Design and Development of Compressed Air Controller Tire Inflation System (CACTIS) Using a System Engineering Approach and Elements of the KEEN Framework

Prof. John M. Santiago Jr, Colorado Technical University

Professor John Santiago has been a technical engineer, manager, and executive with more than 26 years of leadership positions in technical program management, acquisition development and operation research support while in the United States Air Force. He currently has over 18 years of teaching experience at the university level and taught over 40 different graduate and undergraduate courses in electrical engineering, systems engineering, physics and mathematics. He has over 30 published papers and/or technical presentations while spearheading over 40 international scientific and engineering conferences/workshops as a steering committee member while assigned in Europe. Professor Santiago has experience in many engineering disciplines and missions including: control and modeling of large flexible space structures, communications system, electro-optics, high-energy lasers, missile seekers/sensors for precision guided munitions, image processing/recognition, information technologies, space, air and missile warning, missile defense, and homeland defense.

His interests includes: interactive multimedia for e-books, interactive video learning, and 3D/2D animation. Professor Santiago recently published a book entitled, "Circuit Analysis for Dummies" in 2013 after being discovered on YouTube. Professor Santiago received several teaching awards from the United States Air Force Academy and CTU. In 2015, he was awarded CTU’s Faculty of the Year for Teaching Innovations. Professor Santiago has been a 12-time invited speaker in celebration of Asian-Pacific American Heritage Month giving multi-media presentations on leadership, diversity and opportunity at various military installations in Colorado and Wyoming.

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Introduction

The key contribution is that two frameworks are described in this paper for an undergraduate capstone course. The capstone project is the Compressed Air Controller Tire Inflation System (C.A.C.T.I.S.). The project’s intent is to design a system reducing the amount of time and effort involved in achieving proper vehicle tire inflation. The CACTIS uses a convenient touch screen display and a rugged air distribution box such that multiple tires can be inflated simultaneously.

This project serves as another example in an attempt by the Colorado Technical University (CTU), College of Engineering (CoE) to help students build up their entrepreneurial mindset. The approach was successfully implemented to encourage not only a system engineering approach/thinking to augment their electrical engineering skillsets but also an entrepreneurial mindset for project ideas that have increased relevance to the marketplace.

The integration stresses not only going from extensive technical detail but follow the design and development process using a system engineering approach. With the system engineering approach, the COE encouraged students to establish a need and doing some market analysis but extended this approach to provide an entrepreneurial framework to provide further guidance and direction for students to generate innovative ideas for their projects.

Given CoE’s limited experience in entrepreneurial-minded learning (EML), CoE believes this teaching approach proved useful tool to engage students in coming up with relevant ideas for projects and classroom activities that create market value. CoE also believes that the combination of embedded EML ([1], [2], [3], [4]) activities and the system engineering process provide a rewarding learning experience for students. CoE also believes that the system thinking found in the entrepreneurial concept aligns well with the system engineering approach for the last several years in making project ideas become reality ([5], [6], [7], [8], [9]).

Accreditation Board for Engineering and Technology (ABET) Question for the Future

In late 2017, CoE successfully received an Accreditation Board for Engineering and Technology (ABET) re-accreditation for its Bachelor of Science in Electrical Engineering and Bachelor of Science in Computer Engineering for six years with no interim reports. According to the University Dean for the College of Engineering, this is the best ABET accreditation that an engineering college can receive. As a result of the visit, CoE also intends to address the ABET
question, paraphrased as: where do you see your graduates three to five years beyond graduation?

To help address the above ABET question, CoE’s long-term vision is to graduate students who have visionary leadership to create value and innovative solutions not only for themselves but also for their employers and for the benefit of society.

Although CoE emphasized to students that capstone projects must fill a customer need, a useful framework is desired to give students more direction and structure so that their capstone projects or senior design projects can be expanded to have more relevant value for the marketplace. The intent of the entrepreneurial approach is not to graduate students who will start their own businesses (although some of the engineering alumni have already done so), but to motivate and create value for themselves and their employer that benefits society by developing their entrepreneurial mindset [1], [2], [3], [4].

Since CoE does not offer any entrepreneurial courses and system engineering courses due to the crowded undergraduate curriculum, CoE does not require students to take these courses. However, entrepreneurial concepts were integrated in classroom activities in several existing engineering courses. Another reason is that each author who are full-time faculty have taught 35-plus courses in electrical engineering, computer engineering, system engineering, mathematics and physics at the University. This advantage allows CoE to carefully integrate entrepreneurial activities in a number of courses throughout the engineering curriculum to help students build an entrepreneurial mindset.

CoE has embedded entrepreneurial classroom activities in several undergraduate courses [1], [2], [3], [4]. By incorporating EML in different course sequences such as circuits, electronic design, and communication sequences, students will have the opportunity to develop and build up their entrepreneurial mindset before taking the capstone courses.

Based on the authors’ experience, some students have a hard time coming up with a project that meets the requirements for the capstone course. The CoE attempted to provide the student with more structure by using the KEEN framework to create relevant capstone projects, along with the system engineering approach using the VEE-model [5], [6] [7], [8], [9]. This combination of models provided a visual framework to guide students in completing their innovative project ideas. By having students provide weekly deliverables based on the System Engineering V-Model, it gave them more structure for the student to systematically complete the project. In other words, CoE wanted to provide students with a transformational experience.

**Capstone Course Description**

The capstone design is a two-course, sequence for students to integrate into product design teams comprising engineering, engineering technology and logistics. Each team is given a series of conceptual problems to be solved by the creation of a new product. This practicum exposes the team to current product development methods and issues beyond functionality such as human factors, safety, engineering, economics, maintenance and manufacturing. Students completing
EE490 are expected to take the follow-on course (EE491) in the next term. The EE491 course is the completion of the design sequence.

The capstone course offers the student the opportunity to integrate skills developed throughout the undergraduate program and practice system engineering thinking by completing a project that focuses on a current issue or need requiring an engineering solution. Below are the general and specific objectives and requirements for the project.

**General Objectives:**

1. Work effectively in a team environment.
2. Design, prototype and evaluate a new product of your choosing.
3. Develop an effective procedure for the design of a system to meet customers’ needs.
4. Extract system specifications from a functional description and develop accurate testing procedures to critically evaluate performance.
5. Evaluate performance/cost trade-offs and defend engineering decisions in the design of a customer-based system.
6. Account for human and societal constraints in the design of a specified system.
7. Demonstrate effective written and oral communication skills in a team product design.

**Specific Student Objectives:**

1. Students will generate a list of performance criteria from a system description.
2. Students will convert performance criteria to specifications.
3. Students will identify tools appropriate to the design of a system.
4. Students will develop a total plan to design and demonstrate a prototype of a specified system.
5. Students will independently acquire a familiarity with any tools necessary to the completion of the team project.
6. Students will generate a complete investigative report, give a professional presentation and provide a professional demonstration explaining their work.

The Project must include:

1. A proposal with a description of a new or improved product.
2. Specifications (including numerical values) of your project.
3. A complete testing plan (with numbers for passing scores) enabling the reader to recreate the test procedure and verify results.
4. A plan for implementing your project to include a budget with a list of all elements required to construct a prototype, complete with vendor information and cost, and a man-hour cost of the time required to complete the design and demonstrate the prototype.
5. Design tradeoffs and considerations.
6. All appropriate electrical and mechanical drawings and software.
7. Test results for your project.
8. Analysis of your success measured against the performance specifications and need.

**Instructional Approach – Methods and Procedures**

The course consists of class discussions and individual/team requirements designed to reinforce the material throughout the quarter and your college tenure. Students should come prepared to discuss the elements of the design process, including their assignments / project(s), in class and be prepared to contribute to team activities in / out of class to complete that / those assigned the project(s). Any exercises or other work must be done in a complete manner, which includes defining problems/processes, providing illustrations and including a complete explanation of the process and solution(s) used.

**Measuring Learner Achievement.** The course intends to bring together most topics that students have learned in seeking their degree. It will include two primary components: a) the design process; b) productive team behaviors. Grades are based on demonstrated contribution to the completion of the interim and final project(s), including your individual contribution and the final report / presentation. The final report must include all specifications, testing procedures, data collected, design decisions and performance of the final project in comparison to the initial specifications for the product. It will not be accepted after the last scheduled class. The parts list and budget are due with this report.

