Learning to Build and Building to Learn: The Baja Experience

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The Society of Automotive Engineers is a collegiate student design competition where students partake in designing and building a fully functional, off-road vehicle. This specific type of vehicle is known as a mini Baja car. Lacking formal education from any commercial industry, the team of students has succeeded in learning, inspiring, and teaching their peers in various skill sets through generations of students. After twenty years of innovation, Baja has established itself as a top competitor. What contributed most to our success is the diversity of the multi-disciplinary student team that has dedicated themselves to making a difference in this organization. With electrical, industrial, mechanical, and chemical engineers in our organization, the Baja team possessed the skillsets and perseverance to find a solution to any obstacle.

This paper describes the personal experiences of three students who joined the mini Baja team with no prior experience in designing car mechanisms or supporting a student-run organization. As novices in this organization, they sought out ways to contribute to the best of their ability. Through a four-step learning cycle, these students were given the opportunity to begin molding themselves into knowledgeable and experienced engineers. Using hands-on projects, their peers taught them to directly apply textbook learning into real application of design methods. As their experience grew, they developed communication, teamwork, and leadership skills. Through individual research, they were able to acquire knowledge and skills that they would not gain otherwise.

As one of the most successful engineering student organizations in the university, Baja has held dedication as one of the essential values. It is important to realize what is learned and how well people worked together to accomplish tasks. Having a variety of students with different engineering disciplines has allowed Baja to be more successful in recent years. The team values learning the trade independently and through each other, rather than relying solely on experienced students and faculty, and it encourages students who are ready to learn outside of their comfort zones. Following their Baja experience thus far, the authors are now helping lead their peers and new members through the same learning process that they had experienced. This paper discusses the set of activities that helped these three students to grow as future professionals and gave them the experience of working with an interdisciplinary team.

Introduction

Mini Baja SAE (Society of Automotive Engineers), typically referred to as merely Baja, is a student-run organization that designs and builds an off-road vehicle used in competition against other schools. The first Baja vehicle at Western Michigan University (WMU) originated as a senior capstone design project in the mid-90s. Continuation of the project ceased until it was resurrected in 2007 as a student organization. The second WMU Baja vehicle was completed in 2011 for the Baja SAE Kansas 2011 competition, where it placed 73rd of 100 teams. Fabrication

of a car to compete at Baja SAE Rochester 2013 is currently in progress. Thus, Mini-Baja is a young program at WMU, in terms of experience.

Figure 1: Mini-Baja vehicle that competed at 2011 SAE Kansas

Like many student organizations, Baja is a great opportunity for students to gain and demonstrate criteria meeting those thought to represent the best engineering programs. These criteria are provided by the Accreditation Board for Engineering and Technology (ABET)[1]. Student-learning criteria required by ABET include applying knowledge of mathematics, science, and engineering; ability to design a system, component or process; ability to function on multidisciplinary teams; ability to communicate effectively; and the ability to engage in life-long learning. Advantages of having ABET-accredited programs, among others, are that they are more focused on learning outcomes than teaching inputs[1]. The Baja project experience demonstrates a number of these much-valued learning outcomes.

Baja was an opportunity for students to gain hand-on experience as engineers, it was a time to make friends and have fun, but most importantly, it was a time to learn and grow. Through an explanation of the learning cycle, and real Baja experiences, this paper will describe the experiences of two sophomores and one junior student dedicated to their education as undergraduate students in engineering and dedicated to the Baja team. It will be demonstrated how Baja was able to support student learning criteria desired by ABET, Most important to the team, the paper shows how they not only "learned to build, but also built to learn."

The Four-step Learning Cycle

A larger portion of being involved with a student organization, such as Baja, is being a self-learner. In thinking about the process they went through in their Baja experiences, the authors realized they went through a four-step learning cycle. Observing, learning, applying, and teaching are encompassed within this learning strategy. Implementation of this process will

allow a student to gain the most insight from participating in this organization. The four steps of the cycle are detailed below.

Four-step learning cycle: Observing

To better explain the four-step learning cycle, let us create an instance where one is told by their professor to design and build a mobile water fountain for an annual water fountain design competition. The idea of this, to most college students, is obscure and almost insane. Looking for a place to start, a student would go to the Internet, media, books, magazines, etc. to gain a foundation of what is being asked. Also, they may have looked at designs from previous years of said competition. This stage will be referred to as the *observing stage*. Utilization of observation was recommended when working on a project for the Baja team. It allowed students to gain a sufficient understanding of the project as well as familiarize themselves with work done in the past and the flaws that were present in those designs. It is similar to reading about a subject prior to a lecture.

