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Travel for a Penny a Mile: An Engineering Design Challenge Inspiring Student Engagement and Sustainable Living

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Abstract

Student engagement and success in engineering and science is paramount in developing the country's needed technical workforce. Using actual critical engineering design challenges to inspire and engage students in design solutions to real problems is the path to achieving a high degree of student engagement. Sustainability, living better on less, and team projects that directly impact people's lives speak to this generation of engineering students. Energy usage is one of the most critical engineering challenges we face today. Global warming due to harmful emissions from burning fossil fuels and rising gas prices as well as national security issues have driven people to look for new ways to reduce their fuel consumption and to live better on less. It has been known for some time that streamlining vehicles can dramatically improve their fuel economy and in electric vehicles, where energy is precious, you see more streamlined examples.

In this study, an interdisciplinary, multi-university student team consisting of three visiting REU students mentored by the same faculty member (who were part of a large REU summer contingent) and three regular students investigated the research question of whether or not it makes sense, from both an economic and practical standpoint, to streamline a motorcycle for everyday use. (A motorcycle was chosen because they are more accessible and less regulated than cars). To answer this research question, the team gathered data on previous Vetter Fuel Economy Challenge events created by Craig Vetter, an American Motorcyclist Association Hall of Fame motorcycle designer, to test motorcycle fuel economy in real riding conditions. Mr. Vetter was invited to spend a week on campus talking with Engineering and Industrial Design Students about energy usage, streamlining, and aspects of fuel economy. As the realization of this design project, the team designed several components and constructed two streamlined motorcycles to compete in the Vetter Fuel Economy Challenges. This is the only student team involved in these challenges. All other participants are professionals. The faculty mentor met often with the REU students and took them to the three day event in MidOhio.

The objectives were to design and fabricate a streamlined motorcycle system to perform comfortably when driven for at least 100 miles at 70 mph into a 30 mph headwind, carrying a useful load of at least four bags of groceries, and use the least amount of energy possible. The performance and fuel economy of the motorcycle was evaluated before and after streamlining. Examining data from several Vetter Challenges, dramatic improvement in the fuel economy of motorcycles after being streamlined is demonstrated. In parallel with the student team's technical research, their individual reflections before, during, and after the project were formally gathered and analyzed. In this paper, the results of the Vetter Challenge competition are discussed along with students' experience and reflections. Ongoing next steps and a pathway to implement this research at other schools are revealed.

Background & Introduction

In the 1970s Craig Vetter, Designer[1] created and designed things he wanted and found that other wanted them as well. He has always been captivated by the notion of "doing more with less" following the lead of Buckminster Fuller[2]. In the mid-1980s he created the Vetter Fuel Economy Challenges and invited others to participate to see how far a vehicle could go on the least amount of fuel. Motorcycles which started with good fuel economy seemed like the place to begin. Vetter, who was famous for his motorcycle fairing designs, focused this challenge on streamlined motorcycles. At that time, the national speed limit was 55 mph and it was found though his competitions that a streamlined motorcycle could get as much as 450 mpg at that speed. Craig Vetter says, "If fuel ever becomes precious, then this is important otherwise most people don't pay attention. We rely too much on foreign oil." Fuel is precious today in electric vehicles. Terry Hershner[3] riding a Vetter streamlined Zero electric motorcycle has travelled across the US three times and his riding time between charges has increased each trip with ever more effective streamlining. The first trip, streamlined he got 80 miles between charges. On his last trip, he achieved 200 miles between charges.

The current Vetter Challenge is to travel 100-150 miles sitting upright comfortably using any type of fuel. The vehicle must be capable of traveling at 70 mph into a 30 mph headwind carrying 4 bags of groceries which can be loaded in 45 seconds. The goal is to have the vehicle be the first choice of vehicles in the garage.

In the summer of 2013, three REU students funded by an NSF I/UCRC supplemental grant were chosen to work on a critical engineering challenge to reduce energy consumption in vehicles. These students were a subset of a larger group recruited to campus for various REU experiences. These three students were all mentored by the same faculty member. Research using these summer REU students was approved by the VT Institutional Review Board (IRB #13-561). These particular students were chosen for their diversity of disciplines, gender, and university. Two males and one female, one a sophomore from a small eastern university with a general engineering program, one a sophomore from a medium-sized west-coast university with a biomedical program, and one senior from a large eastern university in majoring in Biology and minoring in Scieneering. Not the typical engineering students who would be interested in an aerodynamic and mechanical engineering project, but who might be interested in a project that could benefit the United States and humanity.