Since this course requires students to work effectively in teams, student participation/contribution is considered vital in the learning process. Thus, the participation/contribution grade for this course, and for the follow-on course, will be determined by two factors multiplied together as shown in the tables below. The first factor is participation. The second factor is technical content and effort. Participation is based upon engagement with the team, not merely physical presence, as judged by the instructor and peer evals. Each student is expected to contribute significantly to class discussions and the team’s overall success. The course will be graded based on points assessed as follows:

**First Quarter**

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participation/Contribution</td>
<td>350</td>
</tr>
<tr>
<td>Individual Assignments</td>
<td>250</td>
</tr>
<tr>
<td>Final Project</td>
<td>400</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1000</strong></td>
</tr>
</tbody>
</table>
Students must take an ill-defined problem and use a system engineering approach to implement a proof-of-concept solution. A detailed description of the weekly deliverables is given elsewhere and will not be described here due to space limitations [5], [6] [7], [8], [9]. The Critical Design Review (CDR) rubric was also developed to balance the course weighting between system-level thinking fostered by weekly deliverables and acquired technical skillsets from the BSEE program. The weekly deliverables are guided by the Vee Model [5], [6] [7], [8], [9].

Electrical and computer engineering students, especially those who are international students, may be unfamiliar with the system engineering process. To take this into account, the weighting scheme and weekly deliverables, allows the student to learn about the system engineering process iteratively during the 11-week course without heavily penalizing the students during the first-half of the course.
The Team Leader/Coordinator include the following: confirm participation at the work sessions, report individual student responsibilities assigned and contributions made, consolidate and report overall team progress and problems/solutions each week. If circumstances preclude an individual student from attending class, each student are still responsible for the timely submission of their team’s man-hour and progress reports for complying with course requirements.

Two resumes are required of each student at the end of week two. The first is to be shared with other members of your team and should include the contribution that they can make to the final project/report. Each student should, however, seek to learn a new skill throughout the course. The second resume is for the instructor only; it will be reviewed and returned to the student with suggestions. Students may use the same resume for both purposes. This will be included as part of their participation/contribution grade.

Literature Review of Entrepreneurial Minded Learning (EML) in Engineering Education

Kern Engineering Entrepreneurship Network (KEEN) lists the following title at their website: “Engineers with an Entrepreneurial Mindset Transform the World”. Engineers equipped with an entrepreneurial mindset will understand the bigger picture, recognize opportunities, evaluate markets, and learn from mistakes to create value for themselves, for their employers and for society [10].

In the past, a curriculum of entrepreneurship education was most likely be found in business schools. With the rapid changes in the world and the globalization in the engineering area, more higher education institutions worldwide saw the benefits of adopting the entrepreneurial skills into their engineering curriculum. According to Byers, “…beyond technical expertise, today’s engineers must possess an entrepreneurial mindset in order to be the innovators of tomorrow.” [11]

More and more universities in US are trying to incorporate EML into students’ learning. Some universities have their own entrepreneurship center. For example, MIT has several departments, labs, centers, and over 40 student clubs and initiatives to foster entrepreneurship and innovation. Their educational efforts in this area resulted in having an impressive impact at local, regional, and global levels. “A 2015 report suggested that 30,000 companies founded by MIT alumni were active as of 2014, employing 4.6 million people and producing annual revenues of $1.9 trillion, equivalent to the world’s 10th largest economy.” [12] In addition, there is an entrepreneurship center in the Stanford’s School of Engineering. The Stanford Technology Ventures Program (STVP) targets to accelerate entrepreneurship education at their university and around the world [13]. Santa Clara University has an aggressive extracurricular program complements elements of the EML program. Each quarter, they have activities include seminars, lunch with an entrepreneur events, business and law primer presentations. One highlight of this program is an EML challenge in which teams of students develop ideas based on opportunities they identify in order to validate a market and assess the creation of value. The winner is often offered a “contract” to produce the product for university purposes [14].
Some schools integrated EML in their course projects. The authors of the paper “Entrepreneurial Mindset and the University Curriculum [15]” applied technology based dynamic live case study with color graphics animated computer simulation in their entrepreneurial course. The live case study involves multiple student visits to existing companies. Students construct a company supply chain under the professor’s guidance. Bilen, et al suggested to provide students with multiple exposures to what it means to have an entrepreneurial mindset [16]. Chasaki described a seven-week mini-project “Cyber Crime Scene Investigation” they reserved in their new course for EML activity [17]. The author found that freshman year is a great time to introduce EML concepts. EML objectives are introduced at the beginning of the mini-project. Students form two groups “hackers” and the “defenders”, and rotate roles during the term. Students need to understand what value their business idea brings to the table, and how it fits customer’s need. Wang introduced how they incorporated entrepreneurial mindset materials in a 10-week open-ended design project in a first-year Introduction to Engineering Course at Arizona State University. Students list pain points that bother themselves or others, and select their design project. They used a decision matrix with criteria “Societal Importance, General Interest, Market Need, Engineering Related Problem, # of Current Solutions, and Solution Benefit” to help students identify opportunity [18].

Several universities developed detailed four-year plans to implement EML in their curriculum. Welker, et, al [19]summarized the classes with EML in the four-year civil engineering curriculum at Villanova University. University of New Haven created short, self-paced, e-learning modules into courses spanning all four years of all engineering and computer science programs. They used a flipped classroom instructional model to integrate the modules into courses [20].

Schools applied different technologies when adopting EML. Tabrizi [21] fostered an entrepreneurial mindset in “digital systems” class through a jigsaw-puzzle model. In each lab assignment. They provide students with some components or puzzle pieces as well as the user guide of a digital system. The main EML objectives are to “stimulate students’ curiosity, instill a feeling of value creation in students, and encourage teamwork, collaboration, and connection.” Hoffman [22] introduced how they applied an entrepreneurial approach to a senior design course. In order to simulate the workplace, the entire design class functions as a startup company addressing an instructor generated problem for development of a new product. The University of Florida College of Engineering offers an entrepreneurship course which mimics the real-world experiences of enterprise formation and growth in an academic environment [23].

Universities outside US also noticed the importance of building an entrepreneurial mindset in their higher education systems. In a paper from Romania, the author mentioned the worry about the country’s scores in terms of innovation capability. They are trying to find solutions from promoting technological entrepreneurship through sustainable engineering education. The paper summarized the top 10 technical and personal qualities of an ideal entrepreneurial engineer. These 10 qualities are: “Analytical skills, Rigor, Communication skills, Creativity, Logical skills, Technical knowledge, Economic knowledge, Managerial knowledge, Reliability and Integrity” [24]. There has been a growing concern in Malaysia that the technical students prefer to become
job seekers and to be employed rather than job creators. The ministry of Education aspires to instill an entrepreneurial mindset throughout Malaysia’s higher education system. [25].

Entrepreneurial Minded Learning using the KEEN Framework

In recent years, more universities and faculty are engaged in encompassing entrepreneurial minded learning (EML) into the engineering curriculum. Even though not every student will become an entrepreneur after they graduate, having an entrepreneurial mindset will help them become creative and valuable engineers. “EML is not about start-ups, it is about thinking creatively and creating value for society” [19]. However, it is not easy for students to build up entrepreneurial skills within one course or a couple of courses in an already crowded engineering program. The College of Engineering (CoE) decided to embed entrepreneurial skills in engineering learning activities for a number of courses throughout the program curriculum, requiring an efficient and integrated process. By incorporating EML in different course sequences and capstone courses such as circuits, electronic design, and communication sequences, students will have the opportunity to develop and build up their entrepreneurial mindset.

The three Cs: Curiosity, Connections, and Creating Value [26]’’ found in the KEEN framework are added as course outcomes. CoE included EML activities into the existing problem-based learning (PBL) laboratory projects. For example, the projects help students investigate the market and assess policy and regulatory issues.

