AC 2008-1564: UTILIZING UNDERGRADUATE ENGINEERING STUDENT RESEARCH ASSISTANTS IN FUEL CELL DURABILITY AND RELIABILITY TESTING; ASSESSING THEIR FEASIBILITY, BENEFITS, VALUE AND CONTRIBUTIONS

Robert Fletcher, Lawrence Technological University

Robert W. Fletcher joined the faculty of the Mechanical Engineering Department at Lawrence Technological University in the summer of 2003, after two decades of continuous industrial research, product development and manufacturing experience.

Dr. Fletcher earned his Bachelor of Science Degree in Chemical Engineering from the University of Washington, in Seattle, Washington, a Master of Engineering in Manufacturing Systems from Lawrence Technological University, in Southfield, Michigan, and the Master of Science and Ph.D. degrees in Chemical Engineering focusing on Electrochemical Engineering, both from the University of Michigan, in Ann Arbor.

He teaches a number of alternative energy courses and is leading LTU's efforts to establish a full energy engineering program that addresses both alternative and renewable energy systems, as well as energy conservation and optimization of traditional energy systems. He also is the Director of the Alternative Energy program at Lawrence Tech. Dr. Fletcher and his student research team are currently conducting long-term performance durability and reliability on multiple PEM fuel cell research used under a wide range of operational conditions for the US Army. He is also working with his students supporting DTE Energy in the operation and optimization of their Hydrogen Power Park in Southfield, Michigan, a photovoltaic, biomass, water electrolysis, hydrogen storage, hydrogen vehicle fueling station and fuel cell power demonstration project, funded by the Department of Energy. He is also establishing an alternative energy laboratory at LTU that contains integrated fuel cell and hydrogen generation systems, as well as equipment for solar (thermal and photovoltaic), biomass, wind and other alternative and renewable energy generation equipment.

Utilizing Undergraduate Engineering Student Research Assistants in Fuel Cell Durability and Reliability Testing; Assessing Their Feasibility, Benefits, Value and Contributions

Abstract

The question of whether undergraduate engineering students can provide meaningful support to a university's research program is not unusual. Undergraduate engineering students often have limited technical experience, and sometimes have yet to complete even basic academic courses required to fully understand the research activities involved. This paper evaluates, assesses and reviews the feasibility, benefits, value and contributions of undergraduate engineering students in a major fuel cell system research study at Lawrence Technological University. In the spring of 2006 Lawrence Technological University (LTU) entered into a fuel cell research program with the US Army Tank-Automotive Research, Development and Engineering Center (TARDEC), in Warren, Michigan. The objectives of the research work were to build a fuel cell test stand, install a hydrogen gas tank supply system, and to test two 1.2 kW polymer electrolyte membrane (PEM) fuel cells to assess their performance, durability and reliability over a wide variety of operational and environmental conditions over a sixteen month period. In order to successfully accomplish this work nine student research assistants over the course of the program were required. All of these research student assistants were undergraduate engineering students from LTU's Mechanical and Electrical Engineering programs, with the exception of one who was an international graduate student in the LTU Master of Science in Automotive Engineering program. This paper provides a review of the process utilized to hire and direct these student's work efforts, and gives a detailed description of their contributions and accomplishments. All of the major research objectives for the program were achieved. We have found that students benefited not only from the engineering and technical understanding derived from such participation, but also in the soft-science areas of teamwork, time management, and multi-disciplinary activities. Detailed assessment data obtained from the student participants (by written survey), as well as from participating faculty that augment the understanding and value of such work to both student and institution are provided and reviewed. Some members of the student research team have since graduated and are now working as engineers in industry, and their perspectives on the value of participating in such undergraduate research are included in the assessments. The results of this effort at LTU strongly support the value and benefits of utilizing undergraduate engineering students in our university's research program.

1. Introduction and Background

Lawrence Technological University is a private, fully accredited university located in Southfield, Michigan. LTU has nearly 5,000 students in more than 60 degree programs at the associate, bachelor's, master's, and doctoral levels through the Colleges of Architecture and Design, Arts and Sciences, Engineering, and Management. The College of Engineering is comprised of a Mechanical Engineering Department, an Electrical and Computer Science Engineering

Department and a Civil Engineering Department. Historically the College of Engineering was focused on teaching, but a growing number of full-time faculty members are now undertaking research programs to supplement their teaching efforts. The college of engineering student base is predominantly undergraduates. The college's graduate programs are growing, thought still primarily teaching based. Research work is required at the doctorate degree level.

In May of 2006 Lawrence Technological University (LTU), with the author serving as the Principal Investigator, received a research contract from the Auxiliary Power Group within the US Army Tank-Automotive Research, Development and Engineering Center (TARDEC), in Warren, Michigan, to undertake durability and reliability testing on two Ballard NEXA 1.2 kW proton exchange membrane fuel cells. Contract discussions had been underway for several months prior to the formal contract award. This project involved three components: a literature search to develop a detailed test plan for a NEXA fuel cell system, design and install a test station for long-term testing of the fuel cells complete with electronic power loads, safety features, hydrogen storage and dispensing to the test station and data acquisition capabilities, and finally, fuel cell testing. LTU was to provide research and testing support for the study of these fuel cells.

US Army Tank-Automotive Research, Development and Engineering Center (TARDEC) is part of the U.S. Army Research, Development and Engineering Command (RDECOM) headquartered at the Detroit Arsenal, Warren, Mich. TARDEC is the US Army's nation's laboratory for advanced military automotive technology. The TARDEC mission is to provide full service life cycle engineering support for Army ground vehicle survivability, mobility, intelligent systems, and maneuver support and sustainment [1].

Almost none of the physical infrastructure required for this contractual work existed at LTU prior to starting the project. Two similar fuel cells where already on campus and had been used for educational and other project purposes for intermittent testing and study, but no testing station existed as needed for long-term durability evaluation of fuel cells. In addition, no related research team of students directed by a faculty member existed prior to this project. Meeting the requirements of the contract necessitated the establishment of a project team composed of the author and LTU students capable of conceptualizing, procuring, and installing the required infrastructure, establishing detailed test plans and operating procedures, and carrying out the needed testing within the timeline requested by TARDEC.

This paper outlines the approach used to staff the project predominantly with undergraduate students, reviews the activities and accomplishments of the group regarding this project, and reviews the related benefits and consequences of using those students in this research. With the exception of only a brief description of the data generated to serve as a reference, this paper does not intend to discuss or review the actual testing results generated by this research, nor any subsequent analysis of the work. Such data topics and results are reserved for other future pending publications.

