Sophomore Machine Shop Experience Constructing A Spring-Powered Car

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Abstract:
A new project for introducing sophomore mechanical engineering students to machine shop practice and safety was introduced. For eight weeks of the sophomore mechanical engineering lab course, Grove City College students spend one afternoon each week in the machine shop learning about machine tools, machine shop practice and shop safety. This program introduces students to machining and assembly processes, and qualifies students for working in the shop on design projects. For many years, this project involved constructing a model Stirling engine. This project, based on a similar project developed at MIT a number of years ago, was popular with students, but lacked an organized presentation of shop information. Inadequate assessment was conducted, other than ensuring students built an engine without violating safety practices. Significant advance time was also required of the shop technician to prepare parts. In the 2012 fall semester, a new project was introduced with the goal of creating a more formal learning environment based around a modular organization of the material. Students construct a small car powered by a spring motor. The car consists of an investment cast aluminum chassis requiring machining, wheels machined from aluminum stock, a machined aluminum base, and assembly. The pedagogical approach is improved through a more systematized presentation of machining processes along with frequent assessments. Student completed five modules – turning, milling, drilling and tapping, CNC introduction, and a miscellaneous operations module. Each module included specific instructions, supervised machining, and a quiz. In 2012, each student completed a pre- and post-assessment test of the material in order to assess the level of learning. Results indicate significant improvement in students' understanding of machine shop practice. A secondary goal was reducing the preparation time through reducing the pre-machining required of the shop machinist. This goal was achieved. The car was designed to introduce students to the greatest possible number of machining processes (for the time allotted), while giving them enough informational background and hands-on time to gain a broad introduction to each process. The balanced use of background information directly coupled with hands-on experience has enhanced the learning experiences of students in the machine shop introductory class.

Background:

One of the goals of the sophomore lab for mechanical engineers at Grove City College is to introduce the students to the machines and processes of the modern machine shop. This instruction is achieved through hands-on experiential learning with an emphasis on correct procedure and safety. The lab takes a project-oriented approach as each student fabricates, assembles, and tests a mechanical system. Through this approach, the students learn about the importance of tolerances, quality control, correct assembly, and testing procedures. They are also exposed to technical drawings and design limitations as seen in the machining processes and the materials used.

The lab was developed for a class of 40-50 students. It takes place during the latter half of the fall semester over a period of six weeks. The students are split into five lab sections of 8-

10 students which meet on separate days of the school week. Each lab section lasts a total of three hours which includes 15 minutes for cleanup at the end. This gives each student a total of 16.5 hours to complete the project in the school machine shop.

The machine shop contains several machines with which the students familiarize themselves through the course of the lab. There are two 3-axis milling machines, one manual lathe, three manual drill presses, one CNC mill, and one CNC lathe along with several smaller tools such as clamps and a hand press. For each lab, the shop is manned by the instructor, the shop machinist, and three upperclassmen shop assistants.

Due to the time constraints of the course, it is designed to be an introduction only, and not an in-depth study or inclusive training course in machine operation. Students have a limited time on each machine, and the processes they complete are simple and straightforward. Table *1* shows the maximum amount of time each student theoretically has on each machine. The intent is to lay a foundation for the students so they can develop designs physically possible to create with conventional machining methods and prepare them to continue improving their machining skills through the senior capstone design project.

Approximate Time per Machine per Student							
Machine name	**Drill Press**	**Mill**	**Lathe**	**Belt Sander**	**Grinder**	**CNC Mill**	**CNC Lathe**
Machine quantity	3	2	1	1	1	1	1
Max time (min.)	297	198	99	99	99	99	99

Table 1: Maximum theoretical time each student has per machine based on 10 students per lab

The project previously used for this lab was based on a similar sophomore class project developed by the Massachusetts Institute of Technology (MIT). The Stirling engine was designed by Roger Howes at Dartmouth University.[1] This project was popular with students, and incorporated all the standard machines used in a machine shop. The end product was especially rewarding for the students as they each built a working miniature Stirling engine. However, the pedagogical approach was poor, and comprehension and retention was well below desired levels.