Four-step learning cycle: Learning

To continue with the previous example, it can be assumed that most people are not experts in mobile water fountains and how they operate. Thus, one is forced to acquire knowledge on the subject. This will be referred to as the *learning stage*. In the case of the water fountain, one had to gain understanding on fluid mechanics, static properties, machining processes, mobility, properties of water, material properties, and any other areas of understanding needed for this project. Knowing that a design will not work due to properties found within the material or the structure will allow one to save time by not building something that is likely to fail. When it came to building the Baja vehicle, much of the learning had already been done through engineering courses that have been completed. Alumni and more experienced students also provided assistance by teaching Baja participants subject material more specific to the project.

Figure 2: WMU Mini Baja alumni meeting with drivetrain team

Four-step learning cycle: Application

American author Dale Carnegie once stated, "Knowledge isn't power until it is applied."[2] The wise words of Dale Carnegie created a foundation for the *application stage* of the learning cycle.

Once students had gained a sufficient amount of knowledge, they could get their hands dirty in the design and fabrication of the mobile water fountain. This would allow connection and reinforcement to be made to the material learned. Doing this was the only way to truly expose all of the areas overlooked while learning, showing where students should go back to the learning stage to fill the gaps. For example, one may not have thought or acknowledged that soldering is a required skill when working with tubing for a water fountain. Most likely, one would have made errors during this step, but that's the point; the errors are exactly what make this stage critical. Pausing and resolving issues that arise is one of the characteristics of a successful engineer, and is only learned through this stage. This was one of the stronger areas of the Baja team. Members gained hands-on experience while working on the vehicle, and with the guidance of experienced members, they were able to problem solve real issues.

Four-step learning cycle: Teaching

A characteristic of an expert in a specific area is the ability to educate colleagues about the latest findings in their fields. The last essential step in the learning cycle is being able to teach what you have learned: the *teaching stage*. Doing this allows one to reflect and organize what they have learned in ways that provide a sense of confidence. Teaching also enabled information to be passed on to following "generations." In the sense of the mobile water fountain and the Baja car, it allowed students to teach peers methods of fabrication, materials, and other information that was found to be beneficial. It also allowed mistakes, flaws, and problem-solving to be passed along, so that they can be learned from. A large asset of this step is being able to impact someone that is going through the learning stage while paying it forward in terms of education and experience.

Figure 3: Drive team leader demonstrating how gearbox operates to his team

The Baja Project

The Baja organization was run with a definite structure that allowed work to be done efficiently. Within Baja there was a project manager who oversaw team leaders and ran weekly meetings. Team leaders are the ones in charge of various aspects of the car (for example, drivetrain,

suspension, frame, and fundraising). All other members work under a team leader in specific areas of interest. The team leaders report to the project manager, who keeps everything orderly, and they also act as liaisons to the members who work under them. Also, to unite the team and keep communication lines open, the entire team met once a week to make sure everyone was updated on what is going on and also to build relationships within the team. This structure also allowed for strong communication, leadership, and teamwork – key aspects to any project.

Devotion and value aptly describe the authors' involvement with this organization. With experience ranging from two to three years, they were a part of the more-involved projects. One author took ownership over the frame of the vehicle, as the frame team leader, while the two other authors built momentum for the team by become fundraising team leaders. Personal experiences of the authors are provided in connection with their project activities.

Frame

One very large project for the vehicle was the design and fabrication of the frame. An inexperienced member of the team led the group as he took the role of the frame team leader during his second year of college. To begin the design, the learning stage was implemented, as problems of the previous car were taken into account. Some errors included the frame being too long when compared to other Baja vehicles from various universities, and a large, unneeded empty space that added length to the frame. The general shape of the previous frame influenced the design of current one. Constraints that drove this design included the safety restrictions, found in the *2013 Collegiate Design Series Baja SAE Rules*[3], and various mechanical components encompassed within the vehicle, such as the drivetrain and suspension systems. In order to encompass these systems in the vehicle, compromises had to be made with the drivetrain and suspension teams during the designing of the vehicle.