2. Getting Started

Once a general statement of work (SOW) was defined between LTU and TARDEC a detailed project task list was established by the author. This was done to help define the skills required within the students who would be conducting the research work activities under the direction of the author. The project tasks fell into five main areas, and included:

1. Facilities preparation, hardware system design and installation, including tank farm storage, gas line routing, venting and valving
2. Electrical systems design, including sensors, safety controls, computer interface with data acquisition, data storage and data backup
3. Establishing safety and standard operating procedure documents, defining needed supplies and vendor and procurement agreements
4. Establishing proper testing protocols, testing of the fuel cells, supported by trained student staff and faculty with the subsequent analysis and interpretation of the resulting test data
5. Standard administrative tasks including planning, organizing and scheduling of facilities upgrades as well as the schedules of the working students for the required and eventual system testing

Once these five main areas were well defined, two student job descriptions were written for project support; one being for electrical engineering student workers and one for mechanical engineering student workers. LTU's engineering student population is predominantly undergraduate students, so it was well understood that most, if not all, of the students employed in the project would be undergraduates.

Student research assistants were initially involved with items 1 through 4 above. The faculty advisor initially addressed the items in 5 above, but even some of those duties were eventually successfully passes off to some of the students.

The use of undergraduate engineering students in formal governmentally funded research programs is well established [2-4]. Private and non-profit organizations also recognize the importance and value of undergraduate research [5, 6]. The author was well aware of the challenges when undertaking research at a predominantly teaching institution, such as LTU. Those challenges are eloquently outlined by Schuster and Birdsong [7]. Schuster and Birdsong correctly emphasize that at primarily teaching institutions the pool or research assistants consists predominantly of undergraduate students, with a few graduate students. They state that the main challenges of working with undergraduates on research tasks are:

- "Students will be involved with the research for only a short time – ranging from three months to three years. To have a student on the team for three years, they must either start as a sophomore or stay on for a master's degree.

- In order to have the maximum time with a student, they must start on the research team with little or no engineering coursework completed. As a result, the student may have only completed some introductory classes [7]."

In addition, initially the author shared some of the concerns as outlined by Zydney et al regarding the time commitment needed to mentor undergraduates, the overall benefits of the required efforts, and if the undergraduates would be able to make significant contributions during their participation on the team [8].

A few students in the engineering program were known to the author and where thought to be possible candidates for the positions, but this was to be the first time the author had actually formally hired undergraduates to work on a government funded project. To assure the broadest possible pool of talent and that the best possible candidates were considered for the research positions, the author met with representatives of the LTU Office of Career Services and mapped out a plan with their input [9]. The newly developed job descriptions were placed on the school's link to MonsterTRAK® [10]. The LTU Office of Career Services uses MonsterTRAK® as the official resume posting and job listing service for Lawrence Technological University. Students and alumni can search job listings for full-time, part-time, on-campus, work-study, internship and co-op opportunities on MonsterTRAK®. Additionally, students and alumni can create multiple resumes to submit to employers, schedule on-campus interviews, and register for career fairs.

All possible candidates were required to submit their resumes through MonsterTRAK® for consideration. Fortunately, this approached worked very well and a sizable pool of possible candidates was quickly developed. There was an important side benefit to this approach. Since the funding was ultimately from a US Federal source the use of MonsterTRAK® formalized the process and assured equal opportunities were given to all students to apply with full tracking and documentation. This process also helped to remove any possible perception of bias in the initial application step. One exceptional candidate, who was initially unknown to the author, was gleaned from the resumes, personally interviewed, and was ultimately hired into the project. This hiring process was very helpful and is highly recommended for anyone dealing with the same constraints as the author.

By the end of May 2006 three students were initially hired and formed the group; one electrical engineering student (senior), one mechanical engineering student (junior) and one automotive engineering student (graduate student). Each of these three students, through their previous experiences where familiar with fuel cells and the related technologies. As a result their initial learning curve was minimized and work could begin almost immediately. Students were initially paid $10.00 per hour. Because the research student assistant work was considered on-campus employment a maximum of 20 hours per week was permissible. A recent engineering alumnus was also willing to help the Alternative Energy Program at LTU by supporting some of the research lab upgrades. His contributions were significant and his work experience in the field of installing pressurized process-gas lines proved invaluable to the project.

Regular group meetings were typically held once per week, but initially these meetings were usually more frequently, and work assignments were made. It quickly became evident that some of the work that was originally thought should be "contracted out" to outside labor could (and would) be done by the research team with the support of our volunteering alumnus. Meetings were also held with the LTU campus facilities staff to dole out what upgrades they could best complete.

3. Summery of Work Done in Project

The literature search was completed in mid-July and was submitted to TADREC personnel in July 2006. A possible the test plan was developed and proposed in July 2006 to the TARDEC fuel cell team that same month.

After some hardware delays from a critical vendor the project was able to move forward by the latter part of the summer 2006. In early October 2006 the system hydrogen gas storage and distribution lines, running from the outside from the small tank-farm into the laboratory were fully installed by the student team with the author, the faculty advisor. The small tank farm was installed just outside the building adjacent to the lab in a small caged wire-fence area and could provide enough gas to keep a fuel cell running for approximately six days, or approximately 72 hours, depending on the power setting load of the fuel cell during operations. The outside gas lines were leak tested by filling the lines with hydrogen gas pressurized to 2400 pounds per square inch (psi). No pressure losses were observed over a one-week time period. The outside system was deemed gas-tight and ready for use. Upon installation of the hydrogen sensors in the lab, the in-laboratory hydrogen gas line was pressurized to 120 psi, and allowed to stand valved-off for one week to determine if there were any system leaks as indicated by observable pressure decay over the week. Again, no pressure losses were observed, and the overall system was deemed gas-tight.

A summary of the gas distribution system operation is as follows:

1. The outside hydrogen-tank farm consists of five 2400 psi hydrogen gas bottles ("K" size bottles each containing ~ 7300 standard liters of hydrogen) connected in-line are available as the routine process gas. A sixth 2400 psi "K" size hydrogen gas bottle is available as system backup/reserve should it be necessary to change out gas bottles during a live fuel cell test cycle. See Figure #1 below. Each bottle can be valved-off separately.