Research Questions

The following research questions were arrived at by looking at the project and the students recruited and chosen to participate in the project.

R1. Can a researcher who is passionate about a particular design project inspire others to join in, be engaged in and persist in the project?

R2. Can students of diverse background, but none of whom are mechanical engineers become, engaged in a motorcycle fuel economy challenge design project?

Theory & Methods

Student engagement is one of the biggest issues in engineering education. If you can engage students they will persist[4].

It was decided that using a student motivation model such as the MUSIC model[5] would be a good theoretical foundation upon which to build this project and to answer the research questions posed above.

The 5 key principles of the **MUSIC** model are that students are more motivated when they perceive that: (1) they are e**M**powered, (2) the content is **U**seful, (3) they can be **S**uccessful, (4) they are **I**nterested, and (5) they feel **C**ared about by the instructor and/or other students. Thus, the MUSIC model specifies five primary components critical to motivating students: eMpowerment, Usefulness, Success, Interest, and Caring.

The MUSIC Model guides instructors to ensure that students:

- believe that they have some control over some aspect of their learning
- understand why the content is useful
- believe that they can succeed if they put forth the effort
- are interested in what they are supposed to be learning
- believe that the instructor cares about whether they meet the course objectives

Based on Jones (2009)[6]. More detail about the MUSIC Model can be found on the website[5].

In summer 2013, the above mentioned three NSF sponsored REU students from diverse backgrounds and schools joined the faculty advisor and three experienced students to complete the design and fabrication of two streamlined motorcycles that would compete in the Vetter Fuel Economy Challenge.

In this project, the students were given free reign over what aspect of the design project they wanted to pursue. A day was spent presenting design methodology and the rationale behind the Vetter Challenge as well as previous results in the challenge. Students were continuously encouraged regarding their capability and ability to succeed. Students were given several opportunities to reflect on their interest in the project and purpose for pursuing it. The instructor was very caring about their progress and success in the project. He met and worked with them often. Taking them to dinner and traveling with them to the Vetter Fuel Economy Challenge at the AMA Vintage Days held in Mid-Ohio in late July.

Projects such as the ROXIE Project[7] or EPICS[8] which has goals and outcomes of a Service-Learning model more closely match many students' desire to directly aid humanity. The Vetter Fuel Economy Challenge is a project which needs closer examination before its relevance to bettering humanity is realized. The author's contention is that any project that the mentor/advisor is passionate about can be a valid project to create student interest, engagement and persistence.

An appropriate level of mentoring is important and a key element to student success. Too much hand holding or answer giving is detrimental to student development. Guidance within the context of student exploration, learning, and mistake making is critical to student ownership and success. The truth of this statement is revealed in the student reflections to follow.

Students were recruited and chosen based on their potential to learn (GPA, previous successful projects, and faculty recommendations) rather than any particular interest in or expertize in the subject matter. After the project mentor's presentation of some basic background on the project, some design process instruction and general design exercises, students were allowed to choose what aspect of the streamlined motorcycle fuel economy competition they would pursue and what they would design and fabricate to move the project forward. To assess their interest in and engagement in as well as their general impression of the project, they were asked to answer questions on their interest in and engagement in the project at three different points in the project as well as their overall reflection on the experience.

Student Survey Response Data

The Four Survey Questions asked Students at the A. beginning, M. the middle, and F. finally at the end of the REU experience:

1. When you first saw the VT Student Engineering Education Collaboratory (SEEC) Project "Critical Engineering Challenges", what did you think this project would be about?
2. How confident did you feel about your ability and skills to succeed at the project when you first heard about the Virginia Tech Craig Vetter Motorcycle Fuel Economy Challenge as your research?
3. How much interaction & mentoring did you expect from your faculty research advisor?
4. Any other question you want to answer at this point.

Student Qualitative Responses

Student1, General Engineering sophomore at small East-Coast University. Initial response to the four questions at the start of the project (Note: this was the only student to respond at all three points during the project although the other two recorded their responses and reflections in their Design Notebooks):

Q1. Understanding and Interest. A1. "When I think of "Critical Engineering Challenges", I think it is problems in today's society. I thought I would be working in a team of 3-4, working on some sort of project that saves gas. I thought I would be doing lots of planning & engr. des. work."