Implementation of knowledge from classes had a large influence in the design on the vehicle. Examples of this are concepts such as static principles of how structures transfer loads, bending stress and deformation from a mechanics and materials course, finite element analysis (FEA), experience from a truss optimization class project, and the initiative of how one should design for manufacturing, learned in a course labeled "Processes and Materials in Manufacturing." A successful frame design was the result of these methods.

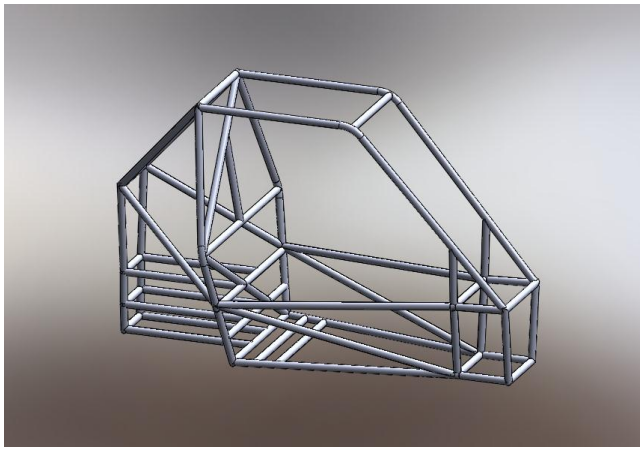

Figure 4: Frame design for 2013 SAE Rochester

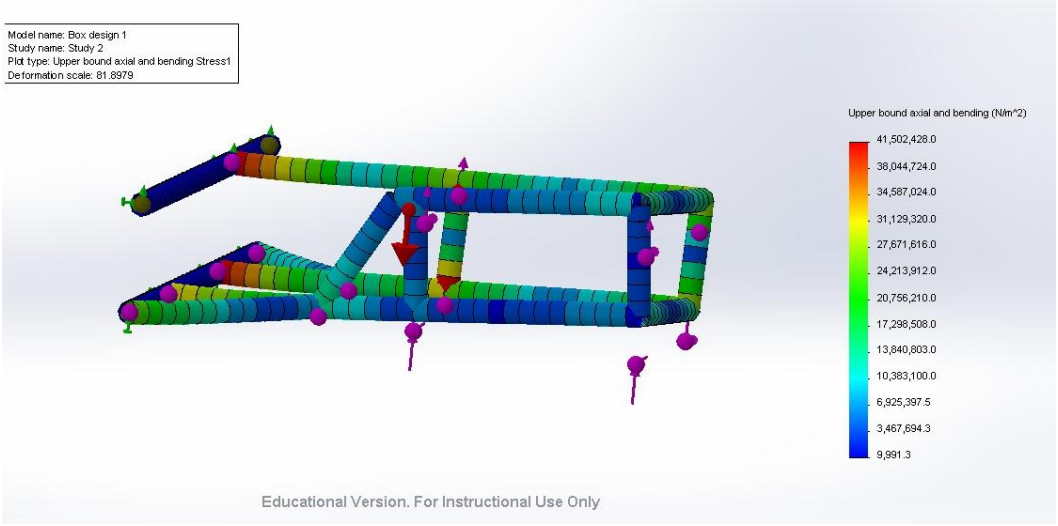

Figure 5: FEA on back-end of vehicle suspension mounting

Fabrication of the frame followed the design. Research was done on how teams from other universities fabricated their frames. Doing this, the frame team found advantages and disadvantages of different processes. The vast information gathered by doing research appeared in a variety of different media, which included pictures, videos, forums, and documentation from various universities and other groups. Other beneficial resources included alumni and experienced members of the team, who offered their insight and knowledge of this process.

Figure 6: Example of tube cuts

Through research, fabrication methods were developed and implemented. For example, creating a multi-use jig allowed a large step forward to be taken. Using this jig, multiple sections of the frame were built in sequence, and several simultaneously. Tube cutting was done by cut templates, a jig for the drill press with a hole saw bit, and an air compressed die grinder. This allowed for tubes to be cut at proper angles. Tubes were placed in jig to be held in place for welding. Tungsten Inert Gas (TIG) welding allowed for a very clean and strong joining of the tubes in the structure.

Figure 7: TIG welding being done on the frame

Some of the measurements and angles within the frame tubing ended up being smaller or larger than what was intended. This resulted from inaccuracies with jig and warping from welding. The length of the cockpit was over-engineered. In the future, a more precise way of implementing ergonomics for the range of drivers will be needed for a more efficiently designed vehicle. A more precise jig will also be implemented to allow for more accurate fabrication.

