by the flywheel as you saw earlier. This causes the hot, high pressure fuel/air mixture to explode, driving the piston from TDC to BDC. This is called the *power stroke*.

   What configuration is the intake valve in: open or closed?

   - closed

What configuration is the exhaust valve in: open or closed?

- closed

d) As the piston moves from BDC to TDC, the exhaust is forced out of the cylinder. Once the piston reaches TDC, the cycle starts over again. This is called the *exhaust stroke*.

As described, each movement of the piston from TDC to BDC or vice versa is called a stroke. How many strokes were there in the cycle you just discussed?

- 4

How many times did the intake valve open and close?

- 1

How many times did the exhaust valve open and close?

- 1

Thus we have a four-stroke engine, which is to say that the piston makes four strokes, the flywheel (and thus the crankshaft) makes two complete rotations, and the valves go in and out once, per cycle (or 720° of crankshaft rotation).

19. Remove the flywheel. Set the shear pin in the small plastic cup.

Discussion point What is the purpose of the shear pin?

- In the event the mower blade strikes something that it cannot cut through, the shear pin, designed to be the weakest link in the system, breaks allowing the flywheel to spin freely and likely saving the engine from any other permanent damage. The shear pin is analogous to a circuit breaker in an electrical system.

20. Disconnect the emergency stop handle cable.

21. Remove the flywheel cowling.

22. Turn the mower on its side and remove the blade.

23. Unbolt the engine from the mower deck and set the deck on the floor. Set the engine on the blue foam block. Think of the crank case as a container with a lid. Set the engine on the block with the lid facing up as shown in Figure 5.

24. Remove the crank case cover.

25. Identify the crankshaft, the camshaft, and the governor (Figure 6).

Discussion point Look at the governor (the white plastic thing). How does it work? Hint: Take it off and spin it.

- The spring tries to pull the throttle open and the governor tries to close it. If you push the mower over a patch of long grass the engine speed slows down. The spring is still trying to pull the throttle open but in this case the governor doesn't resist so much. The governor is attached to the camshaft timing ring and rotates at a speed proportional to the engine. When the engine slows down, the flyweights retract and the throttle arm is allowed to move, opening the throttle and letting more air and fuel into the engine. Once you unload the engine (i.e. push the mower back over short grass) the speed increases, the flyweights sling out, and the governor again limits the amount of fuel and air entering the engine, preventing the engine from over-speeding.

26. Remove the governor if you haven't already done so.

Discussion point The governor, camshaft gearing and cams, and the crankshaft gearing are all made of plastic. Why would the engine manufacturer decide to use plastic?

- Plastic is cheaper than metal parts because the base material is cheaper and the manufacturing process, injection molding, is also cheaper. The whole mower costs around $150, so there isn't a lot of room for profit.

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Figure 5: the engine resting on foam block

We typically talk about crank shaft position in terms of degrees in a circle or crank angle. We arbitrarily set the beginning of the cycle as the start of the intake stroke where the piston is all the way out and the crankshaft is at the top and very center of its rotation – hence top dead center. This is referred to as 0° crank angle. When the piston is all the way down (BDC), the crankshaft angle is 180° from where it started, etc.

How many teeth does the camshaft gear have?

- 21

How many teeth does the crankshaft gear have?

- 42

We just learned that a whole cycle requires four strokes. How many revolutions of the crankshaft is this? Does this make sense?

- Half a revolution. In other words, two revolutions of the crankshaft result in one revolution of the camshaft. You can see this by tracking the cam lobes.

27. Remove the camshaft.

Discussion Point What do the lobes on the camshaft do?

- They actuate the valves via the pushrods, rocker arms, valve springs, and valve stems. You'll notice that for every two revolutions of the crankshaft the cam lobes go around once which agrees with our earlier observations.

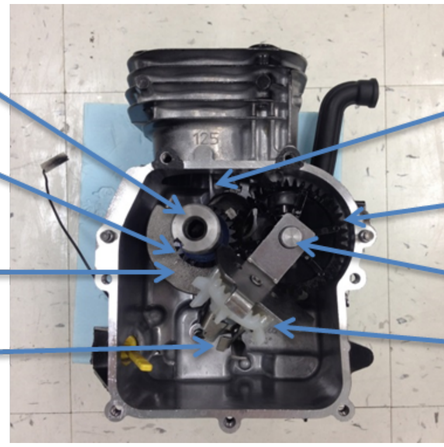

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Figure 6: inside the crank case

28. Remove the tappets.
29. Remove the crankshaft.

    Discussion point What do the counterweights on the crankshaft do?