2. The gas distribution manifold from the gas bottles feeds into a two-stage gas regulator that steps the gas pressure from 2400 psi down to ~110 psi. From the two-stage regulator the gas line feeds through a pressure relief valve, set to actuate at 120 psi, and then into an NEMA-rated electronically actuated ball valve. If actuated due to high pressure the pressure relief valve vents through a line with its outlet above the roof of the building. The electronically actuated ball valve (actuator valve) is controlled by "ON" signals from the three available E-STOP switches and also the hydrogen sensor controller. See Figure #2 below. During normal operation, and when the gas lines are fully pressurized, the actuator valve is open and gas is allowed to flow through the lines to the in-laboratory fuel cell test station. All outside systems are electrically grounded. One E-STOP is located at the gate of the tank farm cage; the other two are located at the entrance of the lab and next to the fuel cell test stand.

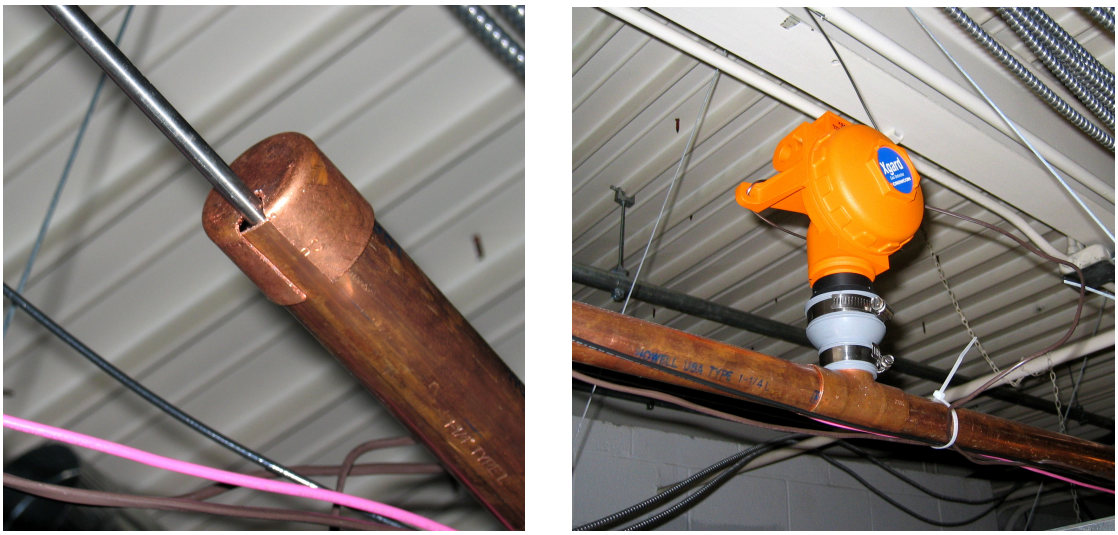
3. The external 110 psi gas line enters the laboratory through the outside wall of the building. The first hydrogen sensor in the safety system is located near the gas line on inside-wall where the line enters the building. Hydrogen sensors are located in-laboratory wherever fittings or unions were required in the system. See Figure #3 below.

4. The upon entering the building the in-laboratory gas line is routed up and into the drop-ceiling crawl-space and runs the length of the laboratory to the fuel cell test stand. This primary gas line did require unions to allow the gas to be routed the length of the laboratory. To prevent any hydrogen leakage that might allow gas accumulation in the drop ceiling the gas-line was enclosed in a larger copper tube. Under normal operation the copper tubing does not see any hydrogen and is only a jacket to contain hydrogen should it leak from the primary gas line. A hydrogen sensor is located midway in the copper jacket to detect any hydrogen leaking from the primary gas line and captured in the copper tube. See Figure 4.

Figure 1: The five-process gas bottles with the additional backup gas bottle (second bottle from the right). Each bottle can be individually valved-out for replacement, as required. Flex-lines from each bottle feed into the main gas line that runs horizontally into the two-stage gas regulator valve located in the upper left.

Figure 2: The two-stage outside gas regulator which feeds into the NEMA rated electronically controlled actuator ball valve. The valve is attached directly below the yellow "Swagelok" box. A pressure relief valve, set for venting at 120 psi, is located between the two-stage regulator and the actuator valve.

Figure 3: The in-laboratory hydrogen gas line from the outside tank farm is illustrated. Batteries provide power to close the hydrogen actuator valve outside should the building lose utility electrical power. The orange disk on the wall in the upper left is one of the hydrogen sensors. The two green lights on the wall-box indicate that the system is on, the actuator valve is open, and that gas is available for use. Two red lights directly below the green lights, not illuminated in this photo, indicate when the system is off and the actuator valve is closed.



(a) (b)

Figure 4: In (a) the stainless steel hydrogen gas line is shown exiting the copper jacketing tube just before it is routed down from the drop-ceiling. The hydrogen gas sensor as it resides in the drop-ceiling is shown in (b) coupled to the copper tubing to detect any hydrogen leaks from the gas line fittings

5. At the end of the gas line run in the drop-ceiling the line is routed down to the gas system feeding the fuel cell test stand. Located on the wall adjacent to that gas line is a third hydrogen gas sensor. Before feeding the fuel cell the gas goes through as second two-stage gas regulator which steps the gas pressure down to an operating range of 60 to 80 psi and is verified using an in-line visual pressure gage. The gas is then routed through a precision mass flow meter. After this the gas can be routed to the fuel cell, or can be purged through a needle bleed-valve in the event of air intrusion into the line. The system at this location has a

second backup pressure relief valve set to vent at ~100 psi just in case any of the upstream safety systems fail to operate. See Figures 5 and 6. Any line-vented gas is routed out of the lab thought an outside line.

Figure 5: The in-laboratory hydrogen gas line that drops from the ceiling to the fuel cell test stand is illustrated. Pictured are the local hydrogen sensor, the orange disk on the wall in the upper center of the photo; the two-stage pressure regulator; one of the three the E-STOPs, located just to the lower left of the regulator; the pressure gage; the mass flow meter; the bleed valve and the gas line feeding into the fuel cell. The fuel cell is located at the lower right. A high – volume air ventilation hood used to vent any possible hydrogen gas leaks is located in the upper right of the photo.

6. In the event that hydrogen is detected by any of the three hydrogen sensors an audible alarm sounds and an internal relay in the hydrogen controller trips and energizes the outside actuator valve to shutoff the feed gas from the outside tank farm gas line. Batteries provide system backup power to close the outside actuator valve in the event of utility power loss to the building. The batteries are continuously recharged by a battery charge controller. The gas sensor requires a manual reset, should its alarm sound, before the system will allow any gas fed back into the system. The manual reset drives the actuator valve to the "open" position. Also, depressing any of the E-STOP switches automatically closed the outside actuator valve. Each E-STOP must be manually reset before the system will allow any gas feeds into the system. E-STOP reset allows the actuator valve to reopen.