The authors of this paper attended an “Innovating Curriculum with Entrepreneurial (ICE)” Workshop on 9-12 August 2017 in Denver, CO. The workshop was held in collaboration with the Kern Family Foundation and Lawrence Technological University. The main goal of the workshop is to promote student engagement in “the three Cs: Curiosity, Connections, and Creating Value” [26]. Kern Engineering Entrepreneurship Network (KEEN) published the framework at their website as shown in Figure 1. The entrepreneurial mindset plus engineering skillset has been used to develop educational outcomes for several engineering courses [1] [2].
Following the experience from the ICE workshop, the authors began to embed their proposed EML modules in several courses for strategic planning purposes starting in September 2017 for the Fall 2017 quarter.

A few examples of EML classroom activities presented at the workshop and implemented in a number of courses described are described in Appendix A.

**System Thinking using the Systems Engineering Process and the Vee Model [28] [29] [30]**

Found in the KEEN educational outcomes is system thinking for ambiguous problems which aligns well with CoE experience in using the System Engineering Concept during the past several years. CoE used a system engineering approach to promote system thinking. The system engineering approach provides useful framework to bring student’s entrepreneurial ideas and so their system solution can become reality. The system engineering concepts incorporates many of the technical KEEN educational outcomes.

The perceived benefits of implementing systems thinking and system engineering concepts include:

- Shift students’ focus from technology-detailed solution to what system must do (e.g. requirements)
- SE helps with planning, organizing, executing and evaluating a project
- SE provides structure through weekly deliverables to guide students throughout a project from start to finish
- The heavy military presence within the local area values systems engineering to meet their defense requirements

The intent of this approach is to help students focus on what the system must do and less on the how the technical solution should be implemented. The Vee Model is one model to describe the system engineering process and will help students bring their system project into being or bringing their ideas to become reality.

Figure 4 depicts the systems engineering Vee-Model from a testing perspective shown in in the left portion of Figure 4 and from an architecture perspective shown of the right portion [28].

In Figure 4, the Vee-Model looks at the system, subsystem and component level of testing. The model starts with an identification of user needs on the upper left and ends with a fully system-level acceptance testing and evaluation on the upper right. Advancing down the left side of the Vee-Model is the decomposition of the system into subsystems, and then into components. The technical activities involve defining and resolving the system architecture to mature the design (or definition) of the system with increased fidelity.

The right side of the Vee-model in Figure 4 involves the integration of system components with testing, moving upward to the subsystem and finally the system level [28]. The testing process flows up and to the right as higher levels of subsystems are verified. Finally, the system level is validated through user acceptance testing and evaluation. The user acceptance test plan insures overall specifications are met while testing is performed at all-levels: component, subsystem and system level. The test plan verifies and validates the entire system in preparation for user acceptance.

The ‘Grand Design’ and architecture perspective is shown in Figure 4 [30]. The definition of the system begins with ‘what’ functions the solution must perform to define an initial functional architecture. These functions are collected and allocated to a subsystem which further defines the functional architecture. Defining the functional architecture increases the system fidelity and definition during the design stage.

The subsystem functions are further decomposed to identify (or design) physical components (hardware/software) which defines the lowest physical architecture. At this point, the physical architecture describes ‘how’ the system solution is implemented. Moving up to the upper right of the Vee Model, components are tested and integrated, then subsystems are tested and integrated and up to the full system level. The result is an enterprise architecture, deployable for intended stakeholders.

The activities or deliverables and schedule was based on the systems engineering approach for each week using the Vee-Model. Students are encouraged and advised several weeks before the capstone quarter to begin thinking about their project so they are well-prepared to start quickly. The student must design a new product, and either demonstrate how it behaves or model its performance. Several self-motivated and talented students followed this advice in the past and successfully completed technically challenging projects while following the systems engineering process.
Teamwork in KEEN Framework

In the KEEN framework, one of the educational outcomes and applicable for this project concerns collaboration where it describes the following educational outcomes:

- **FORM** and **WORK** in Teams
- **UNDERSTAND** the motivation and perspectives in others

This aligns well with CoE’s experience in accomplishing this through student peer evaluations and rotation of the project leader. An initial and final evaluation is conducted for each quarter in this two-course capstone project. Due to space limitations, only the second quarter results of student comments of their peer evaluation is shown. Table 1 shows the peer evaluation comments for the second quarter. Feedback allowed the understanding of the motivations and perspectives of other team members.

Table 3 shows the Peer Evaluation Scores. Based on these results of Table 3, one student (Student 2) is extremely engaged with the project and the team very satisfied with the support. The student felt that he could have gotten more support.

<table>
<thead>
<tr>
<th>Evaluation Item</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Support</td>
<td>Focus was on moving the project forward and continuing development despite setbacks.</td>
</tr>
<tr>
<td></td>
<td>Effective problem solver, and a great leader to work with. Leads team by example.</td>
</tr>
<tr>
<td></td>
<td>Need to focus more on the troubleshooting process and offering solutions</td>
</tr>
<tr>
<td></td>
<td>A great team player. Works effectively with all the team members for the betterment of the project. His experience with space foundation had a lot of input into our project</td>
</tr>
<tr>
<td>TEAM Contribution</td>
<td>Contributed towards development of product and design report</td>
</tr>
<tr>
<td></td>
<td>Figured out most of the psi sensor coding and the screen. Without Student 2, I don't think we would have gotten so far on the project.</td>
</tr>
<tr>
<td></td>
<td>Worked on the screen layout and debugging for the coding.</td>
</tr>
<tr>
<td></td>
<td>Contributed in the programming of the psi sensor. His experience with IEEE came in hand for solving the problems we had on our project</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>Referenced numerous outside sources to overcome build issues</td>
</tr>
<tr>
<td></td>
<td>Most of the positive effective contributions came from Student 2. Helped throughout the process with new ways to figuring out stuff that team had difficulties on.</td>
</tr>
<tr>
<td></td>
<td>Work on seeking outside sources when issues are encountered; this will allow for more creative and helpful solutions to problems</td>
</tr>
<tr>
<td></td>
<td>Knew the responsibility as a team member and work effectively to fix the problems.</td>
</tr>
<tr>
<td></td>
<td>Creative and very effective on gathering resources, when working on problem solving.</td>
</tr>
<tr>
<td>Communication</td>
<td>Maintained communication throughout as to what changes were being made</td>
</tr>
<tr>
<td></td>
<td>Responds on effectively on time. will clear intent</td>
</tr>
<tr>
<td></td>
<td>Always communicated on time, and worked effectively with team's progress.</td>
</tr>
<tr>
<td></td>
<td>Reminds the tasks for the week, which keeps us in sync within the team to work on the progress of the project</td>
</tr>
</tbody>
</table>

Table 1. Comments from Final Peer Evaluation for 2nd Quarter.
Evaluator | Evaluate | Time Management | Contributions | Contribution to Workload | Organization of Materials | Knowledge Gain | Leadership and Teamwork
--- | --- | --- | --- | --- | --- | --- | ---
Student 1 | Student 2 | 5 | 10 | 10 | 10 | 10 | 5
Student 2 | Student 2 | 3 | 9 | 9 | 8 | 10 | 4
Student 3 | Student 2 | 5 | 10 | 10 | 10 | 10 | 5
Student 1 | Student 3 | 2 | 5 | 5 | 5 | 5 | 3
Student 2 | Student 3 | 3 | 7 | 6 | 6 | 8 | 4
Student 3 | Student 3 | 5 | 10 | 10 | 10 | 10 | 5
Student 1 | Student 1 | 4 | 9 | 9 | 10 | 9 | 4
Student 2 | Student 1 | 4 | 8 | 9 | 9 | 9 | 4
Student 3 | Student 1 | 5 | 10 | 10 | 10 | 10 | 5

Table 2. Peer Evaluation Scores

Tables shows the survey results for rotation of team leadership. Table 2 shows that the students like the rotation of team lead since it provided a perspective of the team leader’s role was. Student 1 believes he was doing most of the work based on conversations in class. However, student 3 liked the team but did not seem to be a major contributor to the technical solution but was supportive and contributed in the non-technical areas in completing and presenting the project based on instructor observations as well.