Q2. Confidence and Success.A2. "Having an idea that I will be working on a motorcycle made me a little scared due to my lack of motorcycle knowledge. I felt that I wouldn't be THAT great at building/machining b/c I've done only a <u>little</u> work with mechanical engineering. I did have <u>some</u> confidence because I helped build a tricycle in engr. des. when I originally had no tricycle knowledge. I had about 50% confidence."

Q3. Faculty Mentoring. A3. "Initially, I thought I would be spending all my time with the research advisor. I thought he would tell us what to do, what times to meet, and give us a strict schedule. After some VT REU SEEC meetings, the research coordinator told us the advisors might spend once a week with us, which was surprising.

Q4. Student Choice Question: "Why did you have interest in this research topic?"

A4. "I thought working in the Vetter Fuel Economy Challenge would be very hands-on & not boring (sitting in a chair/ desk). I see that fuel is very precious & the U.S. needs to find ways of different energy sources or drastically decrease our use of oil. This is major problem in today's society & I want to help! Vetter's Fuel Economy Challenge is not HISTORY in the making, it is the FUTURE in the making, and I want to help promote his idea of doing more with less."

Student1, Middle of Project Answers to questions

Q1. Understanding and Interest. M1. "Since I have been working on this project, I am understanding more about how this "Critical Engineering Challenge" relates to engineering education. Engineering Education is about this combination of research & teaching/learning. I was learning how to build a streamliner, teaching/helping colleagues what I learned & researching best ways to get great fuel economy.

Q2. Confidence in Success. M2. So far, my confidence in this project is increasing overall. I make a few silly mistakes that hurts my confidence, but that will happen to me for the rest of my life. The more I work on this project, the better practice I have on working on motorcycles & the more confidence/ideas I have."

Q3.Faculty Mentoring M3. "So far Dr. Goff is practically checking up on us once a day. He sends plenty of e-mails & always communicates with us."

Student1, End of project Answers to questions

Q1. Understanding and Interest. F1. "This project is about many things: Interacting with an interdisciplinary group on something I don't have much knowledge on, trying to overcome a critical engineering challenge that is happening in today's society, and learning how to research, plan, & design a streamlined motorcycle. This project sparked my interest in 'doing more with less' and even motorcycles, so I believe this project will change my future."

Q2. Confidence in Success. F2. "After being involved in this Motorcycle Fuel Economy Challenge, I feel like it was mostly as success. I was more of a help than I thought I would be in the beginning. When we came to the lab, we went to work right away such as drill pressing, using the hack saw, and coming up with design plans. I am pretty confident now about what this team and I have built, but if I had better skills on motorcycle engines & carburetors then the outcome of this project would have drastically improved."

Q3. Faculty Mentoring. F3. "My advisor, Dr. Goff, spent about 3-4 times a week with us. He probably spent way more time with us out of any research advisor. Of course I liked that because it kept everyone clear & up on the progress of this project.

Student2, senior Biology major with engineering minor at large east coast R1 University, Initial response to the four questions at the start of the project:

Q1. Understanding and Interest. A1. "When I first saw the VT SEEC project, "Critical Engineering Challenges", I thought that it would entail approaching engineering issues pertaining to improving the fuel economy of vehicles in *novel* and *unique* ways. I imagined being given a set of particular problems or issues with current engineering designs and asked to research ways to solve them in innovative ways. I did not know what to expect in terms of this particular project relating to education—however, I was open minded and prepared to engage myself in whatever the project encompassed. The major reasons why I applied for this research project were because of my strong interest in interdisciplinary work, my desire to learn about new things, and because I wanted to gain experience in more 'hands-on' research, in contrast to the more theoretical and abstract type of work that I had done in the past."

Q2. Confidence in Success.A2. "When I first began this project, I was a bit nervous about my lack of knowledge in engineering preventing me from bringing anything valuable to the table. Not only was I ignorant in many engineering principles (such as Dynamics, Statics, etc.), but I entered this project with essentially no knowledge about motorcycles. I was also a little worried that I would come off as annoying to some of the more experienced members of the team, due to the endless number of questions that I undoubtedly would be asking them. However, I was, on the other hand, confident in my ability to work well with the team, fully apply myself and to learn a great deal about whatever it was that I would be researching, despite my different skillset and background."