All sensors were checked for calibration using calibration gas provided by the hydrogen sensor manufacturer and were found to be correctly calibrated and working as specified. Each of the hydrogen sensors are set to alarm at 20% of the lower explosion level (which is 4% in air), or 0.8% of the LEL. An illumination light activates at 0.02% of the LEL.

Figure 6: A detailed photo of the gas distribution system feeding the fuel cell test stand shows the major components of the gas feed system. Hydrogen gas comes to the test station from the line located at the upper left of the photo. Gas is routed through the two-stage regulator, the mass flow meter, and then to the fuel cell. The gray box with the blue highlighted center is the hydrogen gas sensor controller.

The gas distribution system, as fed from the tank farm, was fully tested and fuel cells were initially run for a period of about 4 hours from this gas storage and gas feed line. All safety and operational systems operate as designed. The system was commissioned and ready for use. The system was also approved for use by the LTU facilities manager.

Based on these checks, system assessments and system operations, the LTU hydrogen tank farm, and in-laboratory gas line distribution system were available for full operation and use in fuel cell project testing.

Lastly, standard operating procedures have been written for gas bottle handling, gas line pressurization, system operation, fuel cell hook-up and operation, and system shut-down. Safety procedures and safety check lists have also been developed for routine testing.

The formal testing of the two NEXA fuel cells began in October 2006. Testing has continued using various testing protocols each academic semester through late September 2007. These tests consisted of several ten and twelve hour-a-day ramp and step tests, as well as full-power tests both at ambient room temperature and in an environmental chamber designed and built by the research team. The camber was able to operate at temperatures just above freezing and just below the maximum cut-off temperature for safe fuel cell operation.

Over 1400 hours of total operational electrical-load testing undertaken by the student research assistants have now been completed on these two fuel cells.

4. Assessment of Undergraduate Student Participation

The research advisor's perspective:
All faculty and staff involved with the project have been extremely impressed with the capabilities of each of the student researchers. An incredible team camaraderie has been established. No safety violations, near misses or accidents have occurred during the lab

equipment installations or during any of the fuel cell testing activities. Also, the college of engineering got a fully functional fuel cell test station capable of successfully and safely providing hydrogen gas to a fuel cell system for several days at a time at a fraction of the cost it would have been if it were done by an outside contractor.

To-date, a total of nine LTU students have participated in this research group, eight of which were undergraduates. Only one graduate student has been involved. Five students, including the graduate student, have since left the group due to their graduation or to pursue fulltime outside work opportunities. All students during their tenure with the group participated in formal project and program reviews, and each was able to give at least one presentation to the TARDEC project representatives. TARDEC management has been extremely appreciative of the effort, and to highlight the quality and value of the group's work in December 2007 they approved supplemental funding to keep the project active and to continue all the testing operations. This was critical because the original project funding package was exhausted as of December 31, 2007. Additional work objectives and goals have been proposed by TARDEC and are now being mapped out for implementation for the spring 2008 academic semester. This supplemental work is now expected to continue until August 2008.

Since undertaking this research the author has developed a good understanding of what generally will work with undergraduate research groups and the individual members of the team within this setting. Some of these comply with observations made by others who have used undergraduate students as research assistants [11-15]. A general summary of observations made are listed below:

1. Make sure that students clearly understand the objectives and goals of the research. If this is assured they will tend to be more sensitive to nuances in the testing and in the data collected. The experimentation will be more comprehensive and the data more robust.
2. Set high standards and stick to them for the benefit of the group and for the individual student. If errors are made explain why the error is not acceptable, but move on. Overly critical assessments can hurt the moral of the whole group, but unaddressed problems can also have a similar effect.
3. Make team members give presentations regarding their work, and especially regarding data they personally have collected. This forces them to know and understand what they have done and what the data mean.
4. Give team members lab notebooks and encourage the team members to use them regularly for experimental notes and observations, or other lab related tasks.
5. Have well written procedures for routine, but critical, processes with useful checklists to help students follow a repeatable process. This can also help prevent detrimental errors when starting up, operating or shutting down systems.
6. During long and dull testing periods, attempt to provide a few corresponding activities to help keep the student alert (but not distracted), such as manually logging of some pertinent data.
7. Have regular group meetings, and if possible keep them brisk, lively and fun. These are often the things students who move on to pursue other endeavors remember and appreciate most with time.

8. Pay attention to student class credit hours, grades and courses load during the semester. Students can be overly optimistic about what volume of work they think that they can and cannot handle, even the best ones. Lighten the work load as needed and let them know it should be a priority for them to focus on their school academic responsibilities first.
9. If possible have more than one student know critical processes or activities. That way if someone has mid-terms, or major graded projects or assignments due with such redundancy they can share the load and the work still gets done.
10. Make a personal connection with the student, and if possible their close family or friends. In this author's group it can be something as simple as going out to lunch, or preparing lunch for the group. This opens up communication between the members and the advisor that often goes well beyond the data.
11. If possible, lighten the work load and productivity expectations around midterms and during the last few weeks of the semester before finals.
12. Encourage students to stay as long as they can in the group, but also encourage them to move on if a better opportunity comes along for them. This is often a relief for students to hear this from the team advisor, and can prevent needless tension in the group.
13. Publicly acknowledge successes or contributions from team members as often and as soon as possible. Name a procedure, or a process, or even a component developed by that team member. The global science community publicly does this to honor famous scientists, do it in your lab to honor your student contributors.
14. Teach a core class taken by students in their sophomore or junior year so that you can recruit the better students to join your research team.

The student's perspective:

The involvement of student research assistants is a multi-method learning process. The student learns from the advisor, they then learn how to do a task, then they gain knowledge from doing the task, and then the advisor learns form what the student has done. Recently a survey was given to all current and former members of the author's research team. The survey consisted of several questions regarding the student's reasons for joining the group, experiences while in the group, and then assessment after they left the group. Four of the team members have graduated and have since gone on to accept engineering positions in industry. The survey that each of the team members was given to complete is found in the appendix to this paper. Eight of the nine team members were able to complete the survey. The ninth member was unable to do so due to time limitations. Much of the survey was quantified using a 5-point Likert scale (1 being strongly disagree and 5 being strongly agree), although written responses were also gathered.