    - The counterweights smooth crankshaft rotation by counterbalancing the piston. If the crankshaft didn't have counterweights, the whole engine would vibrate like crazy and might even shake itself apart.

30. Remove the piston.

    Discussion points Looking at the connecting rod bracket, why is one side of the "C" shape different than the other?

    - To ensure that the connecting rod bracket is installed correctly - it only fits one way.

    An engine takes in fuel and air and releases work and heat. If we turned the engine backward by hand, would all of the heat released from the engine (along with the work we are supplying with our hand) go back into the cylinder and cause air and fuel to come out? Granted, it's sort of a silly question, but what does it illustrate?

    - That processes necessarily only progress in one direction: forward in time (and this is one of the ways we define what forward means). We can't recover the heat and turn the exhaust back into air and gas making the system the same as it was before we started.

    Previously, you described the flow of air and fuel through the system. Now, describe the flow of energy through the system.

    a) Chemical potential energy, contained in the fuel, is released in the cylinder during combustion as heat, which is a form of energy.
    b) Some of the heat is used to do work in that the heating of the gas results in increased pressure that is applied over the piston area and manifested as a force.
    c) This force applied over the length of the piston stroke is known as work, which is also a form of energy.
    d) The remaining energy leaves as heat through the engine block and exhaust.

    Remember, energy cannot be created or destroyed, only transferred from one form to another. As such, all of the chemical potential energy is converted to work and heat.

Congratulations! You've broken down a lawnmower, a very complex mechanical device, and figured out how it works!

Guided Reassembly

The previous group took these mowers apart. To help you with reassembly, they should have placed the components on the table in the order they took them off, from left to right. Thus, as you put them back on, you should largely pick them up from right to left.

1. Identify the piston and connecting rod. (Figure 7)

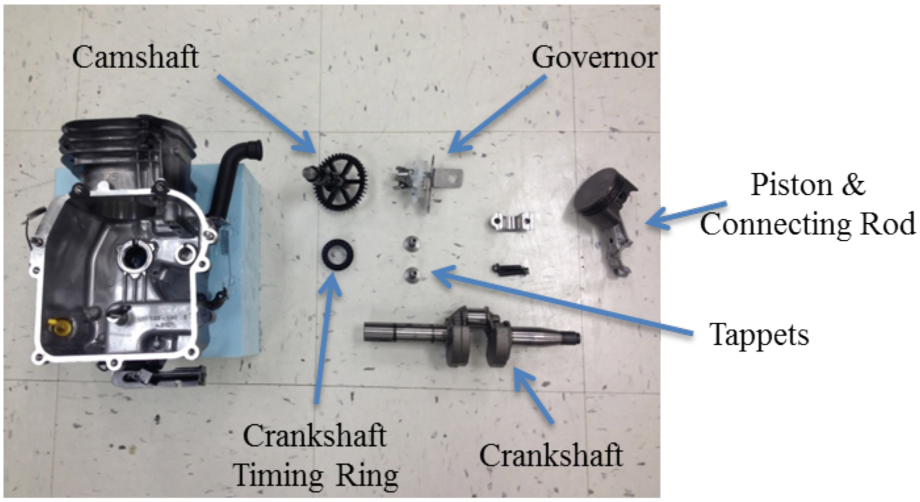

Figure 7: contents of the crankcase; the dipstick and governor lever are still in place

Discussion points You'll notice the piston is a different metal than the connecting rod. Why?

- The piston needs to withstand the force and thermal stress of repeated combustion. Such materials are likely expensive. The connecting rod doesn't have such significant material requirements so it can be made of a cheaper material.

You'll also notice that the bracket on the connecting rod is different in the two places it bolts on – one with a groove and one with a lip. Why are they different?

- To make sure it only goes together one way. This is an example of something called design for assembly.

2. Identify the crankshaft, install it in the crank case.

Discusison point What is the purpose of the crankshaft counterweights?

- To smooth rotation. Without them, the mower would shake itself apart (if it ever even ran in the first place!).

3. Insert the piston and attach the connecting rod.
4. Insert the crank timing ring. Note that one of the teeth is marked with an indentation.

Discussion point How many teeth are there on the timing ring?

- 21

5. Identify the camshaft.

Discussion points What are cams and what do they do?

- Cams actuate the intake and exhaust valves.

How many teeth are there on the camshaft timing ring?

- 42

6. Insert the tappets.

   Discussison point What do the tappets do?

   - Tappets ride along the cams and are the first components in the valve timing linkage.

7. Insert the camshaft so that the indentation between two of the camshaft timing ring teeth straddle the indentation on the crankshaft timing ring. See Figure 8.