Q3. Faculty Mentoring.A3. "As far as the amount of interaction and mentoring that I expected from my faculty research advisor, I did not know what to expect. From my experience in research, mentors vary significantly in their styles and approach of conducting their research and interacting with their students. At the beginning of the project, I second guessed almost every idea that I came up with and did not trust my judgment to do anything correctly or efficiently. I always ran whatever idea that I came up with by either [experienced student 1 or 2] prior to acting on it, no matter how minor it seemed."

Q4.A4. No Response.

Student3, sophomore Bio Medical Engineering major at medium sized West-Coast University, Initial response to the four questions at the start of the project:

Q1.Understanding and Interest.A1. "I misread the title & thought that the project covered more "Critical Thinking" & cognitive base topics in a theoretical approach.

Q2.Confidence in Success.A2. "From past experiences in design projects, I learned not to concern myself in not knowing before engaging in the project and to learn as I go through the project. The courage to learn is enough. I remember holding myself back when I joined my first design team as a freshman. The fact that the project investigated a motorcycle design made me realize I was out of my water in terms of intuitive & heuristic knowledge."

Q3.Faculty Mentoring.A3. "I expected enough interaction to provide structure and direction."

Q4.Student Choice Question.A4. "Did not read project objectives.
Surprised by motorcycle design.

Was initially under the impression that there would be more reading than machine-shop work.
Would enjoy another design project under my belt.
Opportunity to refine my Design Thinking Skills.
Prepared to fail and make a lesson from the experience.
Use this internship as a stepping stone for my Senior Project. Two Birds, One Stone.
For a Design Project: - disregard classes – experience is your best teacher – no one has majored in creativity – Don't be afraid of being wrong.

Results

The above three students' answers to the questions posed at the beginning, middle and end of the project give in their own words a good picture of student interest, confidence in success and faculty advisor mentoring. These answers confirmed the existence of most of the elements of the MUSIC[4] model theory in this project. The sample size was small because there were only three students participating in this particular project although 13 students participated in the SEEC. They also did not completely follow the instructions given for the survey given at three points in time. All completed journal entries in their design notebooks which had many more insights, but was not coded or analyzed for this paper. Two of the students chose to answer the questions at point 2 and 3 in their journal entries. All three students' reflections are given in Appendix B.

The REU students learned very valuable shop skills in the Joseph F. Ware, Jr. Advanced Engineering Laboratory[9] designing and constructing the streamliner attachments on one streamliner and the grocery carrying saddle bags on another. They learned design process and methods. The students also wrote an abstract and a poster for this project which they presented at a final poster session for the Summer Research Symposium held at the Inn at Virginia Tech July 31, 2013. The student poster is shown in Appendix A. These students also did research on motorcycles, fuel use in the US, as well as the results of the previous Vetter Challenges to create the research poster. They gained valuable teamwork experience working with more experienced students as well as a faculty advisor.

The three students' Post Project Reflections are shown in Appendix B. These student reflections describe what learning experiences/outcomes the students achieved and transferred to their next experiences just after the summer project period concluded.

These students travelled with the team to Mid-Ohio (see Figure 1.) and participated in the competition for the weekend of July 18, 2013. At the competition, they met Craig Vetter and the other challenge participants. As they were not motorcyclists, the more experienced students rode the motorcycles in competition. One motorcycle had stability issues and the other ran well. However, it had difficulty starting at the half way turnaround point in the competition, but resulted in 76 mpg compared to an unmodified motorcycle fuel mileage of 56 mpg. The author rode his unstreamlined electric motorcycle and won the electric class (could not finish the entire course) with a fuel cost of 2 cents per mile. The next year (summer of 2014), streamlined the author's electric motorcycle almost finished the course with a cost of 1.3 cents a mile. The REU students had a great time camping, bonding, competing, and working with motorcycle industry leaders.

The Virginia Tech Motorcycle Economy Challenge (VTMEC) team was the only university team participating. All other participants were professional engineers, machinists, and designers. This competition is an excellent opportunity for other universities to become involved as sustainability and fuel economy are important U.S. and global engineering challenges. Results and descriptions of the past several years of the Vetter Fuel Economy Challenges can be seen at http://craigvetter.com/ .

Figure 1. Photo of the VT MEC team at MidOhio Vetter Challenge Competition

Conclusions

Addressing Research Question 1. Can a researcher who is passionate about a particular project inspire others to join in, be engaged in and persist in a design project?

The answer to this research question, from the student responses to the question and final reflections is YES! Find a project you are passionate about and pursue it. Students will become interested and engaged and succeed. Following the MUSIC model is an excellent way to assure student engagement. Students can easily transfer an engaging experience with a project to their future endeavors.