The average time that students were formal (and employed) members of this research team was approximately 8.5 months. This equates to essentially two academic semesters. Three members of the total student group, when they started, where Juniors (3rd year), five members were Seniors (4th year), and one was a graduate student (Master Degree). All were male students. Three were international students and the remaining five were US citizens.

The collected results of the student survey are displayed in Table 1 below. A quick review of the survey questions shows these questions also query the student about topics pertinent to the Accreditation Board of Engineering and Technology (ABET) "Criterion 3 – Program Outcomes and Assessment" [16]. Several of the questions relate to one or a few criterion. This was done

intentionally. It is noted in the Table 1 comments section which criterion are related to a certain question. For reference the criterion are listed here.

ABET Criterion 3. Program Outcomes and Assessment

Engineering programs must demonstrate that their graduates have:

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs

(d) an ability to function on multi-disciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a globa and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

TABLE 1: Summarized Data from the LTU-TARDEC Fuel Cell Research Group Survey

Question	Sample size	Average Score	Standard Deviation	Comments
A-1) I got involved in this work because I wanted a formal research experience in college:	8	4.88	0.35	
A-2) I got involved in this research because I was very much interested in fuel cells:	8	4.75	0.46	
A-3) I got involved in this research because it paid for the work I did and I needed the money:	8	3.75	0.89	
A-4) I got involved in this research because I thought it could help me with my career ambitions:	8	4.88	0.35	
A-5) I got involved in this research because I thought it could help me if I went to graduate school:	8	3.50	1.20	
A-6) Prior to joining the LTU – TARDE Fuel Cell research group I had a good understanding or previous experience with fuel cell technology:	8	2.63	1.19	
B-1) Once involved I believe I understood the primary objectives and mission of the research group:	8	4.63	0.52	
B-2) I learned a great deal about the technical elements of fuel cells while working in the group:	8	4.88	0.35	
B-3) The opportunity to run and test fuel cells was an important benefit of being part of the research group:	8	5.00	0.00	

B-4) Sometimes the long hours of data collection was a little dull and sometimes even boring:	8	3.38	1.19	
B-5) Using the other lab equipment related to the project was an important benefit of being part of the research group:	8	4.75	0.71	
B-6) Regular group meetings were an important component of the research work:	8	4.75	0.71	ABET Criterion 3 Outcomes - d
B-7) Research group meetings helped me understand the primary objectives of the group's efforts:	8	4.50	0.76	ABET Criterion 3 Outcomes -d
B-8) I believe my input was valued and helped contribute to the research group's success:	8	4.38	0.74	ABET Criterion 3 Outcomes - d
B-9) Based on my experiences in the group I now see how important collaborative team work is for the success of such a project beyond what I would have learned in regular classes:	8	4.50	1.07	ABET Criterion 3 Outcomes - d
B-10) I gained valuable insights on what it takes to manage and lead such research work beyond what I would have learned in regular classes:	8	4.50	1.07	ABET Criterion 3 Outcomes - d
B-11) Based on my research experience with the LTU-TARDEC Fuel Cell research group I believe that I understand what constitutes the basic elements of research better than what I would have learned in regular classes:	8	4.63	0.52	ABET Criterion 3 Outcomes - a, b, and e
B-12) Based on my research experience with the LTU-TARDEC Fuel Cell research group I understand the value and importance of test data beyond what I would have learned in regular classes:	8	4.63	0.52	ABET Criterion 3 Outcomes - b
B-13 question dropped from survey	N/A	N/A	N/A	
B-14) Based on my research experience with the LTU-TARDEC Fuel Cell research group my capabilities of handling, analyzing and evaluation of large quantities of test data have significantly improved beyond what I would have learned in regular classes:	8	4.63	0.74	ABET Criterion 3 Outcomes – b
B-15) Based on my research experience with the LTU-TARDEC Fuel Cell research group my capabilities of developing, planning and conducting experiments have significantly improved beyond what I would have learned in regular classes:	8	4.25	0.71	ABET Criterion 3 Outcomes – b
B-16) Regular review of the test data was a key component to understanding the work done by the LTU-TARDEC Fuel Cell research group:	8	4.63	0.52	ABET Criterion 3 Outcomes – b

B-17) Based on my research experience with the LTU-TARDEC Fuel Cell research group my ability to identify, formulate, and solve engineering problems has significantly improved beyond what I would have learned in regular classes:	8	3.75	1.16	ABET Criterion 3 Outcomes - e
B-18) Based on the presentations we had to give to the TARDEC representatives and to the other members of our team my ability to communicate effectively has significantly improved beyond what I would have developed in regular classes:	8	4.13	0.83	ABET Criterion 3 Outcomes – g
B-19) Based on my research experience with the LTU-TARDEC Fuel Cell research group my ability to apply knowledge of mathematics, science, and engineering to problems has significantly improved beyond what I would have learned in regular classes:	8	3.75	1.16	ABET Criterion 3 Outcomes – a
B-20) Based on my research experience with the LTU-TARDEC Fuel Cell research group my ability to design a system, component, or process to meet desired needs has significantly improved beyond what I would have learned in regular classes:		4.38	0.52	ABET Criterion 3 Outcomes – c
B-21) Based on my research experience with the LTU-TARDEC Fuel Cell research group my understanding of professional and ethical responsibility has significantly improved beyond what I would have learned in regular classes:	8	4.13	1.13	ABET Criterion 3 Outcomes – f
B-22) Based on my research experience with the LTU-TARDEC Fuel Cell research group my ability to use the techniques, skills, and modern engineering tools necessary for engineering practices has significantly improved beyond what I would have learned in regular classes:	8	4.50	0.53	ABET Criterion 3 Outcomes – k
B-23) I met and got to work with people in the research group that I did not know before joining the team:	8	5.00	0.00	ABET Criterion 3 Outcomes – d
B-24) I became friends with most, if not all, of the research team members I worked with at the time:	8	4.88	0.35	ABET Criterion 3 Outcomes – d
B-25) Participating in the LTU-TARDEC Fuel Cell research project was a positive addition to my educational experience at LTU:	8	5.00	0.00	
B-26) I believe all students at LTU should have an opportunity to participate in some type of research experience at LTU:	8	4.63	0.74	