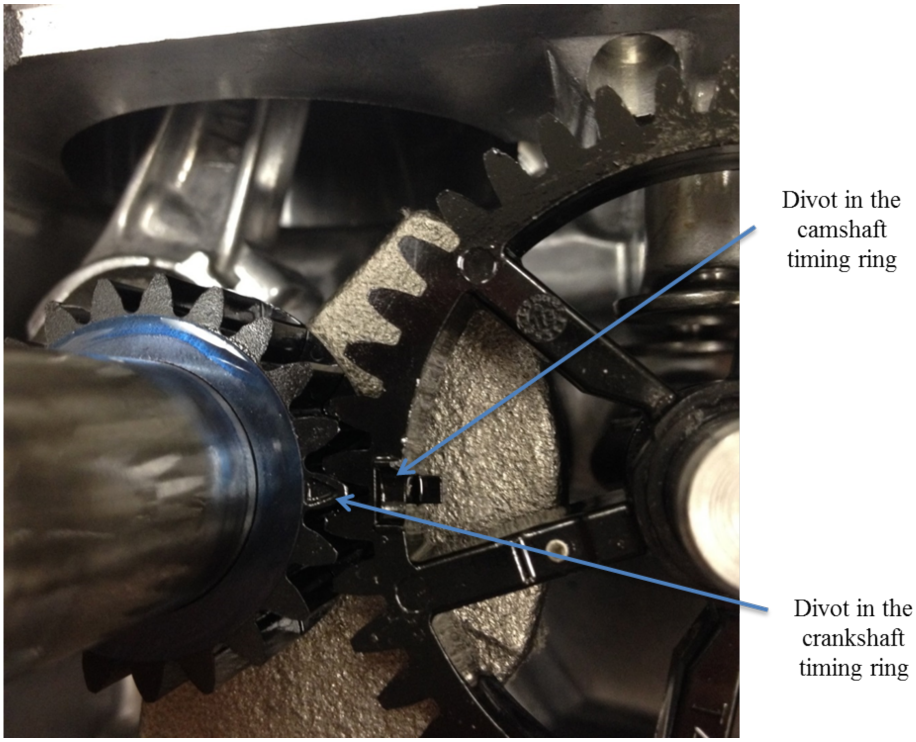

Figure 8: crankshaft timing ring aligned with camshaft timing ring

8. Turn the crankshaft until the piston is all the way up (out) in the cylinder and the lower cam on the cam shaft is pointed in the 9 o'clock position.

   Discussion point This is called top dead center (TDC). Why?

   - Engine nomenclature is based on the cylinder being oriented vertically, thus with the piston all the way up, this is the top. The term dead center comes from the orientation of the crankshaft – the throw is in the dead center of the circle that it sweeps as the crank shaft rotates.

9. Follow along by turning the crankshaft counterclockwise as I talk through it. A reciprocating piston engine works like this:

   a) As the piston moves from TDC to BDC (moves from out to in over 180° of flywheel rotation), the cylinder volume increases, lowering the pressure inside the cylinder and drawing in air from outside. This is called the *intake stroke*.

   b) Identify the cylinder head. Pick it up and push on one of the valve springs. Note the valve opening when the spring is compressed. See Figure 9.

      Why is one valve bigger than the other? Which is which?

      - The intake valve is bigger (it's about the size of a nickel). This is because the pressure differential (the difference between the vacuum inside the cylinder and the outside air pressure) is small, thus a large passageway is needed to get the air in. The exhaust valve is smaller (about the size of a dime). This is because the pressure differential (the difference between the pressure inside the cylinder and the outside air pressure) is large following combustion, thus a smaller passageway is sufficient.

Which valve must be open in order for air to get into the cylinder?