Addressing Research Question 2: Can students of diverse backgrounds, but none of whom are mechanical engineers become engaged in a motorcycle fuel economy challenge design project? This diverse small group of REU students clearly became more confident, more interested, and more engaged in design, in saving fuel, in motorcycles, systems thinking, and team work issues as a result of this project.

Limitations

The sample size was very small. However, the diversity of the three participants and their extensive journals, leads the researcher to conclude that most students would gain value participating in this research project.

Future Directions

The author is currently working with a design team consisting of Industrial Design, Aerospace, Engineering Science and Mechanics, Mechanical, and Electrical engineering students to develop the next generation of streamliner motorcycle which can win the Vetter Fuel Economy Challenge.

Faculty mentors should choose a project that they are interested in pursuing and enroll others to come along for the ride. Choosing projects you are passionate about inspires students and facilitates them finding value working with you in the context of a class, extra-curricular design activity, or summer design research internship.

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The three REU students who participated in this project.

Craig Vetter for his generous contribution and support of our students.

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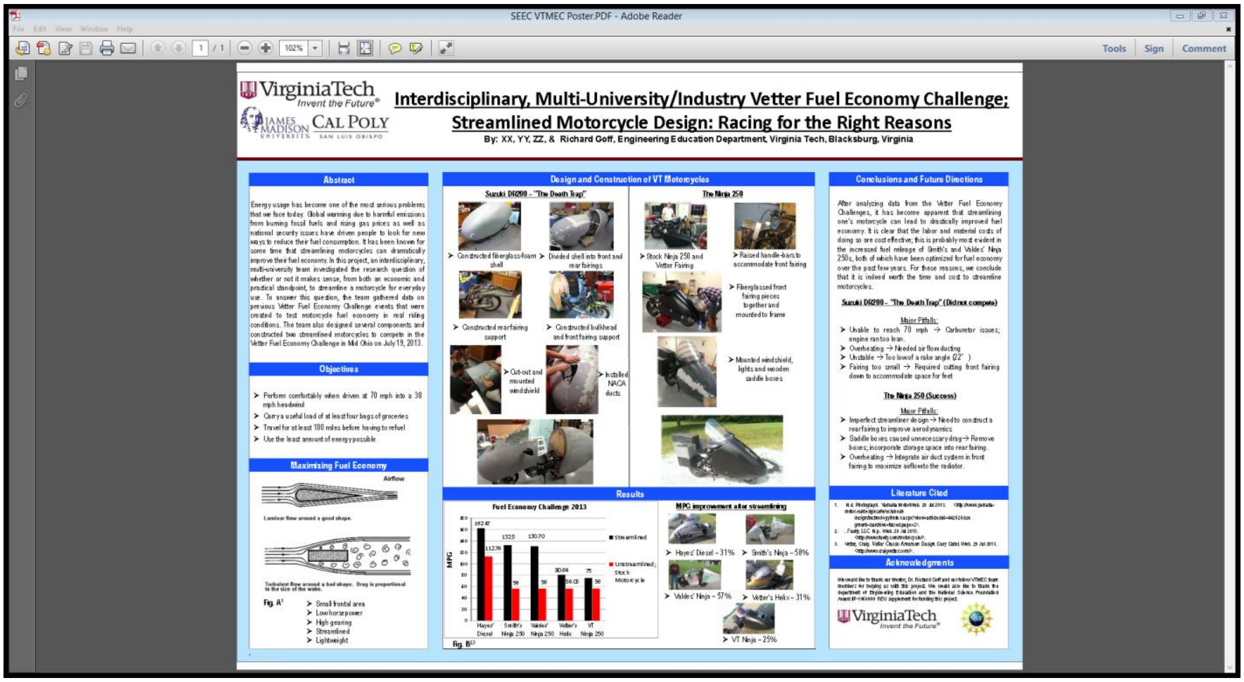
Appendix A:

The REU Students' Research Poster delivered at the Summer Research Symposium July 31, 2013 at the Inn at Virginia Tech, Blacksburg, VA.



Appendix B:

The REU Students' narrative reflections on the Vetter Fuel Economy Challenge project.

