How Solar Boating Teaches the Lessons of Energy Conversion and Conservation

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Having had an interest in science, technology, and engineering from an early age, I complete a two-year vocational electronics program while in high school before attending ITT's two-year electrical engineering technology program. Eventually I desired to continue my education and obtained my bachelor's of applied science degree with a concentration in mechanical engineering technology from Middle Tennessee State University. While perusing this degree I became involved with the university's Experimental Vehicle's Program where I primarily worked with the solar boat team during the last three years of my studies. I served as the solar boat team captain during the last two of those years. Upon successfully receiving my bachelor's degree I was invited by the university's Associate Dean of the College of Basic and Applied Sciences, Dr. Saeed Foroudastan, to work as his graduate research assistant and continue my education by entering into the university's master's of science in professional science degree program. Upon acceptance of Dr. Foroudastan's offer I began working as a researcher within the university's Experimental Vehicles Program where I functioned as a lab supervisor and student mentor until my successful completion of the master's program in December of 2016. Additionally, I am a Gulf War veteran, I have been married for twenty years, and I am the proud father of one son. Having developed a passion for green and renewable energy technology as a result of my work with MTSU's Experimental Vehicles Program, it is my long-term goal to continue doing work and research within this field.

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Abstract

Students gain a tremendous amount of theoretical knowledge during their time in the classroom, but a practical application of that knowledge is required in order for the student to turn what is learned into a skill. This is especially true for students majoring in applied science, and even more so for those with a concentration in engineering. Students who participate in hands-on projects that allow them to apply what has been learned in the classroom in a real and meaningful way not only gain more from their academic experience, they prove the value of their time in the classroom to themselves. This is especially true for larger-scale projects that are intended to be entered into international competitions.

The Middle Tennessee State University (MTSU) Experimental Vehicle Program (EVP) provides students with a unique opportunity to participate in an active engagement project that focuses on energy conversion and conservation with the additional intention of increasing their knowledge and interests in renewable energy sources through the practical application of solar power. The project is an all-electric, high-speed, solar-powered boat that participating students design and construct within the constraints of the rules set forth by the professional organization which sponsors the international competition the craft is designed to compete in. Students are allowed complete autonomy during the design, construction, and testing phases and all participating students are encouraged to attend the competition.

The MTSU EVP solar boat project epitomizes the spirit of innovative teaching and learning strategies. In addition to offering students a unique opportunity to enhance their technical skills, and soft skills and gain solid resume and portfolio building experiences, participation helps them to stay engaged academically. Dedication and enthusiasm are at their highest when people are engaged in work they find stimulating and are rewarding. Here the reward comes from working with a team to complete a complex project and entering it into an international competition. The success in doing so not only validates the effort the students put into their time in the classroom but it also allows them to prove to themselves, and to potential employers, that they are real engineers capable of working with others to solve complex problems.

Teaches the Lessons of Energy Conversion and Conservation

This paper will discuss how MTSU addresses the need for an active engagement program for STEM majors, it will briefly describe the projects that constitute the program and it will describe how one of the projects is uniquely suited for teaching the principals of energy conversion and how the conservation of energy law applies in the real world. Additionally, it will acknowledge the current research that MTSU is putting forth in an attempt to quantify the efficacy of its active engagement program in terms of retention within the program and in terms of reduced attrition rates for STEM majors. Perhaps a more accurate title for this paper would be “Why a Solar Boat Should be Used to Teach the Lessons of Energy Conversion and Conservation.”

For engineering students, core learning outcomes include having a clear understanding of energy conversion and conservation. The importance of achieving these outcomes is underscored by the fact that every successive generation of STEM graduates go forth with an expectation that they will make the world better, either by teaching what they have learned or by applying what they have learned. This expectation highlights the need for expanding the learning environment of STEM students by providing them with additional active learning and research opportunities as it has been shown that active learning opportunities increase their chances for obtaining a degree within their field of study while also helping them turn what has been learned into actual skills [1].

