AC 2008-204: THE USE OF UNDERGRADUATE STUDENTS IN A LONG-TERM AIR POLLUTION REDUCTION RESEARCH PROJECT

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Abstract

Over the last ten years, a research project involving the study of the air pollutant emissions from small utility engines has been conducted. The project studied (1) the extent of the deterioration of the emissions as the engines age, (2) the causes of the deterioration, and (3) strategies for improving the emissions. Thirteen undergraduate students have worked on this project over the years. In comparison, only two M.S.-level graduate students (one of whom originally worked as an undergraduate student on the project) worked on the project over the same time. As a result, much of the research work was completed by these undergraduate students and their efforts played a large role in sustaining the project over its duration.

Students who worked on this project benefited by performing engineering work in a modern research laboratory facility, thereby gaining experience that could be helpful for them in their future careers. In addition, the students had the opportunity to work with engineers from the industrial sponsors of the project. In these interactions, the students needed to learn how to work with other engineers, and communicate their questions, ideas, and results clearly. The reliance on undergraduate students, rather than graduate students, on the project did have some drawbacks. These include an increased need for guidance, and often an increased time for the completion of project tasks due to the students having less time to devote to the project.

This paper describes the research activities of the students on the project, and contains a summary of the results. The educational benefits experienced by these students are described. In addition, project management issues such as maintaining project continuity, interaction with the project sponsors, and student recruitment are discussed. Some consideration on the impact of the project on future graduate school enrollment by the students is also presented.

Introduction

Small, spark-ignition, air-cooled, internal-combustion engines with power outputs of less than 19 kW have applications ranging from lawnmowers, to garden tractors, to snow blowers. Despite operating intermittently, often for a relatively short duration of time, the large number of these engines, coupled with their generally high pollutant emissions output, causes these engines to contribute to a substantial amount to the total air pollution in the environment. It has been estimated that 9% of the volatile organic compound inventory produced by mobile sources in the United States is from these nonroad engines.[1] In order to keep costs down, devices that could lower emissions from these engines have typically not been used; as a result, emissions from new engines tend to be rather high. Further complicating matters, many of these engines do not have exceptional durability. As a result, the levels of pollutant emissions, particularly for unburned hydrocarbons (HC), tend to increase significantly as the engines age.

To better understand this problem, and to find ways to improve the emissions from these engines, a research project was initiated in 1997 at the University of Wisconsin-Milwaukee (UWM). This project has gone through several phases over the years, but the intent of improving the emissions from these engines always remained. Initially, the project focused on characterizing the extent of the air pollutant emissions (HC, oxides of nitrogen (NO_x), and carbon monoxide (CO)), and quantifying how much the emissions increased as the engines aged through their useful lifetime. The project then moved into determining the engine factors most responsible for the increase in hydrocarbon emissions. The focus then shifted towards studying the durability of catalytic converters installed on the engines over the lifetime of the engine.

While some of this work was conducted by M.S.-level graduate students, the majority of the work was performed by undergraduate Mechanical Engineering students. Over the years, 13 undergraduate students worked on various parts of this project, while 2 graduate students worked on the project. Of those 2 graduate students, one began work on the project as an undergraduate student.

The use of undergraduates in research is hardly a new concept. Many examples can be found in the literature regarding research projects using undergraduates.[2-4] Studies have been conducted concerning the impacts of research experiences on undergraduates, with respect to learning enhancements and the potential for attracting students to graduate school.[5-7] One benefit involves enhancing the educational experience for students who tend to learn better in a active or visual environment, rather than in a passive environment.[8-9]

This paper presents a perspective of the impacts on students of research being performed over a long-term project. The project involved 11 years of work, performed by 14 students. Not only does this allow for consideration of some of the results of previous projects involving the impacts of undergraduate research experiences on students, but this also provides a different perspective on some of the project management issues that arise with a research project of this duration. In this paper, the results of the research work will only be summarized, as more detailed reports of the work can be found elsewhere. These summaries help show the progression of the work, as well as the level of work accomplished by the students. The work of the undergraduate students will be emphasized. Following that, the impacts on the students of being involved with this research project will be discussed. Included with this is some discussion of the impact of this project on the students' interest in graduate school. As managing a research project with so many undergraduate students does pose project management issues, those will be discussed as well.