Figure 8: Vehicle firewall being built on jig

Completing of the frame allowed for further work to be done in the vehicle. As far as the frame team, body panel mockups of cardboard were placed on the frame to see how they fit before the actual material was ordered. Gas and brake pedals and their fixtures were made after physically seeing one's leg reach while sitting in the car. This also allowed for the drivetrain leader to

notice where mountings and fixtures for the drive train components could be placed on the frame. Looking at these situations, it can be said the frame was a crucial bridge to cross in order for the Baja project to continue.

Fundraising

A large portion of the projects associated with Baja involves working with raw material fabrication. Most of these raw materials are composed of sheet metal and metal tubing. The final competition vehicle can be thought of as a million little pieces molded together, and these pieces add up to a heavy cost of $6,000 for the car alone. Due to the current state of the economy, the university reduced funding to all student organizations. Two of the authors served as fundraising directors because this was the first year the organization needed major supplemental fundraising.

The first target area for fundraising was team members' families and friends. Financially capable parents of members were happy to donate. Eight members of the team were affiliates with the Lee Honors College at Western Michigan University, and the Lee Honors College responded with $1,000 to support its students. Some members also had connections to businesses and companies that perform work or productions similar to the goals of the team, or they simply wanted to support a group of motivated students. Alumni of SAE and local businesses also supported monetarily. One donation came in the form of tools and team t-shirts.

As the team began receiving donations, the next phase of the fundraising plan began – hosting community fundraising events. Local businesses were sought out to host events to raise money for Baja. For example, restaurants would generously place certain items from their menu onto a list, and a percentage of the revenue earned from these items was donated to the team. These events typically raised $100 to $200.

One successful fundraiser, in terms of public attendance and raised awareness of Baja, came from a car smash held at the center of campus. From a generous donor, the team received a junkyard car and a sledgehammer. For only one dollar and a signed waver, any student could smash the car with the sledgehammer. Over $100 was made in three hours. Even though it did not generate a substantial amount of money, this fundraiser generated strong interest in Baja. This was one of the first fundraisers this year; it provided the team with the confidence to continue seeking financial assistance from others.

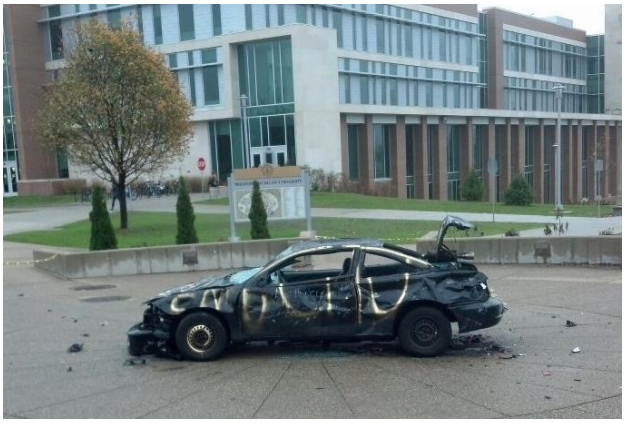

Figure 9: Junkyard car from car smash fundraising event

Success in fundraising was a result of generosity from people in the community who supported the cause. However, none of this could have happened without the skills that were gained through academic, communication, and organizational experiences. Technical communications courses taught the team how to communicate effectively and professionally to business owners and managers. The primary methods used to reach out to others were e-mail and telephone.

While most planning was divided between the two fundraising directors, some events required the efforts of the entire organization. Through SAE nationals, the Baja team was given a special deal in which they received money for each member of the organization that registered with the national organization. Baja received $1,000 this year. Not only did this help the chapter with funding, but registered members received access to learning modules and resources through the SAE national website.

The fundraising directors had a difficult time getting their feet wet at first. They had no idea where to begin; they only knew that they were passionate about keeping this organization up and running. Learning to network with strangers can be a large hurdle, but once crossed, it is easy to see that people want to see you succeed. The team came to understand that, in reality, an employer or business will only give someone one chance to make a great impression and state the purpose of the interface, and the team's communication activities were enhanced and perfected through this process. By exercising the four-step learning cycle, the fundraising team members were able to accomplish their goals. They found an area in Baja that they enjoyed and took pride in. Baja gave these members an opportunity to meet great people, to learn and grow professionally, and to appreciate engineering outside of the classroom.