D-1) Since my leaving the LTU-TARDEC Fuel Cell research group I am no longer a student at LTU:	4	Yes = 4	No = 0	
D-2) I have been employed since leaving the LTU-TARDEC Fuel Cell research group:	4	Yes = 4	No = 0	
D-3) My current (or recent) employment is (was) directly related to the work done by the LTU-TARDEC Fuel Cell research group:	4	3.50	1.73	
D-5) My research experience with the LTU-TARDEC Fuel Cell research group has directly benefited me in my current (or recent) employment situation:	4	4.00	1.41	
D-6) Based on my experiences and what I have learned in the LTU-TARDEC Fuel Cell research group I believe that I am now better equipped to undertake what constitutes successful research efforts in my place of employment or graduate school:	4	4.50	0.58	
D-7) Based on my experience with the LTU-TARDEC Fuel Cell research group, and now with my perspective in industry, I believe industry would benefit from employing students who have had some level of recent undergraduate research experience:	4	4.50	0.58	
D-8) Based on my experience with the LTU-TARDEC Fuel Cell research group, and now with my perspective in industry, I would tend to hire recent undergraduate students who have had some level of undergraduate research experience:	4	4.25	0.96	
D-9) Based on my experience with the LTU-TARDEC Fuel Cell research group, and now with my perspective in industry, I definitely recognize the need for, and an ability to engage in life-long learning that extends beyond my academic degree:	4	4.75	0.50	ABET Criterion 3 Outcomes - i

Student Written Comments and Opinion

A-7) Other comments about why you joined the LTU-TARDEC Fuel Cell Research group?:

- *To gain professional working experience while learning about the technology.*
- *I joined the research group to study and understand how PEM fuels function. Prior to joining the LTU-TARDEC research group, I was a member of the IGVC team at LTU. The team fully integrated a 1.2kW PEM fuel cell into an autonomous vehicle as the primary power source.*

- *The research we were doing actually seemed very relevant in today's growing market for alternative energy. I knew that it would not be a waste of my time. Being paid was important, but the fact that my involvement in this group was something I could state with high regard on my resume was very important to me. I know for a fact that it helped me capture a prime job barely a month into time with the group.*

- *To learn more about the flaws and what needs to be improved for fuel cells*

- *I joined because I wanted to learn more about the performance of a complete fuel cell system and learn more about the balance of plant hardware because prior to the project, my experience focused only on membrane electrode assembly (MEA) components and performance.*

- *Good hands-on experience. Want to eventually work at TARDEC.*

B-27) Any other comments about your participation in the LTU-TARDEC Fuel Cell research group?:

- *Not only did I learn about Fuel Cells while working on this project, but I also got to learn about design and implementation of experiments, was involved in test stand development and about interaction with peers, superiors and clients.*

- *The progress and involvement in the LTU-TARDEC research group nearly eliminated the learning curve that I would have required to become fully successful at an engineering company.*

- *There is no doubt in my mind that the knowledge I gained in this research group placed me in the position I am in today.*

- *My experience with LTU-TARDEC Fuel Cell was very beneficial to my career. Although I didn't pursue a job working with fuel cells, I am indirectly working with alternative energy. I strongly believe that my association with this group helped me secure a terrific job. I only disagree with the few questions above about how my engineering practices were enhanced by this job because in my term the analysis was cut short due to members leaving and other projects ramping up. We had two senior members leave, and the remaining two, including myself, were engulfed in other projects (senior EE project, and Formula zero). One thing I very much appreciate is the ability to work with and operate machinery and systems that are much more complex than anything found in the student labs or used with class work. The trust given to myself from the group and the project coordinator was also very beneficial to my self confidence as an engineer in practice. I used examples from my work in the group at my interview which lead to my current career.*

- *The main things that being in a research group has taught me is how to be patient and analytical. There are so many things that can be extracted from the data, but not all of*

them are useful. If one approach doesn't work, try the other hundreds of approaches that have yet to be taken.

- *I believe that LTU-TARDEC Fuel Cell research group really compliments Lawrence Tech's motto of Theory and Practice and I think we need to have more research groups like this at the university in order to gain more recognition and credibility to the university.*

- *The knowledge gained from fuel cell research was applicable towards my senior design project.*

- *Very interesting and great experience.*

C-1) Overall, was your involvement in the project a satisfying experience? Why?

- *It was very satisfying to me as it helped me build my confidence in taking on challenges where I was not the master of it. It guided me in educating myself on the challenge and preparing to develop a solution.*

- *The project alone enabled me to be a successful addition to a research company. This opinion is based on the principles necessary to launch and successfully complete a research project. I have completed two research projects successfully at my current company because of the knowledge I gained from the LTU-TARDEC research group.*

- *My involvement in the project was a satisfying experience because it is a great change of pace from class work to do some real engineering. Working and being trusted with expensive equipment was terrific for the psyche of an unproven, untested engineer in training. I enjoyed being part of a team that had an actual goal, with actual results, and for an actual third party.*

- *Yes, it was a great experience. I gained experience that not too many people in industry have: fuel cell testing. With this hands on job paired with the hydrogen and fuel cell class, I gained a good understanding of the science of fuel cells. I also gained new friends from the project. And the salary was better than any other on campus employment that was being offered.*

- *Yes, it was a satisfying experience because not only was it a rich, hands-on learning experience but it was also a pleasure to work with the other students in the research group. It was a fun learning experience.*

- *Yes because I was able to simultaneously learn about fuel cells in the classroom and work with them in the lab.*

- *The research was very satisfying because it seems very prudent at this time, socially and technologically.*

- *Yes, it was because IU was able to work with a great professor and other engineering students, and I learned a lot about fuel cells which I knew nothing about prior to working in this group. Also, it is a good engineering experience.*

C-2) How was the project a worthy learning experience, and how did it help in your understanding of the technology?

- *I got an opportunity to experience beyond what we are taught/read in the published media and develop your own conclusions on what you experience.*

- *The project was a worthy learning experience because it both utilized my LTU education and prepared me for career oriented research. All data that I collected and analyzed allowed me to understand how hydrogen fuel cells operate.*

- *I could sit in class day after day and learn how the fuel cell works. Or I could operate a fuel cell for a couple of hours and learn first hand how it works. It is important to learn academically, but the ability to tangibly work with a fuel cell and watch it, see its limitations, and view it's reactions to specific events is the best way to learn hands down.*

- *With the boom of fuel cells that is seen today, it is good for students such as me to be immersed in the technology. Even though the fuel cells that we tested were relatively small in power, the principal of it is applicable to any size PEMFCs, which is valuable to us since PEMFCs are being developed in all different sizes right now. It helped me understand the technology better by seeing it work in front of me. There is (only) so much that you can learn from books.*

- *The project really improved my knowledge on the performance of fuel cell systems, whereas prior to this project, I had experience with the individual components but not on the behavior of the overall system. I also learned how temperature can have a significant impact on fuel cell performance. Furthermore, I was introduced to the tube fitting industry when preparing the lab for testing and realized that it is an industry that I'm very interested in.*

- *I learned about something I did not know anything about. It helped in understanding fuel cell technology because we actually ran fuel cells for many hours and analyzed tons of data for the fuel cells.*

C-3) Would you recommend that LTU students participate in other similar types of projects? Why?