Description of the Research Project

This air pollutant emissions project has gone through several phases over its duration. The experimental work primarily consisted of the testing of the emissions from small utility engines, and of adding operating hours to the engines to produce the aging of the engines. This work was conducted at the Center for Alternative Fuels at UWM. A schematic diagram of the emissions testing facility is shown in Fig.1, and a photograph of the dynamometer setup is shown in Fig. 2. Further physical and chemical analysis of engine components was conducted at the Advanced Analysis Facility at UWM.

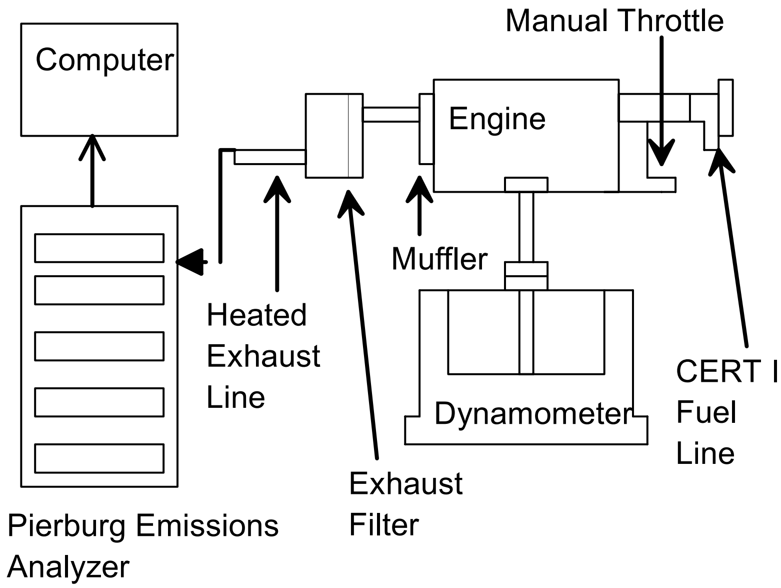

Figure 1: Schematic diagram of the emissions testing apparatus.

Figure 2: Photograph of the dynamometer set-up with one of the engines mounted for testing.

Table 1 contains a listing of the students, the approximate dates during which they worked on the project, the primary work they did on the project, as well as any other major comments. Throughout the paper, these students will be referred to by the letter designations indicated in Table 1. Some of the abbreviations used in Table 1 are explained below in the narrative.

Phase 1 of the project involved characterizing the extent of the emissions deterioration as the engines aged. Part of this project involved developing a laboratory test that would mimic actual field usage of the engines. Students A, B, C, and D worked on this phase of the project from 1997 to 2001. Student A began his work on this project as an undergraduate student, and continued to work on the project as he earned his M.S. degree. Initially, his work as an undergraduate was in support of another small engines emissions project, the details of which can be found in Reisel, *et al*.(2000)[10] Details of the procedures used in Phase 1 of this project can be found in Caceres, *et al.*[11] Briefly, both side-valve and overhead-valve, air-cooled, spark-ignition engines with a nominal power rating of 4.8 kW were tested over a total of 200 hours. The nominal lifetime of these engines is 125 hours, but similar engines have longer nominal lifetimes, and it is expected that most users will operate the engines longer than 125 hours. As a result, the engines were operated for 200 hours. Emissions were tested every 50 hours, using the standard SAE J1088 emissions test for small utility engines.[12] Hours were added to the engines between emissions tests using a laboratory test developed to mimic field usage. Essentially, this procedure involves operating the engines at 25% load (with the load being applied with weighted paddles on the blades) for different lengths of time.[11] As will be discussed below, it was found in Phase 1 that the formation of combustion chamber deposits (CCD) were a primary factor in the increase in emissions. As part of Phase 1, a set of engines were modified to operate on propane, and similar emissions levels were found as from the gasoline engines. This suggested that the deposits were primarily caused as a result of oil entering the cylinder, rather than from a fuel-based source. To help confirm this, chemical studies were performed to gain insight into the nature of the deposits. This also indicated that oil was playing a large role in the formation of the deposits.