Several aspects of the Stirling engine project did not lend themselves to the specific setup of the Grove City College (GCC) machine shop. First, many parts of the project required pre-machining, forcing the shop machinist to spend a large amount of time preparing for the lab during the summer months. Second, some processes such as the use of the drill press were over-practiced by requiring the students to drill a total of 22 holes. Since it does not take such excessive repetition to learn how to use the drill press, time was taken away from more complex machinery such as the lathe and the vertical mill. The project gave a limited amount of experience on the mill as students performed only two operations on the vertical mill. Instructions were process-intensive, giving the students excellent step-by-step instructions, but failing to highlight the reasoning behind each step. Finally, there was no structured pedagogical method for teaching machining principles. Students were given a single test at the end of the project. Performance on this test was generally below desired levels.

These short-falls in the Stirling engine project prompted the design a new project for the sophomore lab. The project was to achieve all the previously mentioned goals for the lab as well as address the difficulties associated with the Stirling engine lab. Additional goals of the project were reducing the cost of the project to the department per student and including additional processes deemed appropriate for the class. The pedagogy of the class was to be enhanced through better organization of the lab and the instructions.

Development:

In order to achieve the objectives, a new project was developed for the students to build and assemble. The students would build a small spring-loaded car based on a 1.81 lb.-in. motor spring from Stirling Instruments. This car project was designed to contain less parts and complexity than the Stirling engine project to reduce the preparation time for the shop machinist as well as minimize redundant processes for the students. Once the students completed the project, they would have a working spring car as well as a display base. The final week of class, the students would participate in a competition with their classmates using their cars in various events. Each event tested the cars in different aspects such as path accuracy and maximum distance. The cars would also be judged for the best looking. The competition would provide motivation for the students as well as a chance to try out the car they built.

To wind the car up, the two rear wheels are turned in the direction shown in figure 1. The wheels are securely attached to the rear axle through the use of set screws. The axle connects to the output drum through a one-way bearing which catches to pull the spring from the storage drum and wind it on the output drum to store potential energy. Once the wheels are released, the spring returns to the storage drum, converting the potential energy to kinetic energy: spinning the rear axle and wheels. As soon as the spring is fully returned to the storage drum, the output drum stops spinning, but the rear wheels continue to freely spin due to the one-way bearing.

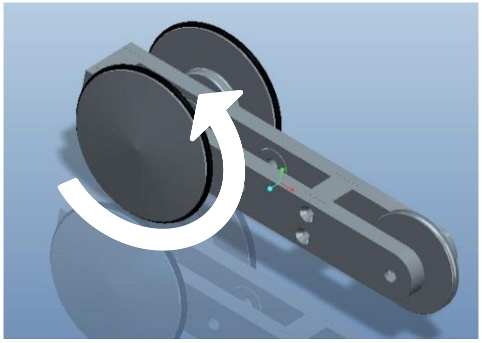

Figure 1: Prototype Car with Wind-up Direction

The initial prototype design was created to test the motor assembly. Figure 1 shows the initial design of the car. The prototype incorporated all the basic features required of the spring-motor car: two powered rear wheels, one smaller front wheel, and the spring motor assembly in the midline of the car body. The prototype exhibited several flaws which were corrected for the final design. First, the output drum would continue to rotate once the spring had fully returned to the storage drum due to the output drum's inertia. This would bend and eventually break the spring in three to four fully-wound trials. The rear wheel set screws also slipped on the axle, scratching the axle surface. During trial runs, the car would often ram into objects, damaging the front wheel and its ball bearings. Finally, the car failed in aesthetic value as the project should be visually pleasing enough to be a display piece.

The new design seen in Figure 2 incorporates features that deal with each of these issues. The over-rotation of the output drum is fixed through the use of a mechanical stop in the form of bent music wire. The set-screw slippage was alleviated through reducing the diameter of the output drum, thus reducing the torque on the axle and the shear force on the set screws. The front wheel was protected through an overhang in the car chassis, and the use of an investment cast chassis gave the car a much sleeker and pleasing look.