Question | Feedback | Comments
--- | --- | ---
Do you like the team lead role rotation method used in the two-course sequence? | 3 – Strongly Agree | • This helps all team members understand the duties of a leader. • Gives an opportunity to all the team members to work as a lead. Which helps the group in solving the problems of non-communication
The team lead rotation method helped you improve the team lead skills. | 2 – Strongly Agree, 1 - Agree | • Responsibility is the key, when it comes to group projects. Lead rotation gives each team member a chance to demonstrate and improve
The team lead rotation method helped you improve your team skills as a team member. | 2 – Strongly Agree, 1 - Agree | • Yes. Effectively, because you got a chance to work as a leader and you know for sure. what is expected of you.

Table 3. Survey on Rotation of Team Lead

The University’s Net Promotor Score (NPS) Survey, shown in Tables 4 and 5, were used for end-of-course surveys. There were only two comments from the surveys. In general, the recorded scores were overall positive for the instructor, course and degree program.
### General Product Description and Capabilities

**Product Description.** The Compressed Air Controller Tire Inflation System (C.A.C.T.I.S.), is designed to reduce the amount of time and effort involved in achieving proper vehicle tire inflation. The CACTIS uses a convenient touch screen display and a rugged air distribution box.
The system is designed for use with air pressure that does not exceed 150 PSI and will automatically shut off the compressor when pressure is above 145 PSI to prevent a compressed air tank rupture. Multiple tires can be inflated simultaneously, tire size, compressed air tank volume, and compressor may limit the system. It is recommended that this system is installed by a CACTIS authorized dealer to ensure proper setup for each vehicle.

The CACTIS is designed such that two tires should be controlled by Port A, two tires by Port B, and an Aux Port is available for the use of air tools, load leveling air bags, or to supply air to a trailer.

**Capabilities.** The CACTIS is capable of controlling air flow to three separate ports through the use of the in-cab controller. While the CACTIS is capable of operating at 150 PSI, the onboard air compressor on the vehicle may limit that to a lower pressure. The Aux Port is the only port that has the MAX option, this will apply the maximum pressure the onboard air system can achieve to the Aux Port for using external air tool. While Port A and Port B may be operated simultaneously, the Aux Port will only run if Port A and B are inactive.

The CACTIS presets, can be used for add time reduction, allowing the user to pre-program set pressures for Port A, Port B, and Aux Port (When not using MAX air function).

The CACTIS air distribution box (ADB) has a rugged design to withstand the abuse of off-road, ranch, or fleet use. The in-cab controller features a convenient colored touch screen, while the system is water resistant, it is not water proof and should never be submerged in water.

The system is designed to operate at 12 Volts Direct Current, however can operate safely within a range of 11.45Vdc up to 14.5 Vdc, in order to be usable with a low battery or while the vehicle is running and charging the battery.

**Detailed Design and Development Considerations of the CACTIS**

Some of the KEEN educational skills include: determine design requirements, perform technical design, analyze solutions, create a prototype and validate functions. These skills are aligned with the authors intent of the design process for the course as well as being aligned with the Vee-Model. Specifically, the intent is to demonstrate:

‘the entrepreneurial mindset through KEEN’s 3Cs (Curiosity, Connections, and Creating Value) coupled with engineering thought and action’. In addition, CoE’s use of the Vee-Model to provide more a methodical design process for the student while using KEEN’s outcome to ‘express through collaboration and communication and founded on character.’

The intent of the project is to focus more on practicing the electrical and system engineering skillset coupled with their entrepreneurial mindset than producing the actual product since completion of this project is over two 11-week quarters. Fortunately, the adult team members, consisting of two military veterans and one active-duty service member, successfully produced the product described below. While highlighting some aspects from the KEEN framework, most
of the text narrative were extracted from a number of student deliverables, based on the system engineering Vee-Model, for this project.

**Problem Statement and KEEN’s outcome demonstrate constant curiosity about our changing world.** Across the globe, vehicles are being used off-road on rough terrain for the purposes of work, utility and recreation. When vehicles go off-road, they should reduce the air pressure in their tires, as this results in better traction, increased maneuverability, a smoother ride, and less chance of tire damage [31]. Often, the terrain demands tire pressure changes of twenty PSI or more. This results in even longer times adjusting tire pressures both before and after the vehicle goes off-road.

Bigger tires and lower pressures can push inflation and deflation times to 20 or more minutes for all four tires, totaling nearly an hour if setup times are included [32] (Under Pressure, 2011). Current on-board equipment available to consumers allows for transportation of an air tank and compressor to alleviate the need to find a gas station or other air supply as a source to refill tires. These systems allow a user to change the pressure in their tires, though the system is far from intuitive, and requires constant monitoring. Based on first-hand research¹, these systems lack many features and are easily recreated by consumers, which results in less-than-stellar sales.

**Needs Analysis for KEEN’s applying creative thinking to ambiguous thinking and system thinking to a complex problem and KEEN’s connections to integrate information from many sources to gain insight.** A need analysis for the Compressed Air Controller Tire Inflation System (CACTIS) was conducted by the project team. The team conducted first-hand research in several prospective markets, as well as utilizing available electronic data to determine the need for the product. The potential markets considered are off-road vehicles, ranch/farm vehicles, utility company vehicles and other fleet vehicles. The product will be used on both recreational as well as professional vehicles.

The need for the product became apparent when presenting the idea to ranchers located in Colorado, Montana, North Dakota and Wyoming. The Parker and Garfield ranches located near Ryegate, Montana, expressed specific interest in the ability of the CACTIS to select different set points for front and rear tires. Rear tires need to be fully inflated while the truck is loaded, but require to be manually lowered when the truck is empty to maintain traction in difficult terrain. The CACTIS would allow quick, nearly-automatic performance of the task, allowing ranchers to wait inside of their vehicle since manual monitoring is no longer necessary.

The DeSaye ranch in North Dakota expressed interest in the CACTIS for similar reasons, in addition to wanting to use the system to inflate ride-leveling airbags on older truck and trailers. With the designed connection points in each wheel well, in addition to an auxiliary port, the CACTIS would be able to meet this demand. Local off-road shops, to include Predator 4 Wheel Drive, R & R Off-Road, and Tanner Off-Road, all reinforced the demand for the product, stating that while similar systems have been attempted, nothing is currently available that have the same capabilities as the CACTIS.

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¹ First-hand research of several different off-road shops, ranches, construction, roofing and utility companies across the United States was conducted, as no information was available for on-board air system sales in the US.
Market Analysis to demonstrate KEEN’s in applying to identify unexpected opportunities to create value. The Beef Industry Statistics report from 2016 indicates there are nearly 750,000 ranches in the United States. Of the 750,000, over 90% are family-owned, small operations. Discarding the 65,000 feedlots from consideration, as off-road needs are likely to be minimal, and the 10% for large operations that likely already have well-equipped vehicles, the number sits around 600,000 ([33], Beef Industry Statistics, 2018). Surveying of the market\(^2\) revealed a great deal of enthusiasm across the board for the services provided by the CACTIS. If just 10% of ranches chose to equip the CACTIS on a single truck, that would still result in sales of over 60,000 units.

Some local construction and roofing companies were also contacted to see if this was a viable market as well. Phil Gutherie, a local Colorado Springs landscape company owner, expressed interest in the time that could be saved by using a CACTIS. The time-saving factor of the CACTIS increases as the number of vehicles and “air-down” situations increase. Current systems do not have a positive cost-benefit ratio, and therefore are not considered in fleet vehicles. When speaking with construction and landscape companies, the availability of the auxiliary port was a common point of interest, especially if the CACTIS is designed to allow the compressor to fill while the vehicle is moving. While there are some similar products currently available, market research has shown there is a high demand for an air controller with the versatility of the CACTIS.

While the main markets for consideration are ones which require off-road vehicle use, there is also a possibility for the CACTIS to become a system installed in standard consumer vehicles. According to American Automobile Association (AAA), 80% of vehicles are running on the road with under-inflated tires. Under inflation results in lower gas mileage-per-gallon, as well as increased tire wear, increased risk of tire damage, and increased risk of accidents (Obringer, 2004). Tires inflated at 80% or below on fleet vehicles are considered “flat” by fleet standards.

