Stirling Engine Project FAQ

for Students and Parents

1. *Why a hands-on project, and what does cutting tin and gluing joints have to do with physics?*

At the time of his death, physicist Richard Feynman kept a motto on the blackboard in his office. The motto read "What I cannot create, I do not understand." Known for his contributions to theoretical physics, Feynman was also a skilled engineer. After the Challenger accident he was brought on to investigate the cause of the crash, and famously exposed the frozen O-ring that led to the explosion. Feynman was known for his deep understanding of physics, not for his ability to regurgitate known facts.

Every piece of educational research we have seen in recent years regarding the teaching of physics has repeatedly asserted that the familiar demo/lecture/worksheet/exam method of teaching physics, familiar to most people who were educated in the 1980s or earlier, has failed to produce proficiency or mastery of physics concepts in students. Every article we've read by people who have studied the problem of physics education asks for a more authentic, more immersive, "messier," real-world, holistic approach to physics education. For years, physics education nationwide has produced students who can calculate the Carnot efficiency of a heat engine, but who do not actually understand what a heat engine *is.* In building the engine from scratch, students know every single piece of the engine. There is no "black box" or unknown component. If we had cut the tin, or provided students with a finished piece for a demonstration, there would be no chance to know the engine *inside-out*.

2. *Do students who worked with models, or who have parents who are engineers, have an unfair advantage in this project?*

No. Students who worked with models as children, or who have parents who are engineers, *do* have an advantage, but it is not an *unfair* advantage. Students in an honors physics class at a nationally-competitive high school come equipped with a broad range of skills. Some are stronger writers, thanks to any number of reasons – for instance, perhaps their parents enjoy books more. Some are stronger at math. Some are stronger at conceptualizing the three dimensions of space, some at conceptualizing the passage of time. We all have a remarkably complex tapestry of skills.

We require students to consult their parents on this project. Some parents can be more helpful than others, and we encourage practically any level of involvement (within reason). For students who need it, we also maintain regular lunchtime, after school, and weekend "work parties" in which students can get regular, specific guidance on their projects.

(As an aside, a few have asked whether boys have an advantage because, well, "they're boys." A quick glance at the YouTube site that shows the chronological order in which videos of working engines were posted demonstrates that gender seems to have made no difference in performance.)

3. *Is performance-based assessment rather than effort-based grading fair?*

The answer to this question depends on your level of comfort with the scientific method. If you believe that physics accurately describes the performance of a heat engine, then you are forced to conclude that a better understanding of physics will lead to a better performing engine. If you believe that the engine does not run on the principles of physics, but instead runs on things like "luck", chance, direct intervention on the part of spiritual beings, etc., then you might believe that performance is not linked to understanding.

It is true that more than one student has put in enormous effort without achieving success. Rather than challenging the nature of the grading system for this project, this fact supports the system. Students should not be rewarded for effort, but *right* effort. *Meaningful* effort. In the usual pencil-and-paper, lecture-and-exam system, students who fail to put in right effort might study for hours and get a low grade on the exam. Their incentive, then, is external, and comes late: you didn't study in the right way, so you didn't understand, so you got a low grade, so here are the consequences. In the case of the Stirling Engine, the incentive that directs student towards *right* effort is the problem of time. Students who think efficiently, who use the laws of physics to guide their thinking, who study the heat engine and how it works, take less time to complete the project. Students who simply follow instructions, who do not think in a physics-based way, who do not deeply understand how a heat engine works, will take more time to complete the project. This is an immediate and direct incentive to *understand*: in understanding, the project will come to fruition more quickly.

Some might argue that they *understand* how the engine works, it just *doesn't work*. I would point these folks back to Feynman's motto: "What I cannot create, I do not understand." If you understand how a heat engine works, you can make a heat engine. What better way is there to assess whether a student fully understands how a heat engine works?

4. *How much time is too much time to spend on this project?*

The project can be completed in approximately 10 hours, including purchase of materials, assembly, and debugging. That said, some students spent less than this (one student's engine worked on the first try) and some students spent more than this. One reason students are willing to spend a lot of time on their engine is that they find the project challenging and engaging, a welcome relief from the lecture-and-exam routine. That said, some students find that they reach a wall, where continued work on the project is not paying off and hurting their performance in other classes. These students have a choice to make: they can back off from the project, earn a C grade for completion of the assembly, and focus on studying for the midterm and final exams in the unit. That is, we do allow "pressure relief" in the form of a deeper theoretical understanding of the project leading to a high grade on the midterm and final exams in this unit.

The project was assigned the first week in January, and the homework load was lightened to account for student work on the project throughout January and February. We have found that giving students more than 8 weeks to work on *any* project does not pay off, that most students have not yet learned to budget their time to take advantage of 12 weeks.