Student1, female sophomore general engineer at small east-coast university

Vetter Fuel Economy Challenge Motorcycle Research: My thoughts and the process

Before starting this summer's research project, I was not fully aware of what I was about to spend my whole summer on. Was I about to build a motorcycle from scratch? Do I actually need motorcycle knowledge? How is this motorcycle project related to engineering education? These questions were actually answered a lot sooner than I expected. After having the team's first meeting with Dr. Goff and first working in the Ware Lab, I realized I'm not going to be building a motorcycle from scratch, but building a streamliner for a motorcycle. I would be promoting Buckminster Fuller's saying of "doing more with less". I would be involved with Vetter's challenges on saving energy; a major problem in today's society. I would not need a high-level of motorcycle knowledge because I was learning along the way of this project, with the help of some individual online research on motorcycles and streamlining. I also realized that this project dealt with engineering education way more than I thought. The way to really learn is from experience and DOING something. I was learning about motorcycles and teaching what I learned to others, which was combining engineering and education. This motorcycle consisted of research, engineering, and education, which was the most relevant project for the SEEC group.

My initial thoughts before starting this SEEC project were consisted of me lacking total confidence. When I thought of the title "Critical Engineering Challenges", I figured I was going to be working on intense engineering challenges in today's society. I pictured myself working with a team of 3-4 other people on challenges that intelligent engineers are working on now. My confidence was not at an all-time high when I first heard about our challenge. I was a little nervous that I would show up unprepared to work on a motorcycle due to lack of knowledge and skill. However, I have had past experiences with working with my dad on car engines and building a tricycle in my engineering design class. I also was taught the concepts of design, such as concept generation and selection, where I have made a morphological matrix, pugh chart, and decision matrix. Since I had these design skills, it gave me a smidge of self-assurance that I can be an impact on the team's progress.

The first time we worked in the Ware Lab, we first learned about the bikes we were working on and where the project stood currently. We then had to brainstorm and come up with ideas on how to store the grocery bags on the Suzuki. It surprised me how quickly we went to work right away. I did not know if the leaders would trust [us] with cutting the fairings and drilling holes into it, but they did! It was good we went to work right away because we had a short amount of time before the competition. Also, we could forever brainstorm and plan, but we would not be able to see if our plans worked if we don't just do it!

In the middle of the project timeline, I gained more confidence on working on the motorcycle than initially. As the time went on, I was learning more about motorcycles and different types of fuel. I was also having lots of fun! I believe this project beats any other research project because I was gaining fun hands-on experience, while also making a difference. I felt very lucky to be a part of this team. Dr. Goff checked up on our team almost daily and kept in touch often. In the beginning of the project, I heard that advisors only meet with their research students about once a week, but this was not the case for our team. The close relationship between the team and Dr. Goff kept the project rolling and everyone on the same page.

As the project moved on, we would undergo minor challenges. A few challenges for the DR200: how to get the windshield on evenly, how to mount the back fairing evenly, how to store the grocery bags quickly, how to attach the front fairing leaving enough room for the driver, and how to cool the engine. The main issues were the rake level and the engine overheating. We should have left more time for possible failures. If we had left a couple more days to spare, then we could have possibly fixed these problems. A few challenges for the Ninja 250: how to store grocery bags, how to stabilize the front fairing, and how to streamline the back fairing. At the competition, Jake gave the Ninja 250 a test drive and figured out the engine was overheating due to lack of air. We all came together as a team to fix this last-minute problem and cut out an air-vent in the front fairing, which was the solution. Basically, we should have left more room in our design timeline for possible failures and for test drives.

The competition went really well, I thought. It is important to take note of the positives and negatives of the trip to better prepare for next year. The positives in this trip: we brought lots of supplies to Mid-Ohio, we brought many bikes to ride, we got extra reimbursement, we planned out each day the night before, our Ninja 250 never broke down during the challenge, and we worked together when there was a problem (Ninja 250 overheating). The negatives in this trip: our departure from the Ware Lab was delayed by 2 hours when everyone showed up late when we planned on packing at 10 and leaving at 2, we did not bring the NACA Duct tubes, we did not have clear communication between the whole group, we should have spent more time on the DR200 engine and carburetor, and we should have streamlined the front Ninja 250 grocery bag boxes. Of course if I were to do this next year, I would simply fix the negatives list. Overall, I am pleased with the hard work everyone, including myself, put into the project and the outcome of the challenge. Our Ninja 250 Streamliner increased by 19 MPG than a regular Ninja 250 stock bike, so that shows we succeeded with our streamliner!