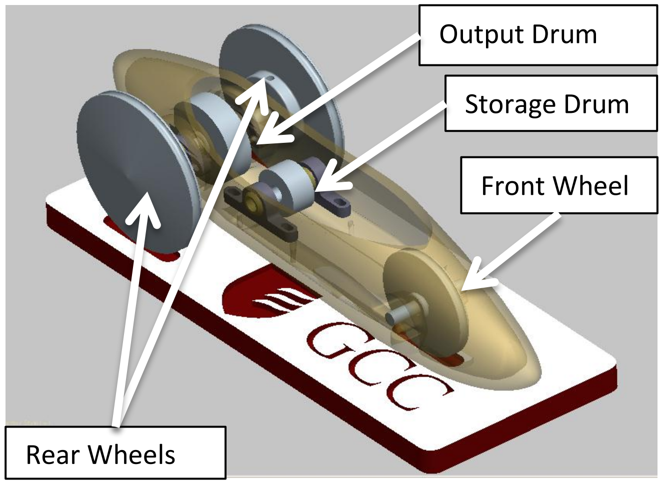

Figure 2: Final Design

The final design was optimized for incorporating as many shop machines and processes as possible. See Figure 3 for the basic overview. The two rear wheels were designed to be both manually turned on the inside and CNC turned on the outside. This allowed the students practice on both machines while maintaining a consistent aesthetic on the outside surfaces. The car chassis requires the students to drill and tap 11 holes on the drill press with the help of jigs. On the vertical mill, students square the ends of the base as well as mill slots for the car wheels. They also complete the output drum by milling a slot and drilling and tapping on the mill for practice using the digital readout. Finally, there are miscellaneous processes such as making press fits and bending the output drum stop.

In order to facilitate learning retention in the students, the different processes were separated into modules. Each module focused on a specific process or machine and the students would work on one or two modules per lab session. This lab organization guides the students by giving them a framework in which they place the knowledge they gain during the lab. Figure 4 is the flow chart for accomplishing each module. Some have prerequisite modules, such as the CNC Lathe Module. The student must first finish turning the inside of their rear wheels before starting the CNC Lathe Module. In order to reduce bottlenecks in equipment use,

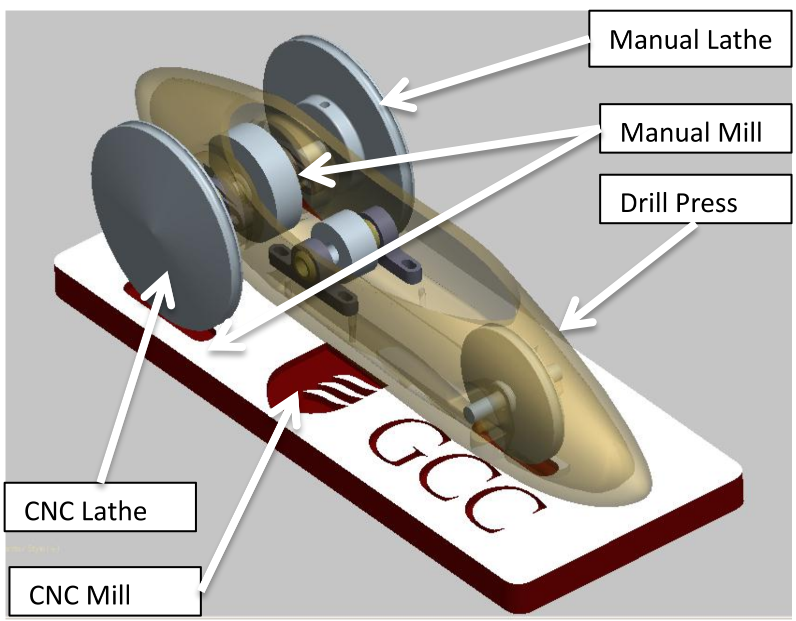

Figure 3: Final Design with major Machining Processes

most of the modules can be started simultaneously by different students. The one module in Figure 4 that was planned but not implemented during the fall of 2012 is the Thermoforming module. It will be incorporated in future classes starting in the fall of 2013.