Phase 2 of the project concentrated on evaluating engine features that would lead to the formation of the CCD through the input of oil into the cylinder. It was thought that if the primary source of the CCD formation could be identified and eliminated, the HC emissions would not deteriorate as rapidly. Students B, C, D, E, F, G, H, I, and J worked on this phase of the project from 2001 to 2004. This phase involved making modifications to the overhead-valve engines, running the modified engines over their 200-hour period, and studying the effects on emissions as a result of each modification. Three separate sets of engines were run during this time, so that the impact of each modification could be compared to the results from the unmodified engines. First, a series of tests were performed on a set of engines that had their breather elements detached (the DB engines) from the intake system. Second, a set of engines with isolated valves (VS engines) was operated to see the effects of eliminating the oil entering the cylinder through the valve stems. The details of the modifications for the VS engines are described elsewhere.[13] Briefly, the modifications to the VS engines included coating the rocker arms and pushrods with PTFE, adding valve stem seals, and greasing the parts frequently. Third a set of engine with both modifications (DB-VS engines) was tested. With these tests, it was hoped to determine the relative impact of oil introduction into the cylinder through the breather

Table 1: Description of students who have worked on this project

Designation	Name	Dates on Project	Major Tasks	Comments
A	Diego Caceres	01/1997-05/2001	Base Tests, Test Procedure Development, Propane Engines, CCD analysis	Graduate Student from 05/1999 – 05/2001
B	Tim Bunkelman	01/01-06/01, 01/02-05/02	Propane Engines, DB engines	Worked as co-op in industry between stints
C	Tim Carlson	01/01-06/01	Propane Engines, DB engines	
D	Pat Windsor	06/01-08/01	Propane Engines	
E	Jeff Dujmovic	09/01-12/02	DB Engines, VS Engines	
F	Jason Krajewski	09/01-08/02	DB Engines, VS Engines	Applied for graduate school in 2006
G	Travis Schisel	05/02-12/02	DB Engines, VS Engines	
H	Austin Schmitt	10/02-05/03	VS Engines	
I	Zack Ouradnik	01/03-05/04	VS Engines, DB-VS Engines, preliminary catalyst work	Later attended graduate school in business
J	Dan Azukas	09/03-05/04	DB-VS Engines, preliminary catalyst work	
K	Samih Zaman	06/04-08/04	Catalyst literature Review	UG student from the University of Michigan
L	Nick Doll	10/04-08/06	Catalyst project	M.S. Student
M	Kevin Rammer	09/06-12/07	Catalyst project	
N	Daniel Janssen	09/06-05-07	Catalyst project	

element, valve stems, and piston rings on the formation of CCD and the increase in hydrocarbon emissions as the engines age.

Phase 3 considered the effects of aging on the performance of catalytic converters inserted into the muffler of side-valve engines. Students K, L, M, and N worked on this project from 2004 until 2007, with Student L being a M.S.-level student. This phase was concerned not only with the changes in the effectiveness of the catalyst with regards to the emissions reduction over time, but also with investigating the physical and chemical deterioration of the catalysts as they were operated over 250 hours. A detailed description of the experimental procedures can be found in

Doll and Reisel.[14] Students I and J had spent some time on this phase of the project by developing a design for a bench-top experiment for testing the catalysts. After further discussion with the industrial sponsors of the project, it was decided to not perform this test. Student L did the majority of the work on Phase 3, and students M and N worked on the project after Student L completed his M.S. thesis.

Results of Research Project

The detailed results from Phase 1 of the project can be found in Caceres, *et al*.[11] Briefly, it was found that the pollutant emissions from the side-valve engines are initially larger, and increase more dramatically than the pollutant emissions from overhead-valve engines as the engines age. While HC, NO_x, and CO emissions all change as the engines accumulate hours of operation, the hydrocarbons tended to undergo the largest increase in emissions. One thing that must be noted, though, is that the HC and NO_x emissions have opposite trends with respect to air-fuel ratio, and so the air-fuel ratio needed to be monitored during the tests. By monitoring the air-fuel ratio, it could be determined if the changes in emissions were due to fluctuations in the ratio or truly as a result of the engine aging. Even with some drifting of the air-fuel ratio, it was still clear that HC emissions were increasing significantly. With the HC emissions being so prominent in the changing emissions, attention focused on the formation of CCD in the engine. Through tests described above, it was determined that oil introduction into the cylinder was the primary cause of the formation of CCD, and the corresponding increase in HC emissions as the engine aged.