The truth is that learning should be fun and exciting. As educators it is our responsibility to keep students engaged and provide them with a learning experience that is both meaningful and exciting. Historically, however, the classroom has primarily been a passive learning environment where knowledge is taught by experts with occasional punctuations of student engagement in the form of discussions and activities, such as limited laboratory experimentation [2]. And while this approach has historically been sufficient for most students, it has been proven that a more active and engaging learning approach works better for some students [3]. It is because of this that MTSU's active engagement program is designed to offer active learning opportunities that are intended to develop skills that are directly related to real-world engineering scenarios as they apply to transportation.

Let us consider how the principals of energy conversion and conservation apply to an automobile. Set aside all of the various sundry systems and let the focus rest solely on the primary purpose of this machine which is to convert chemical energy into mechanical energy. In an ideal world all of the chemical energy available in the gasoline would be converted into an equivalent amount of mechanical energy. Of course, the physical reality is that an appreciable amount of the chemical energy available in the fuel will not be converted in to mechanical energy but will instead be converted into thermal and sound energy due to inefficiencies inherent to the system.

MTSU's 2015 Solar Boat on Display in the Science Building

However, despite the fact that all of the chemical energy does not result in an equivalent amount of mechanical energy, the conservation of energy law tells us that all of the energy potential from the burned fuel can be accounted for. If we were to sum up all of the energy lost due to conversion inefficiencies, along with the mechanical energy that is produced, we will find that all of the energy from the gasoline that is consumed was converted to some other form of energy.

Understanding the conversion inefficiencies allows for design improvement opportunities within the system.

Obviously such information can be conveyed through classroom lectures or from simple laboratory experiments, but a better option would be to provide the student with an opportunity to do something meaningful with the information, something that allows the student to produce something that can be used to assess their level of understanding [1]. Even better, allow the student to produce something significant, and allow them to do it with others, as a team. When students work as a group toward a common goal learning outcomes tend to be increased as members also learn by teaching others in the group [4].

Middle Tennessee State University (MTSU) seeks to take STEM students beyond the classroom by offering them a chance to participate in the university's Experimental Vehicle Program (EVP), an active engagement program that is open to all MTSU students, regardless of their major. However, it is specifically aimed toward, and primarily attracts, STEM majors.

The EVP offers four vehicle projects, to include the human-powered lunar rover, a gasoline-powered off-road Baja, a gasoline-powered formula car, and an all-electric solar boat. These projects are designed to offer students an opportunity to engage in hands-on learning activities and develop organizational, leadership, and communication skills beyond what is possible in the classroom alone by allowing the team members to design and construct the project vehicles from the ground up.

All projects are completed over the course of two semesters. The process exposes students to practical applications for project management, methods of research, computer-aided design (CAD), composite construction processes, machine tool use, 3D printing and other rapid prototyping techniques, hydrodynamic and aerodynamic design principals, the design and implementation of long-range radio links for data telemetry and communications, electrical circuit design, power management, materials science, physics, OSHA safety procedures, and technical report preparation.

Participating students are rewarded with the opportunity to enter their completed vehicle into a professionally sponsored international, intercollegiate, competition that is specific to the project. By doing so they are able to not only see how well their project performs against other teams, they also gain the benefit of exposure and insight into the engineering solutions that were developed by other teams that faced the same challenges they faced during the design phase of the project.

MTSU's EVP lab is supervised by two graduate students who serve as mentors to the participating undergraduates. The mentors serve to ensure that the participating undergraduates employ proper project management methodologies during the lifecycle of their project, they ensure all implemented safety protocols are followed by students working in the lab, and they guide and aid students as needed to ensure the projects remain on schedule and do not go outside of the original scope of the project. They also serve as technical advisers to the teams and accompany them to the competitions that the vehicles will ultimately compete in. Their role as

mentors is considered to be a crucial component in achieving the intended goal of promoting learning within the program and helping the students complete their projects successfully.

In addition to the graduate student supervisors, a faculty member serves as the director of the EVP's operations. The role of the faculty advisor is to maintain oversight of the program and ensure that all of the required resources are available so that the program's operational needs are met. One of the most important functions of the faculty advisor includes acquiring all necessary internal and external sponsorship funding for the projects.