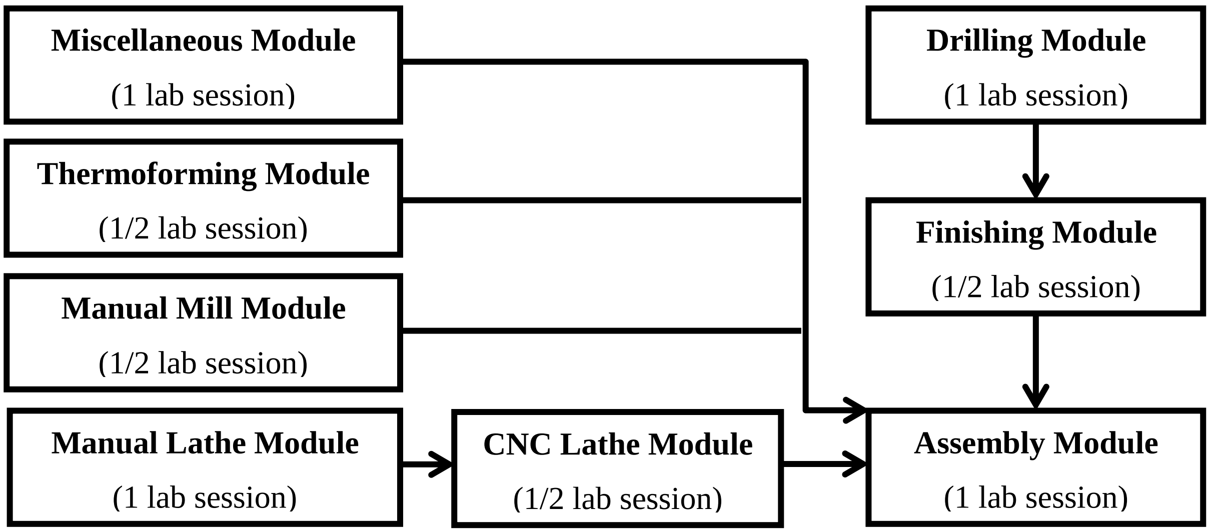

Figure 4: Module Flowchart

The instruction manual was created through direct observation and documentation of each process being performed by the shop machinist and shop assistants. Photographs were taken while the parts were made, and the most informative ones were included in the instructions section of each module. For assembly instructions, a working car was fully disassembled and reassembled while documenting the process in the same way as the machining processes.

Each module contains four sections: background, tooling/machines needed, instructions and assessment. The background section includes a short summary of the process the student will be performing in that module. For the modules that involve a specific machine, such as the Manual Lathe, Mill, and Drilling Modules, a picture of the specific GCC shop machine is included with important features and parts identified. The background section is designed to give the student a quick introduction to the machine and process before they start working, so they have a general idea of the process prior to starting work. After the background section is the tooling/machines needed section. This lists the tools, stock, and machines the students will use with the module so they can gather the required materials. The students are exposed to the correct nomenclature for the tools and jigs they use so they can follow the instructions accurately. The instruction section gives the step-by-step process for the student to follow. The written instructions are on the left, while accompanying pictures and figures are on the right. The instructions also include short explanations as to why the student is performing a certain action to facilitate deeper comprehension of the process. Finally, at the end of most modules, a quiz is given to assess the student’s knowledge and comprehension. This is to help facilitate retention as well as provide the instructor with a good benchmark for how much the student understands the module.

The layout of the CNC module is slightly different than the other modules as there is less hands-on work to be done. The students first fixture their parts in the machine. The shop machinist then gives them an overview of the steps by which a CAD model is converted into G-code for the CNC machine to use. An example of the G-code for the wheels is included in the instruction booklet along with some basic descriptions.

At the end of the instruction booklet, there are two Appendices, one containing the technical drawings of the parts to be machined by the students, and the other contains further instruction on drilling as that module is self-taught. The use of these Appendices gives the students further tools in connecting their engineering design classes with the machine shop lab.

Results:

The first semester of implementing this new project met with success as the students were all able to finish their spring-powered car in the allotted time. The project was also successful as an introduction to the shop as students took an identical test before and after the lab. The student average almost doubled as seen in Table 2. Unfortunately, there is no comparable data taken on the Stirling engine lab with which to compare the two projects.

Assessment Test Results

	Pre-Test	Post-Test
Average (%)	45.6	83.1
Stand. Dev. (%)	10.8	7.0

Table 2: pre- and post-test results

In order to continue to improve the new project, a survey of all the participating students was taken after they had finished the lab. They were presented with positive statements about the lab and given five options to choose from: strongly disagree, disagree, neutral, agree, and strongly agree (ranked 1 to 5 respectively for analysis). The results of that survey are seen in Table 3. The averaged response for every statement was above 3 with the lowest value being 3.395 in regards to hands-on experience with the CNC mill. This indicates that the students felt the lab was worthwhile in all aspects surveyed. Four statements of particular interest are statement numbers 2 and 3, and 9 and 16. Statements 2 and 3 were in regards to safety in the shop, and received high average scores of 4.474 and 4.632 respectively. Statements 9 and 16 were in regards to the primary goal of the lab as being an introduction to the machine shop. These two statements received average scores of 4.421 and 4.132 respectively. According to the survey, the participating students felt that the lab met its primary objective.