The contributions to Phase 1 of the project by undergraduate students were as follows. Student A began working on this project after helping with a study of the speciated hydrocarbon emissions from small utility engines operating under different fuels.[10] As an undergraduate student working on this project, he was primarily responsible for the coordination of our laboratory tests with field tests being organized by one of the industrial sponsors of the project. This led to the development of an in-laboratory test that mimicked the life cycle of the engines in actual field use. This also resulted in the baseline measurements of the emissions deterioration in gasoline-powered side-valve and overhead valve engines. He completed this work as a graduate student, and then began the portion of the project involving the testing of the emissions from the engines after they had been modified to operate on propane. He also worked on performing the detailed physical and chemical analysis of the CCD with the Advanced Analysis Facility. Students B and C joined the project and learned the experimental procedures from Student A. They then assisted Student A in completing the tests on the propane-fueled engines. Student D joined the project for a summer as a substitute for student B who had taken a co-op position in industry. He also assisted in completing the tests with the propane engines.

Phase 2 was performed exclusively by undergraduate students. More detailed descriptions of the findings of this project can be found in Reisel, *et al* (2003).[13] In this phase, much was learned about the impact of the different oil introduction mechanisms into the cylinder on CCD formation. Secondarily, if more oil enters the cylinder as the engine experiences wear, the partial combustion of the oil will tend to increase the HC emissions as well. Of the three mechanisms, the oil entering the cylinder through the breather element was found to be the least important, contributing about 20% of the HC increase in the overhead-valve engines. The oil introduced through the valve stems contributed approximately 45% of the increase in HC emissions, with the rest being primarily attributed to oil leaking past the piston rings (~25%) as well as fuel effects. Perhaps the most interesting result from this work was that there seemed to be a maximum amount of CCD that would form in the engines. Therefore, reducing the oil entering the cylinder through any one source would slow the CCD formation and increase in HC emissions. However, eventually the engines would accumulate enough hours to experience similar amounts of deterioration as the unmodified engines even with one or more of the oil introduction mechanisms having been removed. This also resulted in more difficulty in interpreting the results, and so most of the conclusions of the contributions from the different mechanisms were based on the first 50 hours of engine operation, when CCD in the engines were still increasing.

As mentioned, this work was done exclusively by undergraduate students. The efforts that they performed are as follows. Students B and C worked on the setup and initial operation of the DB engines. Students E, F, and G completed the testing on this set of engines. Students E, G, H, and I then worked on developing and emissions testing the VS engines. Students I and J worked on the developing and testing the DB-VS engines. Students I and J also worked with the Advanced Analysis Facility to perform chemical studies of the CCD from the VS engines. From this analysis, they determined that some of the grease used in these engines for lubrication had leaked into the cylinder, and contributed to CCD formation and HC emissions. This enabled us to explain why, by the end of the emissions tests at 200 hours, the HC emissions were higher in the VS engines than in the unmodified engines.

The work on Phase 3 began with undergraduate student K who performed a thorough literature review. His review considered both the application of catalytic converters on small utility engines, as well as the operating characteristics of catalytic converters in general. Building off of this information, graduate student L performed the majority of the experimental work on this phase. After he finished, undergraduate students M and N worked to finish off the project through 250 hours of engine operation. Detailed discussion of the experimental procedures and results of this project can be found in Doll and Reisel.[14] Briefly, it was found that the catalysts put onto the side-valve engines did reduce the HC emissions from the engines, but had much less impact on the CO and NO_x emissions. The initial reduction level for the HC was approximately 34%. However, as the engines and catalysts aged, this decreased, reaching levels of approximately 18% reduction at 187.5 hours. The deterioration was due to physical loss of the catalyst surface, coating of the catalyst with carbon, and some poisoning of the catalyst. The catalyst poisoning became more pronounced as the hours of operation of the engines exceeded 125 hours.

As mentioned, Phase 3 began with a thorough literature review by an undergraduate student. This student, who was a Chemical Engineering major from the University of Michigan, worked on this project over one summer. His level of chemistry knowledge was higher than our typical Mechanical Engineering student, and so it worked out very well to incorporate his educational background at the start of this project. He was attracted to the project due to its location near his family's home, allowing him to work on the project and live at home over the summer.