When analyzing the need for a product, safety requirements are paramount. An unsafe product will fail and likely result in lawsuits, destroying any profitability and violating several ethical standards. As the CACTIS deals with compressed air, there are several regulations to be aware of, to include OSHA Standard 29 CFR 192, which deals with the burst-rating of different types of pneumatic lines (OSHA, 2018). The product manual will ensure that the end-user is provided all safety information regarding the unit.

Overall, there is a definite need for the CACTIS unit, and market research has revealed a clear viability for the product to thrive in the current market. Positive market sales are projected in several different markets which increases the stability of a production operation. The CACTIS only includes the control module, valves, and a small set of mechanical parts, which allows for interchangeability among different systems. The problems that arise while manually airing-down tires demonstrates a clear need for an automatic system, and CACTIS fills that need.

**Ethical Considerations of the Design Process to demonstrate KEEN’s outcome to discern and pursue ethical practices.** Design engineering is a multi-faceted process, containing several aspects which come together to form a complete product. One of these supporting aspects is founded in ethical considerations. When developing a concept, whether it be for a physical

\(^2\)Again, market research was conducted first-hand as there is no report available that provides the statistical data required.
device, a mobile app or even a business proposal, one must always consider the ethical ramifications of an idea. It is irresponsible as an engineer to design and release a product to the public which has not been properly evaluated from an ethical standpoint. Ethical concerns are wide ranging and could be something as simple as a poorly designed product which does not live up to promised specifications, or something as catastrophic as an environmental disaster caused by oversight [34].

The CACTIS team used a combination of two prevailing models for ethical analysis: the “values-by-design” approach and the “ethics matrices and design processes” method. The “values-by-design” approach, or VSD, “incorporates intuitive, empirical, qualitative, and quantitative, approaches to reasoning through the design of software, algorithms, and hardware systems.” The goal of VSD is to determine the intrinsic value of the design by engaging in a rigorous process that considers many different viewpoints. The gathered data is used to build simulations and hardware models of the proposed design to fine-tune the design process. The “ethics matrices and design processes” method focuses on balancing requirements and strategies. This method guides discussions towards the development of alternative solutions, ensuring all requirements are addressed and adequately fulfilled. Focus is placed on all stakeholders of the design, causing ethical considerations to innate to the process. This approach utilizes a constant set of values throughout the design, enabling every step to be conducted carefully and efficiently by Gorp [35].

During the design for the air distribution box, the CACTIS team used these ethics models to thoroughly evaluate all design steps. For example, when selecting fittings and hose sizes, cost and reliability were compared. Fittings exist that were less expensive than those selected, however, they were of lower-grade brass, and therefore, an alternative was chosen, guaranteeing the design would hold up to required specifications. A similar situation arose when selecting appropriately rated hoses for use with the test system. Hose was chosen with a 300 PSI burst-rating as opposed to lower-rated hose due to safety concerns. There was a slight increase in production cost, but overall, the team decided to provide a design that is far safer, while still maintaining cost-efficiency.

The design process should also be driven by the guidelines delineated in the Institute of Electrical and Electronics Engineers Code of Ethics (2017). This code includes standards to guarantee safety, maintain honesty in claims, provide for the fair treatment of all stakeholders, reinforce principals of engineering, and foster team-based professional development. The Code of Ethics for Engineers, as published by the National Society of Professional Engineers (2007) [36], contains standards that contain similar ethical bases. These standards are broken into three main sections: Fundamental Canons, Rules of Practice, and Professional Obligations.

Many tenants of these ethical codes seem to be common sense; however, they are in place to ensure a standard is followed by all members of the respective organization. Additionally, one must remember that ethics can be relative, and what may be ethical to one may not be ethical to another, and there is usually a trade-off of ethical concerns due to their importance. For example, it is ethical to create an inexpensive design, but it is not ethical to do so if the design is inefficient. (Gale, 2005) [37]. This problem can be mostly alleviated by making use of design models that are inclusive of all stakeholders, to ensure that ethical concerns are prioritized based on the concerns of whomever the design is for, and not the designer.
Social ethical ramifications must also be considered. While the design should address the concerns of the client, it should never do so at the expense of societal safety, which again illustrates that the ethical dilemma is a series of tradeoffs (Gorp, 2001) [38]. If faced by such a situation, an engineer could point to the professional obligations sections of the NSPE Code of Ethics (2017) as a reason to consider any design which causes harm to or deceives that public as being unethical.

These two ethical codes pushed the CACTIS design team to remodel the design several times, making alterations that improve efficiency, lowered cost, decreased the size both the air distribution and control boxes, and decreased the required number of parts. All modifications were done to strive towards providing the safest and most efficient version of a design was achieved before moving on. The IEEE and the NSPE ethics codes both state that work should not be performed in an area in which one is lacking proficiency. These tenants were taken into consideration as issues were encountered in which no member of the CACTIS team possessed familiarity. Research was conducted, and an understanding was gained before any steps were taken when designing the control box, as microcontroller operation was not the strong suit of any team member. However, in the spirit of engineering, this lack of knowledge was overcome, and a solution was created.

Ethical consideration in the engineering design process are comparable to ethical concerns of daily life: safety, honesty, integrity, and thoroughness. An engineer’s duty is first and foremost to the public, to ensure the safety and well-being. Additionally, the NSPE Code of Ethics (2017) states that they are obligated to avoid any deception, and to only perform tasks they in which they are proficient. By providing standardized ethics codes, these ideals remain in the mind of every engineer, forging a path that provides safe, effective and innovative solutions to complex problems.

**Physical and Operational Description to show KEEN’s outcome to convey engineering solutions in economic terms and substantiate claims with data and facts. The KEEN outcome to persist and learn from failure is also demonstrated.** The Compress Air Controller Tire Inflation System (CACTIS) is a microcontroller-based system which allows for automatic adjustment of all four vehicle tires with minimal manual setup. The main system is comprised of two major subsystems, the air distribution box, and in the in-cab controller. There are also some minor systems, such as alarm and protection networks. The CACTIS is intended to be user-friendly, providing several built-in presets for various terrain conditions, as well as detailed installation documentation.

The air-distribution box (ADB) required the CACTIS team conducted numerous revisions before arriving at the final version. The box is composed of five electronically-controlled valves. These valves control the following: compressor input, exhaust-air output, Port A output, Port B output, and an auxiliary port output. The valves run off a single PSI-sensor, which reads the air pressure inside of a 7-port manifold that all valves are connected to. Early designs included a separate sensor for each valve, an idea which was quickly discarded once the single-sensor design was conceived. This single modification dropped the design cost over fifteen-percent. The output of all valves will be directly mounted to the box for easy connection to on-board pneumatic lines. The air-distribution box will also house the relays and wire harnesses for connection to the controller.
The air-distribution box allows the air to be routed to desired points on the vehicle but is useless without control of which signals the box receives. The in-cab controller is the mastermind behind the system, and due to the rapid development of ATMEGA 2560 microcontroller over the past several years, few adaptations were necessary to use a MEGA2560 R3 board manufactured by Elegoo as the backbone of the design. This board interfaces with the alarm, indicator and faulty circuitry to let users know when a fault is present. On-screen displays will direct the user to secure power to the system and will list probable faults based on fault conditions. The user manual contains detailed documentation of fault response procedures. The MEGA2560 board will also communicate with the NEXTION smart-touchscreen display, which is the other main component of the in-cab controller. After a few weeks of weeding through display options that used too many of the available output ports of the MEGA2560 board or were far too expensive, the CACTIS team found a generic version of expensive smart-touchscreens at a fraction of the cost. The capabilities of this display are quite astounding, with a simple, code-free process for programming touchscreen, and space-saving four-wire connection. After some additional research, the team decided that this screen was the compact, economical solution that was desired.

Through these two subsystems, CACTIS interacts with an existing on-board air compressor, allowing for precise, automatic, digital control of the inflation/deflation process, and promises to reduce times by fifty-percent or more. Inflation/deflation times will vary based on the rating of the on-board air system that is being used, as well as tire size and pressure settings.