After this project, I learned many things by participating with this team. I experienced interacting with an interdisciplinary team of different backgrounds and skill. I learned MUCH about motorcycles and how to get better fuel economy. Also, I realized how important it is that we need to stop using so much petroleum and come up with better, more efficient energy. I believe this project has greatly affected my future. I plan to get my motorcycle license and eventually get my own motorcycle. I want to learn how to fix motorcycles so if I were to have trouble with mine, I could fix it. Also, I plan to start a Baja Team and Motorcycle Fuel Economy Team at my University. I know some students and professors that should be interested in participating in this team. I thoroughly enjoyed working with my advisor, my team, and this project here at Virginia Tech!

Student2: male, senior Biology major – engineering minor at large east-coast University

Summer Research Reflection

When I first saw the SEEC project, "Critical Engineering Challenges", I thought that it would entail approaching engineering issues pertaining to improving the fuel economy of vehicles in *novel* and *unique* ways. I imagined being given a set of particular problems or issues with current engineering designs and asked to research ways to solve them in innovative ways. I did not know what to expect in terms of this particular project relating to education—however, I was open minded and prepared to engage myself in whatever the project encompassed. The major reasons why I applied for this research project, were because of my strong interest in interdisciplinary work, my desire to learn about new things, and because I wanted to gain experience in more "hands-on" research, in contrast to the more theoretical and abstract type of work that I had done in the past.

When I first began this project, I was a bit nervous about my lack of knowledge in engineering preventing me from bringing anything valuable to the table. Not only was I ignorant in many engineering principles (such as Dynamics, Statics, etc.), but I entered this project with essentially no knowledge about motorcycles. I was also a little worried that I would come off as annoying to some of the more experienced members of the team, due to the endless number of questions that I undoubtedly would be asking them. However, I was, on the other hand, confident in my ability to work well with the team, fully apply myself and to learn a great deal about whatever it was that I would be researching, despite my different skillset and background.

As far as the amount of interaction and mentoring that I expected from my faculty research advisor, I did not know what to expect. From my experience in research, mentors vary significantly in their styles and approach of conducting their research and interacting with their students.

At the beginning of the project, I second guessed almost every idea that I came up with and did not trust my judgment to do anything correctly or efficiently. I always ran whatever idea that I came up with by either David S. or Justin B. prior to acting on it, no matter how minor it seemed. About half-way into the research program I began to feel far more comfortable with the whole design process. After we had finished mounting the rear fairing on the Death Trap and constructing/mounting the bulkhead and shelving, I was proud of our work. However, we did run into a few snags before we got it right—it was pretty embarrassing when Dr. Goff saw our first attempt at mounting the rear fairing—our measurements were way off and the entire fairing was lopsided.

There were plenty of other snags that we ran into during this project as well, including making incorrect measurements for the Ninja's saddle boxes—

again, I felt pretty embarrassed to be working on such a project and not even being able to make wooden boxes correctly. However, with every mistake that we made, we learned something. In the previous two mistakes that I've mentioned, the thing we learned (which one would think to be obvious) was to make careful measurements and plans prior to jumping into the cutting, drilling etc. processes.

I liked the fact that neither Dr. Goff nor the more experienced team members intervened with some of the more novice mistakes that [we] made in our designs and construction techniques. At the time, I probably would have welcomed their input with open arms, however, I would not have learned a lesson that would sink in if I had not actually made the mistake and seen the consequences/reasoning for it later on. For example, I had believed that flat bar would be sturdy enough to support the rear fairing because it was very light. I later learned that we should have used either L-bracket or square bar support beams, because the flat bar did not restrict horizontal bending/movement of the fairing, and resulted in a pretty shaky attachment. [One of the more experienced students] told me that he foresaw this, but allowed us to proceed with our design anyway.

While we were in Ohio, I learned so many things about how to improve our designs by looking at some of the professionals' bikes, such as Alan Smith and Vic Valdes, and also from talking with them. The experience that I gained from Ohio makes me want to continue to participate in the VTMEC team next year. I feel that if I don't, then a lot of the knowledge that I have gained about streamliner/motorcycle design would go to waste. I also have an urge to build and design something better next year, and I feel extremely confident that we would be able to—especially with [the same leader] leading the team again.

All in all, I had a tremendous time with this research project—I can say with confidence that it was far more enjoyable than my previous two years of research in the BSE and Chemistry departments.

Student3: male, sophomore Bio Medical Engineering student at small west-coast university

A story for engagement: After working on the motorcycle and looking back at what the team can do to improve their collective performance, we as a team agreed that many problems we encountered were a result of system neglect.