While MTSU's EVP does offer four project vehicles, all of which are equally capable of offering practical energy conversion and conservation learning opportunities, let us consider only the all-electric solar boat project. This project is unique in that it offers students an opportunity to design and build a system that, by design, requires multiple energy conversions to operate. Additionally, the resulting performance of the craft hinges solely on the efficiency of each conversion.

Students choosing to work on this project are immediately faced with designing a boat that is capable of both high-speed operation for short periods and traveling long distances at slower speeds. The primary constraint they are up against is that the rules for the competition the boat will be entered into, the Solar Splash, only permits them to use photovoltaic panels with a maximum output of 480 watts, and the constraints for the onboard battery pack include it being limited to 36 volts, being limited to a weight of no more than 100 lbs, and the chemistry for the battery pack is limited to lead-acid. To sum this up, they must design and build a boat that not only can go fast, but can operate for two hours and go farther than the completion with only 480 watts of solar power available to them.

View of MTSU's 2016 Solar Boat Cockpit

For this craft to be successful, in terms of competition placement, the available 480 watts of solar power must be used wisely. Design considerations by the team will include the efficiency of the panels selected, how they will be mounted, what type of charge controller will be used, the best battery model to purchase,

the best motor controllers to use, the best motors to use, determining an optimum drivetrain design and configuration, determining the best material for the hull, designing a hybrid hull that is most efficient at both planing and displacement operation, and establishing how the telemetry system will function so that useful data can be acquired during the testing phase. Additionally, they must determine how to ascertain that they are making the best decisions in terms of hull design, component selection, and in the design of the testing procedures they will employ for the purpose of either validating or invalidating the decisions they are making.

Students who participate on the solar boat build team show an extraordinary amount of dedication to the project. This dedication is evidenced by their performance as it is measured in terms of the numerous awards they garner at the Solar Splash competition. The awards received by the team during the 2015 Solar Splash include the Design Achievement Award, Outstanding Workmanship Award, 2nd Place Qualifier, 2nd Place Sprint, 1st Place Solar Slalom, 4th Best Technical Report, 3rd Best Technical Display, the Sportsmanship Award, and 2nd Place Overall.

MTSU's 2015 Solar Splash Awards

This success was repeated again during the 2016 Solar Splash where the team received the Design Achievement Award, Outstanding Workmanship Award, 1st Place Qualifier, 2nd Place Sprint, 3rd Best Technical Display, and 2nd Place Overall.

MTSU's 2016 Solar Splash Awards

Here we have a project that gathers solar energy and converts it directly into electrical energy through the use of photovoltaic panels. That energy is then stored in batteries in the form of chemical energy. From there it is converted back into electrical energy and then into mechanical energy that is transferred to the propeller through some type of transmission. How efficiently the craft operates hinges directly on the efficiencies of each conversion, and the hydrodynamic efficiency of the hull, and it is a desire for efficiency within the system that ultimately encourages students to understand how to improve the conversion efficiencies and understand of the energy conservation law.

MTSU Team Photo at the 2016 Solar Splash Awards

While having students build cars and boats may seem a bit extreme, projects of this scale offer the same types of engineering challenges that a STEM major would expect to encounter in a real-world engineering job. Students must learn to work in groups and solve complex problems as a team. In undertaking and participating on a project of this magnitude students are able to develop skills that can only be developed by actively participating in something that is extraordinary in its complexity and extraordinary in the challenge that it presents in being able to take it all of the way through the projects lifecycle. Participation in this type of active engagement project not only provides them with proven and marketable skills, it also increases the chance that they will graduate and graduate within a STEM field [5].

Students that participate in the EVP are openly encouraged to describe how they were impacted by the program, both in academic, personal, and professional terms. The following are summarizations of the responses provided by four MTSU students who previously participated in the program. While not all worked directly on the solar boat, all participated directly on one or more of the program's project vehicles.