The following is an informal description of the standard deflation use of the CACTIS:

| Step One: | Attach on-board pneumatic lines to all four Schrader valves on tires. Ensure fittings are properly attached and retention latch is closed before proceeding to step two. |
| Step Two: | Ensure vehicle is running, then activate power to the CACTIS in-cab controller. |
| Step Three: | Move the cursor to desired PSI setting for tires. For demonstration purposes, chose the “OFFROAD: SAND” preset, which will reduce all four tires to 5 PSI. |
| Step Four: | Press the “SELECT” button, then press “SET TIRES” to begin operation. |
| Step Five: | Once the “PRESSURE SET” prompt is received, disconnect all pneumatic lines. Ensure the lines are returned to a safe position and will not interfere with vehicle movement prior to resuming operation. |

Operating Limitations. There are minimal operating limitations for the CACTIS. The two subsystems will be located at different spots on the vehicle. It is recommended that the air-distribution box be installed under the hood of the vehicles, allowing for easy connection to the battery. Alternatively, the box may be installed in the rear of the vehicle, close to the on-board air system. The air-distribution box should not be installed at any portion of the vehicle which may become submerged, or in an area with poor ventilation (i.e. underneath a seat). The only valid installation point for the controller will be inside of the vehicle; installing the controller in any other location, or in a location with poor ventilation, will invalidate the warranty. Operation of the CACTIS is limited to low PSI, operating at 0-145 PSI, and a temperature range of 0-100 degrees F.
Build Process demonstrated KEEN’s Engineering Thought and Action (Based on the Vee-Model for testing and grand design Vee-Model) and KEEN’s outcome in creating value – persist and learn from failure. The build process became much more complex for the team from the start date, as the parts that were ordered had not been received. As parts began to arrive, the team began to test individual parts to ensure they were functional within the given tolerances.

The assembly of the Air Distribution Box (ADB) once parts had arrived had only minor complications which were quickly overcome. Complications such as the microcontroller the team had chosen was not capable of producing enough current to close the relay (30/40 Amp) required by the compressor. The solution to this problem was using the Lanzio 8-channel relay board, as it was the most cost effective solution. This doubled as an added layer of protection for the MEGA2560 during compressor operation, because the 10 Amp relay activated by the board, would then activate the 30/40 Amp relay. The final design of the ADB can be seen in Figure 3, the block diagram of the final ADB assembly.

The current draw for the ADB was a concern, when the team had realized that the maximum current draw of the on-board air compressor was 30 Amps. However, the ADB was promised to draw less than 30 Amps, so before turning on the air compressor, the box was operated with four of the electronically controlled valves open. (This is one more than the max when the box is operated normally.) Even with the additional valve open the current draw did not exceed 2 Amps. The compressor was then turned on and the current draw was measured over the course of ten minutes of operation, the maximum current draw was 28.75 Amps over the ten minutes of operation. The ADB is protected from a current draw of above 30 Amps with a 30 Amp blade-style automotive fuse.

Upon completion of the ADB, the entire team was able to focus on the in-cab control unit. The in-cab controller proved to be much more time consuming than anticipated. The team had chosen the Nextion 3.2 inch touch screen display based on a multitude of factors. These factors included easy of screen design, the multiple source claiming ease of use with the Arduino platform microprocessors, and cost was less than competitive screens.

The Nextion screen was easy to create the screen pages necessary for the CACTIS, however; it took a lot more research in order to establish reliable communication between the screen and the Arduino microprocessor. The screen mapping process was instrumental in the coding of the Arduino after the screen was created.

The next big hurdle was that no team member was familiar with the Nextion-Arduino coding process. This took the majority of time to research and develop code that was compatible. It took many hours of looking through the Nextion-Arduino open-source libraries and tutorials to find a coding method that was compatible with both the screen and the MEGA 2560 microprocessor. The MEGA 2560 can be programmed primarily in C/C++ language, however there were many commands that the MEGA 2560 or the Nextion screen did not recognize. That is why the programming was done be examining the programing from the Nextion-Arduino libraries and tutorials.

Unfortunately, due to the learning curve of new programing syntax not all of the functions of the in-cab controller were able to be achieved in the time allotted. The team will be continuing to work on the CACTIS until it is complete in its entirety.
Block diagram of the subsystem and subsystem are given in Appendix B. Requirements and details of the test procedures can be found in Appendix C. The students developed a 3’x2’ project poster showing their Vee-Model and program details of their product. In simple terms, the team described it where the left side of the Vee-Model is the design definition part (first course of the product design sequence) and the right side is testing and producing the product (second course of the product design sequence). The text on the poster is too small to be shown in this paper.

**Conclusion**

The successful implementation and demonstration of the innovative CACTIS project displayed the following:

- The students have successfully applied their technical skillset from the engineering curriculum and began developing an entrepreneurial mindset for this innovative project and they were fully engaged in this project
- Peer evaluation and team rotation provided a means in meeting KEEN outcomes, including: form and work in team while understanding the motivations and perspective of others
- The approach to carefully embed EML activities throughout the engineering curriculum contribute to developing an entrepreneurial mindset for these students
- The KEEN-Vee Model framework provides a visual framework for the student on developing an entrepreneurial mindset and provided direction in applying their technical skillsets
- The Vee-System Model provided a methodical approach to bring their ideas to the real-world.
References


APPENDIX A: Past Classroom Activities and Project Ideas using the Kern Entrepreneurial Engineering Network (KEEN) to Build an Entrepreneurial Mindset

A framework on entrepreneurship was needed to provide more helpful guidance in generating relevant capstone projects generated by the students. Project ideas generated by students gives them more ownership of the project rather than an instructor assign a project to students who have little or no interest in doing them.

One of the authors attended a Kern Entrepreneurial Engineering Network (KEEN) conference where the keynote speaker, Dr. Doug Melton and colleagues, provided an excellent and interactive presentations on entrepreneurship. Dr Melton explained how having an entrepreneurship mindset and a technical skillset can be a job multiplier for the local community. That is, for every one engineering job, it creates 3-4 non-engineering jobs. As a result of this conference, the authors attended a 2017 workshop entitled, ‘Innovating Curriculum with an Entrepreneurial Mindset Workshop’, sponsored by Lawrence Technological University, in collaboration with the Kern Family Foundation.

The 3.5-day workshop featured activities and presentations covering key aspects in entrepreneurial-minded learning (EML), problem-based learning (PBL), and Active and Collaborative Learning (ACL). The workshop provided a number of examples and experience to integrate the entrepreneurship mindset into the course curriculum without adding entrepreneurial courses. The KEEN approach aligns well with CoE’s strategy to integrate EML learning activities in an already crowded engineering curriculum. EML activities have already been tried in several courses to show relevance of the theoretical content intrinsic in electrical engineering concepts. CoE presented proposed EML modules and received feedback from the workshop cohorts.

Digital Communication Course. This set of EML activities was implemented for both undergraduate and graduate courses in digital communications. The student must deliver a presentation and a written report focused on the entrepreneurial mindset for a digital communication course. Several Entrepreneurial-Minded Learning (EML) activities prepared students for the research project and report. Although the senior and adult students were exposed for the first-time to the KEEN framework, they performed tasks to foster an entrepreneurial mindset based on the following topics covered in six of the eleven weeks: Internet of Things, Light Fidelity (LiFi), Deep Learning/Artificial Intelligence, Smart Everything (Smart Cities, Smart/Driverless Cars, etc.), Bitcoin/Block Chain Technology, and 5G and Enabling Technologies. Each student must summarize their findings in a discussion board for the assigned topic and make at least one connection of a communication system concept studied in class. Their discussion must also include either a business opportunity/business model, economic or social implication. Each student was asked to develop a discussion question to lead a 10-15-minute discussion for the next lesson. The discussion boards are intended to prepare the
students for doing the research paper and presentation, described in Figure 2. An end of course survey and positive student feedback are presented shown in Figure 3 for this early implementation of EML activities. Detailed discussion on the results and set of EML activities are described in another paper.

Again, the intent is not to have students become entrepreneurs after they graduate (although some have already done so), but to have an entrepreneurial mindset that will help them become creative and valuable engineers.