Students M and N were employed to finish off the project after the graduate student had completed the bulk of the work. The graduate student had operated and tested the engines through 187.5 hours. Unfortunately, the progress by the undergraduate students was plagued by equipment problems. The students were able to operate the remaining engines through 250 hours, and performed the base emissions test at that point. The students were also able to measure the level of physical wear on the catalysts. The students then worked on attempting to regenerate the catalysts by heating them in an oven at a set temperature. The purpose of this was to determine if the catalysts were experiencing significant carbon coating. The catalyst regenerated after 62.5 hours did show significant deterioration due to carbon coating, and the performance of the catalyst was mostly restored after regeneration. However, a catalyst tested after 187.5 hours showed that while it did have carbon coating, it had been further damaged by other poisons which prevented significant improvement after regeneration. These tests at 250 hours were to see if that behavior was typical of well-aged catalysts.

Instead of obtaining many results after the regeneration, Students M and N gained much experience in trouble-shooting equipment. While student N graduated after working on the project for about 8 months, student M worked on the project for approximately 15 months. In this time, they had to determine the cause and fix a malfunctioning dynamometer controller. After that was fixed, student M was again able to perform the emissions tests, but found that not only had the NO_x analyzer failed (this had occurred during their original 250-hour tests, but was deemed to be less important to the purpose of the study,) but now the HC analyzer either failed or was not communicating with the data acquisition equipment. While student M tried many things to fix this problem, the problem remains unsolved. So, while these undergraduate students may not have obtained as many results as many of the other students who had worked on the project, these students did learn about the need for engineers to often have to work to fix equipment, and that that is an important part of engineering research. One other item of note is that most of the students working on this project over its 11 years have had to deal with issues related to engine component failure, dynamometer issues, emissions equipment malfunctions, and controller issues which slowed progress.

Student Impacts

There were numerous benefits that the undergraduate students working on this project have received over the years. Some of the primary ones are listed and discussed below.

1) *The students had an opportunity to perform useful research on an industrial problem of current interest, using equipment that would be typically found in an industrial setting.* This benefit provided at least two positive impacts. First, the students in Mechanical Engineering at UWM are required to take a course, *MechEng 438 - Mechanical Engineering Experimentation*, in which they learn how to design and conduct experiments. This course is in addition to other laboratory courses, where they primarily perform experiments already designed. This research project enabled the students to enhance the education they received in MechEng 438 by giving them more experience in the design and performance of engineering experiments. In many cases, the students were already working on this project before they took MechEng 438, thereby giving them an advantage in the course when they took it. Second, the benefits of either interning or co-oping in industry while still studying engineering in college are often promoted. While we have noticed that this significantly improves the knowledge, maturity, and

preparation of our students who take advantage of those opportunities, it does also slow progress towards graduation by either requiring students to miss several semesters of school (for formal co-ops), or reducing the amount of time they have available for courses (for internships). By working on this project, students were able to enjoy many of the benefits for co-oping or interning. This project enabled the students to work closely with the industrial sponsors, on a practical engineering research project. Yet, this was done without negatively impacting their time to graduation. Students would typically spend 10-20 hours a week on the project, when they had time. As some of that time was spent just accumulating hours on the engines, they were sometimes able to work on homework at the same time.

2) *Students gain experience working with practicing engineers*. One activity emphasized in the Mechanical Engineering program at UWM is that students will gain experience by interacting with practicing engineers. In fact, this is one of the Program Outcomes for ABET assessment of the program. The reason why this is considered so important is that by interacting with practicing engineers, the students will benefit from learning practical engineering from the experienced engineers. The students can also gain an understanding of some of the issues that they will face in a corporate culture, which can not be adequately explained in the classroom. For example, the students learn about the impacts of limited resources on their projects. In this project, most of the students worked closely with one or more practicing engineers from industry on the project, and were able to learn from them.

3) *Students gain experience making presentations and communicating the results of their work*. As part of their work on this project, all of the students had to periodically present their results to others. Some of the students also had to make monthly oral presentations to the industrial sponsors. Both of these gave the students valuable experience in making oral and written presentations.

4) *Students gain experience writing technical papers*. While not all students co-authored technical papers, seven of the undergraduate students working on this project did act as a co-author on either a journal or conference paper. This experience introduced the students to the technical publication writing process, and gave them experience that may benefit them later in their careers.