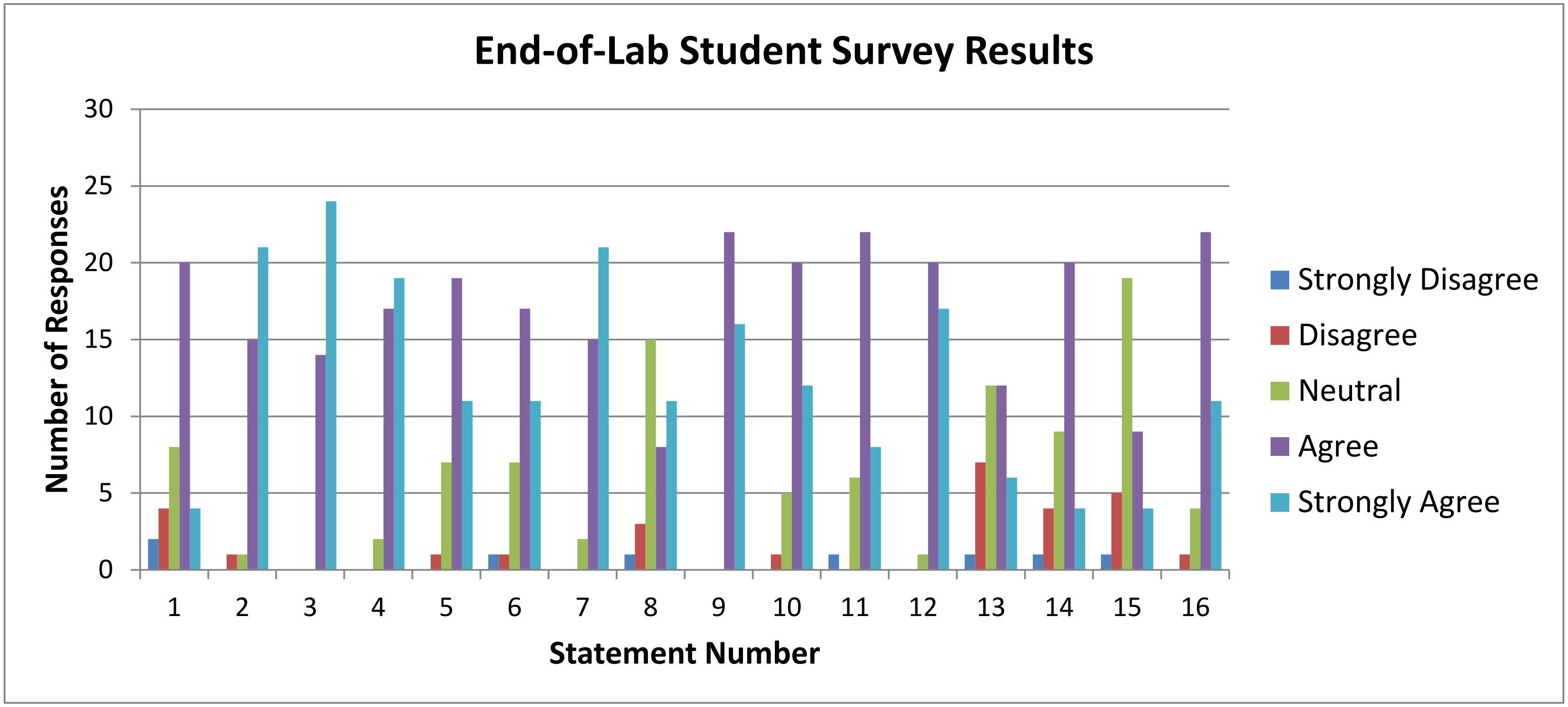

Figure 5: Survey Results Chart

Table 3: Student Survey Results

End-of-Lab Student Survey Results					
1	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The written instructions were clear and understandable.	2	4	8	20	4
Response Percent	5.26%	10.53%	21.05%	52.63%	10.53%
Average	3.526				
2	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I felt safe while working in the machine shop.	0	1	1	15	21
Response Percent	0.00%	2.63%	2.63%	39.47%	55.26%
Average	4.474				
3	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I felt the instructors emphasized safety adequately.	0	0	0	14	24
Response Percent	0.00%	0.00%	0.00%	36.84%	63.16%
Average	4.632				
4	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
This lab helped me feel more confident in the machine shop.	0	0	2	17	19
Response Percent	0.00%	0.00%	5.26%	44.74%	50.00%
Average	4.447				
5	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel comfortable performing basic operations on the mill.	0	1	7	19	11
Response Percent	0.00%	2.63%	18.42%	50.00%	28.95%
Average	4.053				
6	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel comfortable performing basic operations on the lathe.	1	1	7	17	11
Response Percent	2.70%	2.70%	18.92%	45.95%	29.73%
Average	3.973				
7	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel comfortable performing basic operations on the drill press.	0	0	2	15	21
Response Percent	0.00%	0.00%	5.26%	39.47%	55.26%
Average	4.500				
8	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel comfortable performing basic operations on the CNC mill.	1	3	15	8	11
Response Percent	2.63%	7.89%	39.47%	21.05%	28.95%
Average	3.658				

9	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The lab gave me a basic understanding of the machine shop practices.	0	0	0	22	16
Response Percent	0.00%	0.00%	0.00%	57.89%	42.11%
Average	4.421				
10	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
There was enough hands-on experience to learn the basic operations on the mill.	0	1	5	20	12
Response Percent	0.00%	2.63%	13.16%	52.63%	31.58%
Average	4.132				
11	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
There was enough hands-on experience to learn the basic operations on the lathe.	1	0	6	22	8
Response Percent	2.70%	0.00%	16.22%	59.46%	21.62%
Average	3.973				
12	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
There was enough hands-on experience to learn the basic operations on the drill press.	0	0	1	20	17
Response Percent	0.00%	0.00%	2.63%	52.63%	44.74%
Average	4.421				
13	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
There was enough hands-on experience to learn the basic operations on the CNC mill.	1	7	12	12	6
Response Percent	2.63%	18.42%	31.58%	31.58%	15.79%