5. *I'm too stressed out by this project! What should I do?*

Real-world, "messy" projects like this can be deeply emotionally engaging. There is a feeling of "Not working …. NOT working … NOT WORKING …" which can be very frustrating. Students who are successful academically might not be aware that plenty of their classmates have this experience when working homework and exams. Often it is the "A" student who does well on homework and exams who bristles at the thought of real-world project. That said, the moment of success is made sweeter by the lack of success before that. Research shows as well that people have much stronger learning experiences if that experience is accompanied by a strong emotion. If the strong emotion is a positive one, like those that come with success, the benefits are extremely rich, particularly in comparison to success on a paper-and-pencil exam.

If, however, the strong emotion is a negative one, that can also provide an educational opportunity. For instance, students who are deeply frustrated with their engine find themselves wanting to prove that they understand the *theoretical* underpinnings of the experiment. This will pay off in later exams. Furthermore, students might want to engage in a dialogue with their teacher about the nature of the project. This bears fruit in terms of student understanding of this educational method. (This FAQ, in fact, is aimed at just these students, and has the not-so-subtle aim of teaching students something about physics education.)

Still, if you are a parent or a student and you are concerned about the level of student stress associated with the project, come have a chat with one of us. We are constantly available by e-mail or in person. We have designed several "pressure-relief valves" into the project, including a rolling deadline, and we would be happy to explain this as needed.

6. *Is this project dangerous?*

The project as specified is no more dangerous than cooking dinner. This is not to say that it isn't potentially dangerous – it is at a danger level consistent with your maturity level. It is far less dangerous than driving a car. Still, you must be careful -- just as you can cut yourself slicing carrots or scald yourself heating a pot of water, you can cut yourself on tin or burn yourself with a candle.

In the first generation of the project, we did not anticipate that students would turn to blowtorches to increase the heat into the bottom of their project. Blowtorches are not allowed for reasons of safety.

Power tools are not encouraged. If a student wishes to use a power tool with the support and presence of their parent or guardian, that's fine.

Some students did not follow instructions and used a flammable epoxy at the bottom of their device. This epoxy burned when put in the presence of large flames. The burning epoxy generated a small amount of smoke and fumes. Please use nonflammable epoxies (like JB Weld) at the bottom of the project to avoid this. Also, use proper ventilation as instructed by the directions on the epoxy.

These engines are the safest possible engine to build and run. They do not produce exhaust; they do not build up high pressure.

7. *Is it too much to ask students at this level to build a tin-can engine?*

In the first iteration of this project, we had 43 of 127 students (34%) make the first deadline and earn a grade of A+. Of the remaining students, 23 made the A-/B+ deadline a week later. This means that over half of all honors physics student earned grades of 3.5 or higher on a 4.0 scale.

Tin-can engines have been a part of science faires and physics classes for some time. However, with the increased focus on standardized tests (such as the SAT II Physics and AP Physics exams) there is the danger of losing these types of projects. In the summer of 2006, one of us (BJP) traveled to Caltech to meet with the chair of the Engineering department to discuss the question "How can we at the high school level prepare students to be future engineers?" We talked for some time, but the chief message of his response was that he desired students who have had experience *building something*.

8. *Why should I build an engine if I'm not going to be an engineer?*

The purpose of a broad liberal education is to create leaders who can communicate across specialties. It is true that we specialize in college with a major, but even then colleges require breadth of understanding. You might not become an engineer, but you might hire engineers, you might consult engineers in your political capacity, or you might write about an engineer in your novel. If engineers are important to society, then so are engines. An *honors* physics class at a competitive high school should prepare students to enroll in science or engineering programs at any university in the country. To that end, we do prepare our students as if they *could* become engineers in the future.

9. *What does this have to do with any of the physics we've learned (or will learn) this year?*

All aspects of our physics curriculum are represented in the Stirling Engine project. From the first week of physics when we learned about *displacement* we were – unknowingly -- preparing to learn about a *displacer* like that found in a Stirling Engine. Many student engines fail to work due to friction problems, and it helps to be able to discuss frictional forces as the *product* of intrinsic "stickiness" *and* the normal force. Normal forces arise in misaligned displacer pins, etc. Many student engines fail to work due to balloon inflation not in the direction of motion. This gets at the definition of work as the product of force and displacement *along* the direction of motion. In fact, all problems that have arisen with the engine that we've seen can be cast in the framework of the physics we've been teaching all year.

One of the wonderful things about the project is that it has given us an opportunity to solicit *authentic* student questions. That is, a student is asking us a physics question not to solve a problem on paper, but because they actually *need* to know the answer to save them work. This is a delight as a teacher, though it can be confusing for the student who is used to more directed, less free-form Q&A.