5) *Students were able to learn more about different facets of engineering*. These students gained much experience in the testing and research aspects of engineering practice. Many of the students obtained experience in doing some design work, as they had to design and build components to make the experiments work. This helped students learn if they would be interested in pursuing these directions as part of their future careers.

6) *The students were able to learn that not everything goes smoothly in real-world engineering work*. Most of the students on this project experienced some frustration associated with equipment (either the test equipment or the engines) failure during their time spent on the project. Most of the students also experienced delays resulting from events beyond their control, such as the availability of equipment or delays in the repair

of equipment. This is a benefit to the student in that they are more prepared for such problems when they begin their own careers. In some cases, it might make them aware that research and development careers might not be what they are best suited for.

Dukhan and Jenkins[2] also identified several positive student impacts, which were noted in this project as well. They found that the research experiences promoted independent student thinking, served as a good active learning and cooperative learning environment, and improved professor/student communication. These same impacts were noticeable in this project as well.

As mentioned above, the use of undergraduates in research projects is seen as a way to attract students to graduate school. Therefore, it is interesting to consider the impact of this research experience on the students working on this project, with regards to graduate school enrollment.

Considering that the author would not necessarily have contact with the students after they graduated, only the immediate enrollment of the students in graduate school can be definitively gauged. Of the undergraduate Mechanical Engineering students who worked on this project, as seen in Table 1, only 1 of 11 immediately started graduate school (student M has not yet graduated). In Table 1, it can be noted that one of the students did later have definite interest in attending graduate school in engineering, and one other did attend graduate school in business. It should be noted that most students studying undergraduate Mechanical Engineering at UWM do not go to graduate school immediately upon graduation. In the last 2 years, only 14.5% of the graduating mechanical engineering seniors indicated any intention (on their senior exit survey) to attend graduate school in an engineering discipline in the year following their graduation. Therefore the 1 out of 11 is statistically similar to the whole undergraduate population. While it is difficult to definitively judge from this sample size, there appears to be no discernable increase in immediate graduate school attendance from work on this project as undergraduates. Also note, student L was an undergraduate student at UWM who did not work on an undergraduate research project, but then went directly to graduate school.

What makes these results more intriguing is the academic abilities of the students involved in this project as undergraduates, and the level of research they were performing. The author had all the students (except Student K) working on this project as students in one or more of his courses. In the author's assessment, at least 5 of the students who did not immediately go to graduate school could have succeeded academically in graduate school with little difficulty. At least 2 others probably would have succeeded in graduate school. The level of research performed by the students was also, with some minor modifications, often equivalent to what would be necessary for a M.S. thesis. This is especially true of the work done by the undergraduate students on Phase 2 of the project.

It should also be noted that there is a solid research environment at UWM. The College of Engineering and Applied Science has a Ph.D. program. Most faculty members in Mechanical Engineering will employ undergraduates, to some extent, on research projects. It is estimated that approximately 10% of the undergraduate students in the program do participate in undergraduate research projects. So, while the program may not have as strong of an emphasis on undergraduate research as other institutions, many opportunities abound for interested undergraduates to participate in research.

What these items suggest is that the opportunity to work on a significant research project as an undergraduate student may not be enough to persuade students to proceed directly to graduate school, if their original inclination was to graduate and then work in industry. Despite the presence of funding for graduate stipends, and the fact that the students had a very favorable experience working on the project (as evidenced by only one student resigning from the project before graduation, and that was due to his taking an internship in industry for his last semester before graduation), these students chose to get jobs in industry rather than go to graduate school upon graduation. One reason for this may be that the students at UWM tend to enter college with the idea that they will get their B.S. degree and then go and work in industry, with many of the students having little exposure to people with graduate degrees. In other words, the background of many of these students may predispose them to not even consider going to graduate school upon completion of their undergraduate education, and the opportunity to work on an undergraduate research project in their last year or two of school is not sufficient to change their views. Further study is needed on this issue.

Project Management Issues

While providing undergraduate students with the opportunity to conduct research is a noble goal, there are a number of project management issues that a faculty member needs to be concerned with before planning on primarily using undergraduate students for a long-term research project. Some of the issues that developed over the course of this project are discussed below.