**Electronics Course.** During the fall of 2017, the authors started to extensively modify four out of the original five labs in order to add the entrepreneurial elements. The EML objectives were taken directly from the KEEN framework. The labs and KEEN outcomes include:

**Lab 1** – Signal Measurements (Lab 1) with a KEEN objective to “Integrate information from many sources to gain insight;  
**Lab 2** – DC Power Supply Design with the following KEEN objectives:  
- Demonstrate constant curiosity about our changing world.  
- Integrate information from many sources to gain insight.  
- Identify unexpected opportunities to create extraordinary value.  
- Persist through and learn from failure.  
- Assess policy and regulatory issues.  
**Lab 3** – Bipolar Junction Transistor (BJT) Amplifier and **Lab 4** – CMOS and BJT  
- Demonstrate constant curiosity about our changing world.  
- Integrate information from many sources to gain insight.  
- Identify unexpected opportunities to create extraordinary value.  
- Persist through and learn from failure.

The four labs and results are discussed in detail in another paper. Based on student feedback, the new labs helped students become more aware of the entrepreneurial mindset and KEEN’s 3Cs: curiosity, connections and creating value. Student feedback on the integrated EML lab modules are in general positive. Integrating the EML in the electronic design course helped engage students: (1) to combine information from different sources, (2) to become aware of the importance of doing market research, (3) to understand customer requirements, and (4) to consider policy and regulations in their engineering design solutions. The students began to form an entrepreneurial mindset during the design process when going through the series of labs.
INTRODUCTION

In a world of accelerating change, today's solutions are often obsolete tomorrow. Since discoveries are made by the curious, you must empower yourselves to investigate a rapidly changing world with an insatiable curiosity. Discoveries are not enough. Information only yields insight when connected with other information. You must habitually pursue knowledge and integrate it with your own discoveries to reveal innovative solutions. Innovative solutions are most meaningful when they create extraordinary value for others. Therefore, you must be champions of value creation. Be aware that this course and associated activities are intended to allow you to persistently anticipate and meet the needs of a changing world.

5G has many implications and applications that have societal benefits and economic value:

- 5G
- Driverless Everything
- Distributed Ledgers (bitcoin, block chain etc.)
- Smart Everything: City, Grid, Cars
- Light Fidelity (LiFi)
- Next Generation 911

PROJECT: HOGGING THE BANDWIDTH…NOT…BUT AT WHAT PRICE

An angel investor of communication technologies gave your company $500 million to make 5G and its applications a reality in the next five years. You are the lead engineer. Your KEEN and KIND boss assigns you to:

- Describe some key limitations and lessons learned of past communication systems
- Identify the operating frequencies of previous and proposed frequencies for communication systems
- Investigate economic value and societal benefits of 5G and its applications
- Prioritize at least 7 items (Internet of Things, LiFi, Deep Learning/Artificial Intelligence, Smart Everything, Bitcoin/Block Chain Technology, 5G and Enabling Technologies, plus one more of your choice) with allocated monetary costs of the applications researched in this class. Provide your reasoning of prioritization.

- Your paper should identify any opportunities that create value for others
- Your paper should communicate your findings in terms of market interest and customer value,
- Your paper should communicate your findings in economic terms and societal benefits.

CONNECTIONS: The project should tie some key concepts in the course on digital communication system. The research project should include one or more of the course objectives and should include some analysis using equations and if possible, a Matlab simulation. As a reminder, the course objectives are:

- Determine the sampling rate for a continuous-time signal, the spectrum of the sampled signal, and identify any aliasing effects
- Identify and explain the components and functions of a basic Pulse Code Modulation (PCM) system.
- Demonstrate the effects and tradeoffs of Delta Modulation and other variants of a PCM system.
- Explain Intersymbol Interference (ISI) in baseband transmission and explain methods to minimize these effects.
- Demonstrate the tradeoff/performance of basic bandpass modulation systems (ASK, PSK, and FSK) in a noisy environment
- Demonstrate error coding techniques in digital transmission methods.
- Apply software design tools to demonstrate the above concepts.

EML Objectives (showing relevance of analytical techniques)

- Lessons learned of previous systems used to improve proposed implementations of 5G and applications
- Contrarian views for one of the proposed 5G implementation schemes

Your research paper should be 5-7 pages in IEEE format.

Figure 2. EML-centered Research Paper and Presentation
### Survey on the Entrepreneurial-Minded Learning (EML) Activities for
EE 463 – Communication Systems II

Given the EML/thinking activities (e.g., discussion boards for reflection, in-class student-led discussions and the research project/presentation) and in comparison, to other courses, the EML course activities emphasized the following?

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<th>Topics/Questions</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
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<tbody>
<tr>
<td>1. Applied learning in new contexts</td>
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<tr>
<td>Comments: 1. Definitely made me research and learn new material. 2. Applications were not really used, more conceptual.</td>
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<td>2. Furthered learning beyond the course content curriculum</td>
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<td>Comments: Encourages you to look outside at the scope of the course</td>
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<td>3. Formulated questions and generated own inquiries</td>
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<td>Comments: Got all students to discuss many other questions</td>
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<td>4. Explored alternatives or encouraged forming contrarian views of accepted solutions</td>
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<td>Comments: (Professor emphasized to students that there is no “school solution”)</td>
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<td>5. Supported diverse perspectives</td>
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<td>Comments: EML allowed students to further expand their interests within the curriculum.</td>
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<td>6. <em>Increased awareness of the Entrepreneurial Mindset along with the Technical Skillset</em></td>
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<tr>
<td>a. Stimulated <em>Curiosity</em> about the changing world</td>
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<td>b. Encouraged making <em>Connections</em> to integrate knowledge to everyday life</td>
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<td>c. Fostered to think about <em>Creating Value</em> for yourself or society</td>
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<tr>
<td>Comments: 1. Definitely stimulated curiosity. 2. Enjoyed it.</td>
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#### Figure 3. Student Feedback of EML modules/activities.
APPENDIX B: System and Subsystem Block Diagrams of the CACTIS System

In addition to the system engineering deliverables by the team and as part of the final report, the student provided system block diagrams, subsystem diagrams (Figures 5 to 8). The students tested the components, subsystems and successfully demonstrated overall CACTIS system which was recorded in video and demonstrated to the Dean of the College of Engineering and one of the Lead Faculty members of the College of Computer Science and Technology.

System Block Diagram.

Figure 5: CACTIS System Block Diagram

Subsystem Block Diagrams

Figure 6: In-Cab Controller Block Diagram
Figure 7: Air-Distribution Box Block Diagram

12 Pin Connector Pin Diagram

1. 5Vdc to 8 Channel Relay Board
2. 5Vdc to Pressure Transducer
3. Pressure Transducer Signal
4. Air Input Valve Relay
5. Port A Valve Relay
6. Port B Valve Relay
7. Aux Port Valve Relay
8. Air Exhaust Valve Relay
9. Channel 6 Relay (not used)
10. Compressor Relay
11. Pressure Transducer Ground
12. 8 Channel Relay Board Ground

Figure 8: Pin Diagram of 12-pin connection
APPENDIX C: Requirements and Outline of Test Procedure

Requirements. Below are the requirements for the CACTIS system as defined by the team.

1.) The In-Cab controller shall not be larger than 6 inches in width, 4 inches in height, and 3 inches in depth.
2.) The system shall be compatible with vehicle supplied voltage 12 Volts DC.³
3.) The system shall not exceed specified current draw⁴.
   a.) The In-Cab controller shall not exceed a 15 Amp draw.
   b.) The Air Distribution Box shall not exceed a 30 Amp draw.
4.) The In-Cab controller shall have a backlight display for low light use.
5.) The In-Cab controller shall have an option to turn on the air compressor only, to allow contractors to fill onboard compressed air tanks prior to use.
6.) The In-Cab controller shall allow the user to adjust the three output ports individually.
7.) The In-Cab controller shall allow the user to input presets for quick adjustments
8.) The system shall alert the user when desired pressure is reached.
   a.) The In-Cab controller shall have an audio alert that sounds when set pressure is reached.
   b.) The In-Cab controller shall display a message on the screen when set pressure is reached.
9.) The system shall provide safety alerts to the user.
   a.) The In-Cab controller shall display a warning if possible, air leak is detected.
   b.) The In-Cab controller shall sound an audio warning if possible, air leak is detected.
   c.) The In-Cab controller shall display a warning if the input to distribution box exceeds 150 PSI.
   d.) The In-Cab controller shall automatically turn off the compressor if PSI exceeds 150.
10.) The system shall alert the user in the event of possible air compressor failure.
    a.) The In-Cab controller will display a warning if compressor turns of unexpectedly.
    b.) The In-Cab controller will sound an audio alert if compressor turns of unexpectedly.
11.) The system shall set pressure to within +/- 1.5% of setting.⁵
12.) The system shall be able to reach set PSI in no longer than 10 minutes.⁶
13.) The cost of the prototype system shall not exceed $800.00.