Figure 10: Fundraising team planning events

The Big Picture

As mentioned before, ABET supports student learning outcomes important for the development of a proficient engineer. A number of these criteria are ones that are not learned in a classroom setting alone, but have to be developed first-hand. The following includes ideals and lessons the authors found not only benefit them in the classroom, but also in their personal lives and in the working world, including diversity, teamwork, problem-solving, professional development, and lifelong learning.

Value of diversity in teams

Having many inexperienced members, the Baja team could have relied solely on the older members to bear the weight of the workload. However, this did not occur. The team's greatest strength is their diversity. When an organization is diverse, it has both new and old members, as well as members of different backgrounds and educational disciplines. Baja is comprised of mechanical, electrical, manufacturing, and chemical engineering students, and even non-engineering majors. Baja is not solely about engineering; it is also about business, design, planning, and other areas of study. Members include both U.S. and international students. The team this year consisted of two women, fifteen men, and Caucasian, Hispanic, African-American, and Asian ethnicities. Of these members, several brought other non-school experiences, having performed as mechanics, manufacturers, safety technicians, and more.

The Baja team values the different perspectives and skills that its members bring, and also values their ignorance. Ignorance brings about an unprecedented passion to learn, and it is by this very passion the foundation is established for teamwork and peer-to-peer learning. The diversity makes this organization interesting, makes it run, and makes it unique. The team knows how to seek out answers, and the search begins within themselves and their team members.

Self-learning and lifelong learning

Being a part of the Baja team taught the authors skills and information that they can use every day in their classes. And vice-versa; the hands-on experience of Baja allowed them to take what they had learned in the classroom or through a textbook, and see it in a real life scenario. It allowed them to better understand what they had learned in classes and it encouraged them to further research on their own. An example of this is in the building of the frame. None of the authors had any prior experience with building a car, yet they all managed to learn on their own and with each other how it works. Without help, the frame team leader taught himself through research and application of what he learned in his classes to design, test, and build a Baja vehicle frame. Independent research methods included the use of the Internet, library text references, and professors who are experienced in the area of research. Visual understanding allowed the enhancement of education both in and out of the classroom.

Professional development and communication

Being a part of Baja also affected the personal lives of the authors in a professional manner. The goal was made for Baja in the beginning of the academic year "to run it as a corporation." Dealing with different situations as they arose was done in a businesslike manner to acquire the best outcomes. The team has learned how to network with others while performing in an environment that is similar to professional workplaces. Also, the team learned how to communicate when working in a project group. These are very important values to have while making the transition from university curriculum to the business world.

Social development

Like almost all student run organizations, Baja would not continue if it were not fun. The authors have learned how to create friendships and work with peers all while helping each other, and having fun while doing so. Attending a meeting for a first time, one will see that they are with a group that likes to have fun but who are also passionate about the same thing: the Baja experience. Because of this, the authors will look for this in a future employer. They will try to

Figure 11: 2012 SAE World Congress at the COBO Center in Detroit, MI

find a field of work or company where friendships can be made, hard work will be done, and they can enjoy doing it.

Assessment of Baja project learning and results

Baja is a student-run organization; thus no university-based formal assessment was provided. Although no formal assessment was given to any of the team members, the pre- and post-project review by the students themselves showed greater knowledge of the vehicle building, comfort with team participation, and ability to research independently. And the effectiveness of fund-raising, of the final car design, of teamwork, and of performance at competition, is in itself an evaluation of developed skills and abilities. An important assessment will be if the Baja experience has engendered commitment in current and future members so as to support its ongoing existence, always a concern of student-based organizations. The authors intend to "pay it forward," so to speak, and to recruit and continue to support new members.

Conclusion

Baja at WMU has a history of diligence and hard work, allowing for its growing successes in recent years. The team has found a commonality among its members: all share a passion for learning. As described in this paper, it is a different learning that is accomplished; it is a more interactive and hands-on learning than that found in the classroom environment. Through their Baja activities, its members have accomplished professional development. This paper has shown the team's ability to learn, to work together, to design, and to fundraise. Through their research, time commitment, and communication, these students have developed into robust leaders with the intention and ability to inspire others in the same ways that they were inspired.

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