- The intake valve

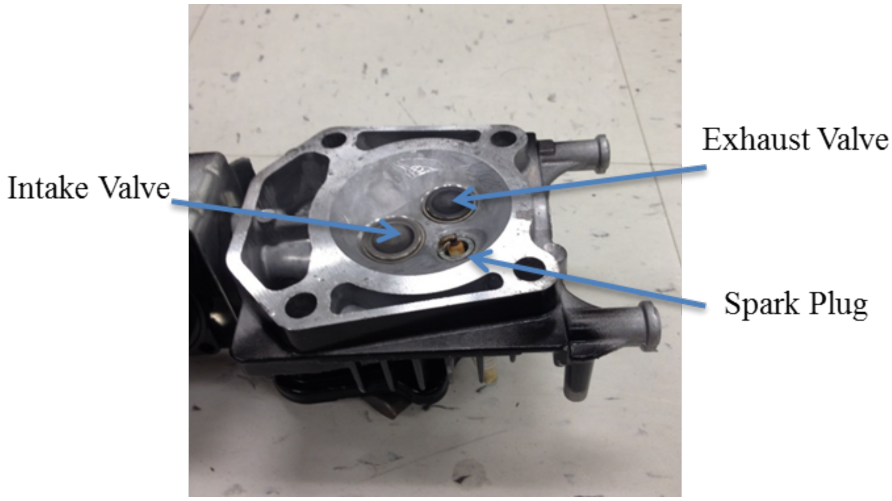

Figure 9: the cylinder head

c) As the piston moves from BDC to TDC (moves from in to out), the cylinder volume decreases, increasing the pressure and temperature inside the cylinder. This is called the *compression stroke*.

   What configuration is the intake valve in: open or closed?

   - closed

   What configuration is the exhaust valve in: open or closed?

   - closed

   What relationship describes the relationship between volume, temperature, and pressure in this case?

   - The ideal gas law

d) When the piston reaches TDC, the spark plug fires, timed by the flywheel as you saw earlier. This causes the hot, high pressure fuel/air mixture to explode, driving the piston from TDC to BDC. This is called the *power stroke*.

   What configuration is the intake valve in: open or closed?

   - closed

   What configuration is the exhaust valve in: open or closed?

   - closed

e) As the piston moves from BDC to TDC, the exhaust is forced out of the cylinder. Once the piston reaches TDC, the cycle starts over again. This is called the *exhaust stroke*.

   As described, each movement of the piston from TDC to BDC or vice versa is called a stroke. How many strokes were there in the cycle you just read?

   - 4

   How many times did the intake valve open and close?

   - 1

   How many times did the exhaust valve open and close?

   - 1

f) Thus we have a four-stroke engine, which is to say that the piston makes four strokes, the flywheel (and thus the crankshaft) makes two complete rotations, and the valves go in and out once, per cycle (or 720° of crankshaft rotation).

10. Identify the governor. The governor maintains engine speed when the engine is loaded and unloaded. Inspect it. Spin the white gear with your fingers. Install it in the engine and observe where it is with respect to other components. See Figure 10.

    Discussion point How does the governor work?

    - The spring tries to pull the throttle open and the governor tries to close it. If you push the mower over a patch of long grass the engine speed slows down. The spring is still trying to pull the throttle open but in this case the governor doesn't resist so much. The governor is attached to the camshaft timing ring and rotates at a speed proportional to the engine. When the engine slows down, the flyweights retract and the throttle arm is allowed to move, opening the throttle, letting more air and fuel into the engine, speeding it up. Once you unload the engine (i.e. push the mower back over short grass) the speed increases, the flyweights sling out, and the governor again limits the amount of fuel and air entering the engine, preventing the engine from over-speeding.

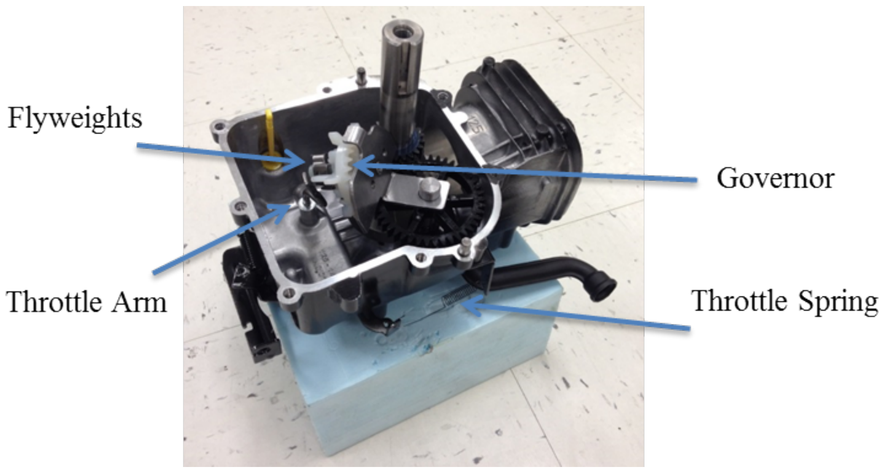

Figure 10: engine speed governing system

11. Identify the crank case cover and install it.
12. Place the mower deck on the table and bolt the engine to the deck. Note: the bolts are screwed up from beneath the mower deck.
13. Attach the blade. Be sure it is oriented correctly (the mower spins clockwise when viewed from above)
14. Connect the emergency stop handle.
15. Insert the shear pin and slide the flywheel down over top of it.