- *I would recommend LTU students to participate in similar projects to gain not only technical knowledge in the area of their project but also a brief insight of professional work atmosphere they would have to get into in the years ahead and to help get an idea of the career they would want to choose for themselves.*

- *The LTU-TARDEC research group replicates, in detail, the way an engineering research team operates in post-graduate careers.*

- *I would strongly recommend any LTU student to participate in this or any similar project. In today's job market, anything to separate you from the pack is highly regarded, and real world experience is at the top of that list. Working for TARDEC is especially terrific given their respected and nationally known name. LTU is a great school, but in all honesty it is not known outside of Michigan and therefore its reputation alone will not separate you from other job candidates out of state. Any reference on your resume from a reputable company will go much farther than most academic achievements*

- *Yes I would. As I said before a hands on experience will enhance the learning experience for anyone. Being in a research project means a lot of data and managing this myriads of data can be a challenge. Being careful and being organized goes a long way.*

- *Yes because I think that projects such as this can significantly enhance a student's learning experience and expose them to new career paths that they never knew were available to them. Furthermore, research such as this can assist students in finding better jobs after graduation.*

- *Yes, I would. The skills learned in research projects are applicable to many jobs and fields.*

- *Definitely, because they are great learning experiences and he student gets hands-on work experience in a lab, and overall engineering experience that will help their careers.*

C-4) Any other comments you think would be appropriate?

- *I think the LTU-TARDEC Fuel Cell research supervisor and coordinator deserves more credit for the amount of hours and work put in to make this a successful research group. This group has logged more fuel cell test hours than most other universities in the country. This would not have been possible without the organization and dedication of the faculty research coordinator.*

- *The corporate research world would significantly benefit if LTU involved all disciplines in research groups such as this one. Research companies would benefit because of the quality of the skill sets that prospective research engineers would have already obtained at the college level. I hope that one day the LTU-TARDEC research group expands so that it may employ full research teams similar to those found at corporate research companies.*

- *I cannot stress how important it was to me to have such an enthusiastic and dedicated work leader. It made everyone in the group work harder and actually care about the results. A leader's enthusiasm goes a long way. It is easy to work when you know your work is appreciated. If only all students were lucky enough to have an opportunity to*

work with someone as dedicated as our group leader was they would understand just how important not just the work is, but how important being a good team is. There is not much more to say that has not been said above. I cherish my time in the group and honestly feel it is a direct factor in my hire at a terrific company. I am still friends with the people I worked with and will always be proud to say I was a part of this group.

- *It's also a fun experience.*

5. Discussion of Survey Results

Not all of the survey results are discussed here. However, starting with the numerical survey results several items quickly become apparent. Questions A-1 through A-6 reveal that the student assistants were very interested in participating in a formal research experience, that it could help their career, and that they were particularly interested in fuel cell research. Monetary renumeration was helpful, but not critical in their decision. Clearly, fuel cells are a hot topic on any campus today, but these results indicate that this is more so than expected.

Questions B-6 through B-10 and B-23 and B-24 are related to ABET Outcome-d, the multi-disciplinary teams outcome. Students working in our research group fully understood the collaborative nature of this research and the need for teams. Question B-11 through B-16 address Outcome-b the ability to design, conduct and analyze experiments. This research work generated literally millions of data points, so one had to become extremely proficient in data manipulation and handling. Students on the team repeatedly stated how they were now much more comfortable working with large quantities of data. Questions B-17 and B-19 address Outcomes e and a, respectively. Both of these scored only moderately above "no opinion". The question of real interest is B-21 which addresses professional and ethical responsibility, which scored an average of 4.13. The students gained an understanding of the honesty of data and, hopefully, from the faculty advisor. Questions B-3, B-23 and B-25 unanimously between all of the respondents scored a "strongly agree". Clearly, the research experience was perceived as an extremely positive experience for the students and they recommend that other students in engineering should try to get a chance to do some form of formal research, if they get the opportunity.

Questions D-3 through D-9 deal with now graduated and fully employed research team alumni. All stated that they feel their research work benefited them in getting their current job, or is helping the now in their current job. The interesting response is that they would now tend to hire undergraduate engineers who have had an undergraduate research experience. These alumni also clearly see the need for life-long learning.

The primary importance of these ABET Outcomes-related questions is that the respondents believe that these outcomes were more obtainable in their research experience than from what was possible in their formal academic course work. This has a lot to say about how we as engineering educators might change the structure of some of our key engineering courses.

The Student Written Comments and Opinions are self explanatory, and are not discussed in this paper.

6. Future study

An important approach for future efforts is to survey students in more detail before they begin the research experience to assess the change of perspective and understanding. This was not a concern when the research project or team was assembled. Future research groups formed by the author will have a relevant survey for before and after comparisons.

Another option is to survey the same team alumni a year from now to see if they have modified their views. This could be challenging as students get farther away from their undergraduate experience it can often be difficult to even locate them in our highly mobile working society. It is worth pursuing, however, and will be considered.

8. Conclusion

This paper positively concludes that undergraduate engineering students can indeed provide meaningful support to a university's research program. But the corollary is also true, in that a research experience is extremely beneficial to the undergraduate engineering student. This is clearly expressed by the responses to most of the student survey questions, but especially so to the ABET outcomes related questions. These results suggest that there may be something missing or that needs augmenting in standard engineering courses that captures the positive and beneficial elements found in an undergraduate research experience, such as that undertaken in the LTU – TADERC Fuel Cell research project.

We have found that students benefited not only from the engineering and technical understanding derived from such participation, but also in the soft-science areas of teamwork, time management, and multi-disciplinary activities. Detailed assessment data obtained from the student participants (by written survey), as well as from participating faculty that augment the understanding and value of such work to both student and institution are provided and reviewed. Some members of the student research team have since graduated and are now working as engineers in industry. Their perspectives were extremely positive regarding the value of participating in such undergraduate research. The results of this effort at LTU strongly support the value and benefits of utilizing undergraduate engineering students in our university's research program.