1) *The use of undergraduate students as the primary conductors of research on a long-term project will lead to greater turnover in the number of students working on the project than if graduate students are primarily used.* As an example from this project, the project probably could have been performed in less time with 4 M.S.-level graduate students. If one waits for them to have received enough education to be able to be the ones who are primarily conducting the research, undergraduate students will generally only have about 1 year that they can devote to the project. This is illustrated in Table 1. This leads to two negative impacts on the project.

1a) Greater turnover of personnel increases the time needed for training. If one or more students need to be trained each year, the project will be slowed as those new students are trained. It is a great benefit, though, to try to have the students overlap so that one experienced student can train a new student as they finish up their work on the project.

1b) Continuity of the project is more difficult to maintain with greater student turnover. The new students need to spend time figuring out what the old students had completed, in order to have the project performed adequately. On this project, the undergraduate students usually did not end their work at a logical stopping point, and so care was needed so that the new students would continue the project at the correct point.

2) *Recruitment of undergraduate students can be difficult*. When recruiting undergraduate students to work on a research project, it is important to find an effective means to communicate the opportunity to the students. The author found that the most effective practices were to announce the opportunity in appropriate classes, and by word of mouth

from students already working on the project. Placing posters around the building was not deemed to be effective. As many of the students are initially not inclined to do undergraduate research, a personal appeal was more effective. The best continuity for the project, and the method that attracted some of the best students to the project, was by word of mouth, when students who were finishing up their work essentially identified replacements in younger students. However, this was not always sufficient, and at that point, the class announcement was the most effective method. One problem that exists in the recruitment process is that the number of applicants tended to be the same as the number of positions available. This, at times, led to the necessity to employ students who may have been less capable than other students.

3) *Full-time undergraduate students require more attention for balancing their coursework and the research project than do graduate students.* Most of the students treated the research project as a secondary activity, and placed their coursework first. This is a realistic expectation, but does lead to slower progress in the project.

4) *Undergraduate students tend to need more supervision and guidance*. Again, this is a realistic expectation, as undergraduate students have less knowledge and experience than graduate students. The undergraduates tend to need close guidance to stay on track, and to know what needs to be done. In addition, it tended to be a good practice for the students to work together. For some tasks (such as accumulating hours on the engines), it was fine for students to work alone. But for more complicated tasks, or tasks with a greater risk of injury, it was advisable to have the students either work together or to have direct supervision present.

5) Tied together to the last two points*, the use of undergraduate students as the primary people performing a research project can result in a longer period of time required to fix problems*. The combination of a lack of experience with a lack of urgency to get the project done (as they don't have to finish a thesis to graduate) did result in there being long delays on a project as the students methodically worked towards solving a problem. Over the length of the project, the author estimates that approximately 3 years were added to its duration as a result of the use of undergraduates to resolve problems. This estimate is primarily based upon the number of hours the undergraduates devoted to the project, in comparison to graduate students, and secondarily on the experience level of the students.

Clearly, there are management issues that become more significant with the use of undergraduates to primarily conduct a long-term research project than with graduate students. At least for this project, though, the benefits to the students by being able to work on such a project tend to outweigh the negative effects of the increased management issues on the PI.

Summary and Conclusions

A long-term research project involving the deterioration of the pollutant emissions in small utility engines has been described and the results have been summarized. As much of the work on this project was conducted by undergraduate students, the project allows for some insights into the benefits and detriments of employing undergraduate students as the primary researchers on a project. The activities of the students on this project were detailed, so that the extent of the type of activities which undergraduates could be expected to perform could be seen.

Numerous benefits to the students were noted, primarily revolving around enhancing their classroom education, as well as being given the ability to interact with practicing engineers from industry. It was noted, though, that the process of being involved in an undergraduate research project did not significantly change the likelihood that these students would immediately enter graduate school upon graduation. The reasons behind this warrant further investigation.

Employing undergraduates as the primary researchers on a long-term research project introduces many project management issues for the PI. These include maintaining continuity of the project, the need for undergraduates to concentrate more on their classroom work than graduate students, and the delays that are produced by inexperience and insufficient time. Overall, though, the author has found that providing undergraduate students with an opportunity to perform meaningful research on an engineering topic of current interest outweighs the problems caused in this pursuit.

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