Test Procedures. Test procedures are outlined below:

1) Measure the In-Cab control unit.
   i) Pass if the control unit is less than 6 inches in width, 4 inches in height, and 3 inches in depth.

³ Modified 24FEB18 from 11.5-24.5 VDC to 11.5-14.5 VDC as 24 VDC vehicle systems provide a 12V pickoff point.
⁴ Current design shows both amperage requirements falling below 10 amps.
⁵ Modified 13FEB18, from +/- 1 PSI to +/- 1.5% due to inability to find a reasonably priced pressure sensor within tolerance.
⁶ Time to reach set pressure will vary based on rating of on-board air system, tire size, and pressure demands.
ii) Fail if the control unit is larger than 6 inches in width, 4 inches in height, and 3 inches in depth.

2) Test system removed from vehicle, ranging from 11.5 Volts DC to 14.5 Volts DC in 0.5 Volt increments to ensure:
   a) Controller turns on and is fully operational.
   b) Air Distribution Box is operating properly.
   c) Current draw is not higher than specified in system requirements 2.a and 2.b.
      i) Pass if system operates within 11.5V-14.5V DC and within current draw limits.
      ii) Fail if system does not operate properly or current draw exceeds specification.

3) System shall not exceed specified current draw:
   a) Turn on in-cab controller.
   b) Measure current draw at control unit and air distribution box.
      i) Pass if current below specification of 3.a and 3.b.
      ii) Fail if current draw goes above specification of 3.a and 3.b at any time.

4) Test In-Cab controller backlight.
   a) Turn on In-Cab Controller.
   b) Verify the display is backlit while power is on.
      i) Pass if display is backlit with the power on.
      ii) Fail if display is not backlit with power on.

5) Test procedure for compressor control option.
   a) Turn on In-Cab controller.
   b) Use In-Cab controller to turn on air compressor only.
   c) Ensure air compressor turns on.
   d) Ensure no air distribution box output ports are on.
   e) Use In-Cab controller to turn off air compressor.
      i) Pass if only air compressor turns on and off.
      ii) Fail if air compressor does not turn on or off.
      iii) Fail if any air distribution box output port releases air.

6) Test ability to individually set output ports with In-Cab controller.
   a) Attach empty air tank with burst rating of above 150 PSI to Output Port A.
   b) Turn on In-Cab controller.
   c) Select Port A only.
   d) Set PSI to inflate to 50 PSI.
   e) Ensure air tank is being inflated.
   f) Ensure no other output is releasing air.
   g) Repeat test for ports B and C.
      i) Pass if only selected Port is active.
      ii) Fail if selected output is not active.
      iii) Fail if output other than selected is active.
7) Test ability to store and use preset with In-Cab controller.
   a) Turn on In-Cab Controller.
   b) Select preset 1.
   c) Set Port A to 20 PSI and Port B to 30 PSI.
   d) Select preset 2.
   e) Set Port A to 30 PSI and Port B to 20 PSI.
   f) Run Preset 1.
   g) Ensure Port A sets pressure to 20 PSI and Port B to 30 PSI.
   h) Run Preset 2.
   i) Ensure Port A sets pressure to 30 PSI and Port B to 20 PSI.
   j) Turn control unit off.
   k) Turn control unit on.
   l) Ensure Presets are stored.
      i) Pass if controller allows setting of preset, storage of preset, and presets set the desired
         output ports to set pressure.
      ii) Fail if user cannot set preset.
      iii) Fail if preset does not set the correct ports to the correct pressure.
      iv) Fail if preset does not remain after power off and on.

8) Test that the In-Cab controller alerts the user when desired pressure is reached.
   a) Turn on In-Cab controller.
   b) Connect empty air tank to output Port A.
   c) Set Port A to 30 PSI.
   d) Allow system to inflate tank to 30 PSI.
   e) Ensure message is displayed on In-Cab controller when 30 PSI is reached.
   f) Ensure audio alert sounds when 30 PSI is reached.
   g) Repeat test for each output port.
      i) Pass if audio alert and display occur at 30 PSI. (+/- 1.5%)
      ii) Fail if no audio alert.
      iii) Fail if no alert is displayed on control unit.
      iv) Fail if audio or visual alert is active prior to reaching 25 PSI.
      v) Fail if audio or visual alert is not active prior to reaching 35 PSI.

9) Test system safety alerts. (For 9.a and 9.b)
   a) Attach empty air tank to output Port A.
   b) Turn on In-Cab Controller.
   c) Set Port A to 50 PSI.
   d) Begin inflating air tank.
   e) Open pressure release valve on air tank.
   f) Ensure audio and visual warning of possible are tank activate.
      i) Pass if audio and visual warnings activate within 3 seconds of opening the pressure
         release on air tank.
ii) Fail if audio alert does not activate within 3 seconds of open pressure release.
iii) Fail if visual warning does not activate within 3 seconds of open pressure release.
g) Test system safety alerts for 9.c and 9.d.
h) Attach air tank with a minimum burst rating of 170 PSI to output Port A.
i) Using In-Cab control set Port A to 150 PSI.
j) Ensure that visual and audio alerts are active if pressure reaches above 150 PSI.
k) Ensure controller turns off air compress if pressure reaches above 150 PSI.
   i) Pass if visual and audio alerts are active at 151 PSI and air compressor is shut off by
      the In-Cab controller.
   ii) Fail if visual alert is not active at pressure of 151 PSI or above.
   iii) Fail if audio alert is not active at pressure of 151 PSI or above.
   iv) Fail if compressor is not automatically turned off at pressure of 151 PSI or above.

**Test procedure 9 was reduced from 150 PSI to 145 PSI for safety concerns, in that the
majority of on-board air systems have a burst rating of only 150 PSI.

10) Test that the system alerts the user of possible air compressor failure.
a) Attach empty air tank to Port A.
b) Using In-Cab controller set pressure to 50 PSI and begin inflation.
c) Disconnect power from air compressor only.
d) Ensure that system closes Port A to prevent air loss.
e) Ensure that system sounds audio and visual alerts.
   i) Pass if system closes valve and gives audio and visual alerts.
   ii) Fail if system does not close valve.
   iii) Fail if system does not have both audio and visual alert.

11) Test that the system is within 1.5% of set pressure.
a) Attach air tank to Port A.
b) Using In-Cab controller, inflate air tank from 0 PSI to 150 PSI in 10 PSI increments.
c) Ensure tire pressure is within +/- 1.5% with calibrated digital pressure gauge.
d) Repeat for all output ports.
   i) Pass if set pressures are within 1.5%.
   ii) Fail if set pressures are not within 1.5%.

12) Test that the system can achieve set pressures within 10 minutes.
a) Attach 4 tires to the system.
b) Using In-Cab controller deflate tires to 10 PSI.
c) Inflate tires from 10 PSI to 5 PSI below max tire PSI.
d) Time inflation from 10 PSI to 5 PSI below max PSI.
e) Use In-Cab controller to deflate 4 tires back to 10 PSI.
f) Time deflation from 5 PSI below max to 10 PSI.
   i) Pass if system can achieve pressure in under 10 minutes.
   ii) Fail if system takes longer than 10 minutes.
iii) Individual system times will vary. If longer than 10 minutes to reach desired tire pressure settings, ensure vehicle onboard air system is operating correctly and can produce enough volume to inflate tire size in specified time.

13) Ensure that prototype system cost did not exceed $800.00.
   i) Pass if prototype was built for less than $800.00.
   ii) Fail if prototype cost exceeded $800.00.