Last Quarter, I took a System's Engineering class (IME 510, a graduate level course) so that I could learn about what kind of tools Systems Engineers use when designing a system. I would refer to my experiences working on the Vetter bikes all throughout the quarter for the class.

There are various reasons why I took the course.

First, I truly enjoy learning about big picture systems, I would go as far to say that I have passion for learning about and using systems analysis like systems thinking and systems engineering.

I would not have recognized my knack for seeing big pictures without working on this project. Most engineering classes I have encountered focus on reducing, isolating, and analyzing. The Vetter bike gave me an opportunity to experience big picture things.

Second, I was motivated by failure to take the Systems Engineering course. Failure in the sense that I wanted to perform better on the next design project I would work on so I knew what to do to enrich my classroom experience with project experience. I made a mistake in the past and wanted to improve on that mistake. It was nice to have a class that I could relate to a project that I had encountered in life.

Working on the Vetter bike did improve my engagement in my Systems Engineering class because I was able to relate the theoretical knowledge to my experiences. I guess +1 points for constructivism theory too.

I think it is also possible for undergraduates to take courses that compliment projects that they are working on outside of the classroom experience. Almost like a year-long lab.

I would also agree with you, based on my experience, that current challenges help with student engagement. There were many good discussions in my Systems Engineering class that involved current events like the typhoon in the Philippines, Obamacare (PPACA), global warming, predator drones, the new stealth jet, Amazon's Octacopters. These discussions also allowed students, like myself, to learn about the world and not stay trapped in their college bubble.

In the design team I am working on now, we get about a regular crowd of 20-28 people to show up. I can't say why it's about 20-28 people, it could be me and the individual. But when finals week begins to roll around, I plan to not have a meeting because, from past experiences, students want to study for their exams.

Daniel Pink wrote a book about intrinsic motivation and extrinsic motivation titled DRIVE. In it he talks about "hygiene needs" which he explained to be the minimum threshold needed to "survive". In a student's perception, surviving can be equated to passing a class. What this could imply is that students see their classes as the "hygiene needs". There's almost a hierarchy in time management. "Of course, classes come first." So when the decision between extracurricular design team versus class comes up, it's an easy choice. Furthermore, many classes are structured for extrinsically motivated students with the use of grades. Design teams require creativity and a large body of research opposes the use of extrinsic motivators if you want a creative culture.

There is a drop in design team attendance during midterm week and before finals week.

And I, as a co-leader, would even cancel meetings in anticipation of low attendance.

Students are often distracted by classwork during meetings too. So if you have a big midterm tomorrow, your mind would be focused on studying on that midterm. An individual can be physically present, but mentally checked out which makes them useless to me since I want the student for their mental contributions and creativity. Distractions don't help.

In context of working on the bike over summer, I had no problem coming in everyday to work on the motorcycle...or at least when the weather isn't super thunderous. There was one time where I think we cancelled meeting at the Ware Lab because of the flash flood. However, I had no major obligations to attend other than maybe Dr. Vess's lectures, and since we were not "getting a grade" for attending Dr. Vess's lectures, if I wasn't interested in attending the lecture, I wouldn't go and just stay to work on the bike.

There are definitely times where I would be in the boring lecture mentally checked out thinking about what we needed to accomplish for the bike for later that day or itching to make the PPT for the cortisol sensor device [another project this student worked on] simply because I was more interested and more engaged by those projects. Heck, teachers might be competing for student engagement between lecture topics.

In one class I helped TA for this past quarter; part of the student's grade was on participation. Students would be presented on the PPT a question to submit using an iClicker, points were awarded for participation. One particular question was more difficult. What students did to *game the system* was to submit a guessed answer, then proceed to solve for the correct answer after the points were secured. Another "hygiene threshold needs" example.

So to condense my thoughts, tests/evaluative metrics are correlated (and maybe even causes) reduced retention in and participation in extra-curricular design team activities. Bit of common sense, but if a student has a midterm next period and their sitting in a lecture, that student too can be physically present and mentally checked out, engagement is a mental state not a physical state.

Another thing I find to be interesting is how [the more experienced students] worked on the motorcycle without any obvious extrinsic motivators (at least to me). Furthermore, the rest of the competition (like Alan Smith) work on motorcycles without any obvious motivators (to me at least) other than to design a better motorcycle. I think that this would support the "Greater Sense of Purpose" idea found in creativity literature.

---The End ---