Average	3.395				
14	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The written instructions gave enough background information to introduce the equipment and/or machining process.	1	4	9	20	4
Response Percent	2.63%	10.53%	23.68%	52.63%	10.53%
Average	3.579				
15	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The Appendices were useful.	1	5	19	9	4
Response Percent	2.63%	13.16%	50.00%	23.68%	10.53%
Average	3.263				

16	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am satisfied with this lab as a whole as an introduction to the machine shop and machining practices.	0	1	4	22	11
Response Percent	0.00%	2.63%	10.53%	57.89%	28.95%
Average	4.132				

Conclusion:

Most of the goals set for this project were attained through the use of the spring-powered car project and the modular set-up of the lab. The project successfully addressed safety and basic machining operations as seen in the high survey results (above 4.0) in the related survey statements. The modular design gave the students a focus for each lab session as well as provided the instructors with enhanced assessment capabilities compared to the Stirling engine lab. The design itself significantly reduces the preparation time for the shop mechanic by minimizing the need to pre-machine parts. Excessive and repetitive machining operations were minimized through the reduction of drilled holes by 50%. The Mechanical Engineering Department cost per student was reduced approximately 25%.

There remain some improvements and additions which will make the course more effective and reduce bottlenecks in machine usage. The Thermoforming Module had not been developed enough to implement it during the first semester of lab. Once the module is complete, students will also thermoform a clear canopy which will fit in the investment cast chassis. The finishing module also requires more detailed instructions in polishing or painting the chassis. Finally, the music wire stop required a lot of adjustment to work properly, so an alternative design should be developed.

The use of a simple hands-on project in conjunction with a modularly organized instruction booklet has improved the structure of the lab and assessment tools available to the professor. These improvements are hoped to have a positive effect on knowledge retention in the students in preparation for their senior capstone design project and future careers.

Bibliography:

[1] Morris, Stacy J., “Development of the Machine Shop Instruction and the stirling Engine Project for 2.670:ME Tools,” Bachelor’s thesis, department of Mechanical Engineering, Massachusetts Institute of Technology, June, 1996, http://dspace.mit.edu/bitstream/handle/1721.1/28174/36228783.pdf, accessed Jan. 24, 2013 , p. 14.