Jeremy Posey, an Electrical Engineering Technology major who graduated December of 2012 and found immediate employment as a Powertrain Controls Engineer at FCA Fiat Chrysler Automobiles in Detroit, MI describes his experience within the EVP as follows: "It provided me with a way to gain CADD and machining experience that, as an Electrical Engineering

Technology Major, I would not have otherwise been able to obtain. I worked on every project within the program during the three years prior to my graduation and feel that the overall experience was a major boost in terms of my leadership and management skills."

Brian Julian, a Mechanical Engineering Technology major who graduated December of 2013 and found immediate employment as a Manufacturing Engineer at Gastite in Portland, TN describes his experience as follows: "I worked primarily on the NASA Human Exploration Rover during my last two years at MTSU, the first year as a team member and the second year as the captain. The rover I designed won many awards at the 2013 NASA Human Exploration Rover Challenge, to include being the 1st place US entry, 3rd place internationally, and 1st place most improved. When I went for my interview with Gastite I took all of my CADD drawing, the design report, and photos of the rover as proof of my engineering abilities. I also showed them pictures of the other vehicles the EVP produces and explained to how my success within the program bolstered confidence in my engineering abilities. They hired me on the spot."

Nicolas Cronin, a Mechatronics major, and current student at MTSU, was able to reach the position of Lead Engineer at The Davis Groupe in Murfreesboro, TN while still in school as a result of his work within the EVP. He describes his experience as follows: "I had been eyeing an engineering position at The Davis Groupe, where I was employed, and I wanted to be able to show them that I was good with electrical systems. By working on the solar boat team for two years and helping the team increase their performance each year I was a member, I was able to prove to my boss that I had what it took to be promoted to the position of Lead Engineer. While I no longer have the free time to commit to the EVP or the solar boat team I'm grateful that I was able to work on the boat and use that work to prove to my worth to my boss and advance to a position that I thought I would have to wait until I graduated to obtain."

Dustin Taylor, a Mechanical Engineering Technology major, who graduated December of 2014, started his own company specializing in freelance CADD work immediately after he graduated. His description of his EVP experience is as follows: "My physics study partner encouraged me to become involved with the EVP as he was working on the solar boat team at the time. While working in the lab I became involved with the baja, the rover, and the solar boat, helping each team as needed. This provided me with an opportunity to learn how to use Solid Works, design software that was not a part of MTSU's MET curriculum at the time. I also found that working in the lab caused me to look forward to going to campus every day and working with all of the new friends I had made in the lab. Frequently we would also work on homework problems together in the lab as well as most of us were in the same classes together. Some of the most meaningful relationship I formed while on campus were with individuals that I met while working in the EVP."

William Harper, an Environmental Science and Technology major who graduated December of 2013 who found employment as an Engineering Designer at Coburn's Exclusive in Nashville TN prior to his graduation offered the following description of his EVP experience: "I was looking for a green project to get involved with during my freshman year when I learned of the EVP. The two projects that interested me the most were the NASA rover and the solar boat. The rover is human powered and the solar boat is, of course, solar powered. After spending three years in the program, one of those as the rover captain, I was surprised at how much I learned and how many

skills I gained that were well outside of my field of study. One of the primary skills that I picked up was being able to use Autodesk products like AutoCAD and Inventory and operate CNC milling equipment. It was these skills that allowed me to obtain employment at Coburn's. My position there would have been unobtainable to me if not for my time in the EVP."

Conclusion

At the bachelor's level, research has put the attrition rate for STEM students as high as 48 percent [6]. At MTSU research is currently underway in order to determine the most effective method to answer the questions that will determine not only the current efficacy of the university's EVP as an active engagement program but how it may be improved. There is a strong desire to understand why some students abandon the projects so that a meaningful retention effort may be put forth within the program. Additionally, and despite the published benefits of such programs, there is a need to quantify the program's efficacy as a tool for reducing the attrition rates of participating STEM majors as reducing the number that switch majors or drop out altogether is considered to be the program's primary goal. The end result of this research, along with all quantifying data, is slated to be the topic of a future paper.

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