    Discussion points What purposes does the flywheel serve?

    - Quite a few, actually. It maintains rotational inertia, the fins on it move air around the engine helping to cool it, it also coordinates spark timing inside the engine.

    What purpose does the shear pin serve?

    - In the event the mower blade strikes something it can't chop through, the shear pin is designed to fail, reducing the rotational inertia of the engine and saving the engine from damage. Thus, the shear pin is designed to fail to protect the system like a fuse in an electrical circuit.

16. Insert the governor connecting rod into the arm on the crank case.
17. Pick up the cylinder head and connect the governor connecting rod to the throttle plate.

    Discussion points What does the throttle do?

    - As previously discussed, the throttle mixes and meters the air and fuel that enters the engine.

    What is the name of the component that houses it?

- The throttle is contained inside the carburetor.

18. Then insert the four head bolts and turn them only about five full rotations. Be sure the head gasket is oriented properly (it will warp if it's seated incorrectly).

    Discussion points What does the head gasket do?

    - The head gasket creates a seal between the cylinder head and the engine block ensuring the combustion gasses push the piston down versus escaping out through the cylinder head.

    Why are the cylinder head bolts so long?

    - They've got to withstand the combustion explosion, precluding the cylinder head turning into a projectile!

19. Replace the valve spring caps as necessary and swivel the rocker arms so that they are on the valve spring caps and the pushrods are seated in the rocker arm indentations. See Figure 11.

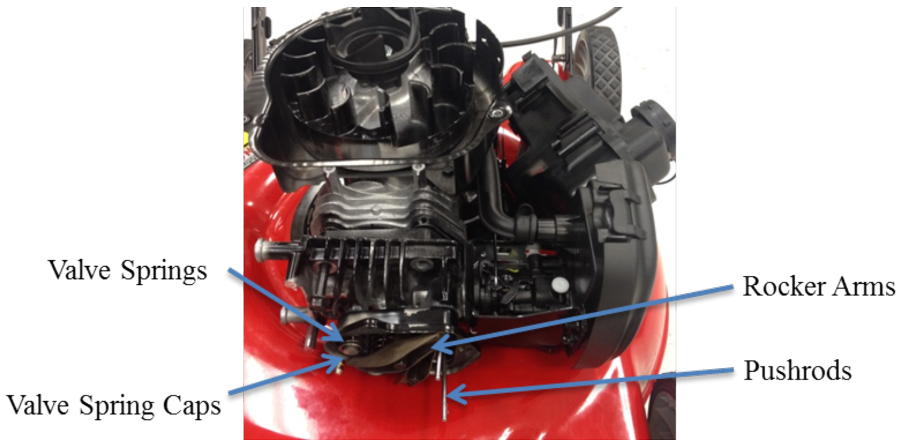

Figure 11: valve springs, rocker arms, and pushrods

20. Holding the rocker arms over the pushrods (they tend to slip off), push the head against the engine block and tighten the bolts.

21. We previously identified which valve was the intake and which was the exhaust. Remind yourself which is which.

22. Remember, the intake valve opens and closes during the first 180° of crankshaft rotation. Squeeze the emergency stop handle and turn the flywheel clockwise until the intake valve just starts to open. This is TDC. Count 720° of rotation of the flywheel. As you do, you should see the intake valve dip and rise, and 360° of rotation later the exhaust valve dip and rise. If so, you have reassembled the valve timing system correctly.

23. Slide the gas tank back into place.

24. Replace the OHV cover.

    Discussion point What does OHV stand for?

    - Overhead Valve

25. Replace the muffler.

    Discussion points What does the muffler do?

    - The muffler is filled with baffles that slow and mix the exhaust, quieting and cooling it.

    Why is it metal compared to the intake manifold which is plastic?

    - The exhaust gasses are very hot compared with the ambient (inlet) air. The exhaust would probably melt the plastic used to make the intake manifold.

26. Replace the magneto. Be sure to reconnect the thin wire that extends to the flywheel brake assembly.

    Discussion point How does the magneto work?

    - There is a magnet in the flywheel. When the magnetic field of the flywheel magnet cuts through (moves past) a conductor (coils of copper wire inside the magneto itself) a flow of electrons is created and thus an electric field. As the magnet moves quickly past the conductor, the electric field collapses. This creates a voltage of more than 20,000 V which is enough to cause a spark to jump across the air gap, igniting the fuel.

27. Replace the cowling.
28. Squeeze the emergency stop handle and lightly pull the starter line. Does the blade move in the correct direction?

If so, congratulations! You've made order out of something that once was quite a mess!