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Appendices

LTU - TARDEC Fuel Cell Research Student Survey, January 2008

This survey is to gather information about your experiences with the LTU-TARDEC Fuel Cell research project. I am studying the work we have done and am writing a paper that will be presented at the Annual American Society of Engineering Educators in Pittsburgh, PA at the end of June 2008. A compilation of student survey responses will be extremely useful in the study. Your responses will remain completely anonymous and your name will not be used in the paper. Please be honest and forthright in your responses.

I joined the LTU - TARDEC Fuel Cell research group in _____
(month) (year)

When I joined the group I was a: **Freshman Sophomore Junior Senior Grad Student**

Are you still in the group: **Yes** **No**: I left in _____
(month) (year)

If you left the group, why did you do so (the best pick one only): - graduated
- outside work opportunity
- class load at school

A) Why you wanted to join the LTU-TARDEC Fuel Cell research group.

Circle your response to each statement.

A-1) I got involved in this work because I wanted a formal research experience in college:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

A-2) I got involved in this research because I was very much interested in fuel cells:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

A-3) I got involved in this research because it paid for the work I did and I needed the money:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

A-4) I got involved in this research because I thought it could help me with my career ambitions:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

A-5) I got involved in this research because I thought it could help me if I went to graduate school:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

A-6) Prior to joining the LTU –TARDE Fuel Cell research group I had a good understanding or previous experience with fuel cell technology:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

A-7) Other comments about why you joined the LTU-TARDEC Fuel Cell research group?:

B) Your experiences while in the LTU-TARDEC Fuel Cell research group.

Circle your response to each statement.

B-1) Once involved I believe I understood the primary objectives and mission of the research group:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-2) I learned a great deal about the technical elements of fuel cells while working in the group:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-3) The opportunity to run and test fuel cells was an important benefit of being part of the research group:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-4) Sometimes the long hours of data collection was a little dull and sometimes even boring:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-5) Using the other lab equipment related to the project was an important benefit of being part of the research group:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-6) Regular group meetings were an important component of the research work:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-7) Research group meetings helped me understand the primary objectives of the group's efforts:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-8) I believe my input was valued and helped contribute to the research group's success:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-9) Based on my experiences in the group I now see how important collaborative team work is for the success of such a project beyond what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-10) I gained valuable insights on what it takes to manage and lead such research work beyond what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-11) Based on my research experience with the LTU-TARDEC Fuel Cell research group I believe that I understand what constitutes the basic elements of research better than what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-12) Based on my research experience with the LTU-TARDEC Fuel Cell research group I understand the value and importance of test data beyond what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

(Note that question B-13 was dropped from the survey)

B-14) Based on my research experience with the LTU-TARDEC Fuel Cell research group my capabilities of handling, analyzing and evaluation of large quantities of test data have significantly improved beyond what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-15) Based on my research experience with the LTU-TARDEC Fuel Cell research group my capabilities of developing, planning and conducting experiments have significantly improved beyond what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-16) Regular review of the test data was a key component to understanding the work done by the LTU-TARDEC Fuel Cell research group:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-17) Based on my research experience with the LTU-TARDEC Fuel Cell research group my ability to identify, formulate, and solve engineering problems has significantly improved beyond what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-18) Based on the presentations we had to give to the TARDEC representatives and to the other members of our team my ability to communicate effectively has significantly improved beyond what I would have developed in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-19) Based on my research experience with the LTU-TARDEC Fuel Cell research group my ability to apply knowledge of mathematics, science, and engineering to problems has significantly improved beyond what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-20) Based on my research experience with the LTU-TARDEC Fuel Cell research group my ability to design a system, component, or process to meet desired needs has significantly improved beyond what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-21) Based on my research experience with the LTU-TARDEC Fuel Cell research group my understanding of professional and ethical responsibility has significantly improved beyond what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-22) Based on my research experience with the LTU-TARDEC Fuel Cell research group my ability to use the techniques, skills, and modern engineering tools necessary for engineering practices has significantly improved beyond what I would have learned in regular classes:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-23) I met and got to work with people in the research group that I did not know before joining the team:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-24) I became friends with most, if not all, of the research team members I worked with at the time:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-25) Participating in the LTU-TARDEC Fuel Cell research project was a positive addition to my educational experience at LTU:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-26) I believe all students at LTU should have an opportunity to participate in some type of research experience at LTU:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

B-27) Comments about your participation in the LTU-TARDEC Fuel Cell research group?:

C) Other additional comments/observations:

C-1) Overall, was your involvement in the project a satisfying experience? Why?

C-2) How was the project a worthy learning experience, and how did it help in your understanding of the technology?

C-3) Would you recommend that LTU students participate in other similar types of projects? Why?

C-4) Any other comments you think would be appropriate?

D) Please answer the following if you have since left the LTU-TARDEC Fuel Cell research group. Please do not answer if you are still part of the group.

Circle your response to each statement.

D-1) Since my leaving the LTU-TARDEC Fuel Cell research group I am no longer a student at LTU:

Yes – graduated and not at LTU any longer No – I'm still there

D-2) I have been employed since leaving the LTU-TARDEC Fuel Cell research group:

Yes No

D-3) My current employment (or recent) is (was) directly related to the work done by the LTU-TARDEC Fuel Cell research group:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

D-4) My research experience with the LTU-TARDEC Fuel Cell research group significantly contributed to my ability to secure my current (or recent) job:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

D-5) My research experience with the LTU-TARDEC Fuel Cell research group has directly benefited me in my current (or recent) employment situation:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

D-6) Based on my experiences and what I have learned in the LTU-TARDEC Fuel Cell research group I believe that I am now better equipped to undertake what constitutes successful research efforts in my place of employment or graduate school:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

D-7) Based on my experience with the LTU-TARDEC Fuel Cell research group, and now with my perspective in industry, I believe industry would benefit from employing students who have had some level of recent undergraduate research experience:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

D-8) Based on my experience with the LTU-TARDEC Fuel Cell research group, and now with my perspective in industry, I would tend to hire recent undergraduate students who have had some level of undergraduate research experience:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

D-9) Based on my experience with the LTU-TARDEC Fuel Cell research group, and now with my perspective in industry, I definitely recognize the need for, and an ability to engage in life-long learning that extends beyond my academic degree:

Strongly disagree	disagree	no opinion	agree	strongly agree
1	2	3	4	5

D-10) Comments about your former experiences with the LTU-TARDEC Fuel Cell research group?: