AC 2011-849: INTEGRATION OF INNOVATION AND ENTREPRENEURSHIP TOPICS INTO DESIGN COURSES EXPERIENCES AND LESSONS LEARNED

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Abstract

Teaching and learning a fundamental core course such as Machine Design continues to be fun but a challenging task for many instructors, as well as for students. Strong foundation in Statics and Mechanics of Materials is a must to appreciate the inherent open-endedness that is typical to a Machine Design course. After briefly reviewing the literature, this paper discusses the experiences of including innovation and entrepreneurship topic as a part of one of the design courses taught by the author. Assessment of students’ feedback of this effort is also discussed. While the use of math and/or CAE tools enhanced in studying alternative designs, many students still lack the motivation to develop an appreciation for the open-endedness and ambiguity of design requirements. These are some of the attributes for innovation and creativity that may be necessary to develop a mindset in both faculty and students for possible entrepreneurship.

Integration of entrepreneurship is done through discussion of case studies, open-ended projects and a discussion of the five (5) principles of innovation. A math professor was also invited to teach a topic on the applications of calculus and statistics in the design and selection of rolling contact bearings. For each mini-project and the final project, the students are asked to write a brief review of NABC analysis. (Need, Approach, Benefits and Competition). The overall appreciation for inclusion of innovation and entrepreneurship topics and the NABC analysis seem to be encouraging.

Introduction

While many universities are considering, developing and/or implementing a separate curriculum in entrepreneurship and innovation, however, little seems to be done to realize that these topics are highly interdisciplinary across many areas such as business management, engineering, sciences and other areas. What makes an innovator and an entrepreneur? What can universities do to prepare students for an economy that depends on innovation? What learning will lead to the creation of new jobs? And how do you develop and enhance entrepreneurship and innovation capacities through an entire university? These are some of the questions that are partially addressed and answered at our university by implementing an effort to create EAC (Entrepreneurship Across Curriculum). EAC was made possible by a Foundation who provided funds to the university. Under this program, many faculty and staff members of the university attended a workshop specially designed to get some training in this direction. As a part of this workshop, it was expected that the faculty should propose plans to implement any ideas and innovation principles learned during this workshop and bring those to the classroom.

As one of the outcomes of the workshop, namely, the implementation plan, the author discussed a few case studies on innovation and entrepreneurship and how those topics can be related to the regular course material. Practically every course can include a discussion of these topics (innovation and entrepreneurship) to promote the mindset in students. The course that the author
attempted is Machine Design, which usually involves open-endedness and ambiguity of requirements. The idea was to integrate the common design topics and the NABC analysis between the math and the other engineering disciplines through applications to real life examples. As a part of assessment the students filled out the brief summary of the lectures and also the assessment survey that they were given to them. In all, there were over 100 surveys and NABC analyses were filled out by the students based on the lectures, HW, mini-projects and the final project. Some of the results of this survey are presented later in this paper in the form of charts and discussed.

**Background and Literature Review**

There is a lot of literature available in this area: for example the Kauffman Foundation, Kern Foundation, etc., who initially provided massive support to educational institutions to develop mindset in faculty, staff and students to appreciate innovation and entrepreneurship principles. Also, many universities offer courses and curriculum in EAC. In this paper, the efforts of only a few universities are presented, noticing however, that this list is not complete.

Because entrepreneurs and innovative ideas can arise from within any academic discipline, the Ewing Marion Kauffman Foundation has encouraged the expansion of entrepreneurship programs and activities campus-wide to provide educational opportunities in entrepreneurship to all students, regardless of their field. To this end, in 2003, the Foundation launched the Kauffman Campuses Initiative (KCI) in eight U.S. universities. The universities together received a total of $25 million in five-year grants from the Foundation and committed to raising an additional $75 million in support of their pledge to make entrepreneurship education available across their campuses. Their data shows that over the last few years there is a steady increase in startup business activities in U.S.A. due to a promotion of the innovative mindset amongst faculty and students.

One of the vehicles to promote and to measure the innovative mindset is the NABC analysis. NABC Value Proposition Analysis (VPA) has been reported in reference, which contains several modules (see below) that specify a methodology to develop value propositions for projects.

- Identification of the marketplace Need for a product or service
- Defines the “golden nugget” or the unique advantage of the Approach
- Outlining the Benefits to the customer, partners in the market ecosystem
- Pinpointing the Competition and systematically compare one’s approach to competitive products or services

Duening discussed a few examples of innovation in his paper. As part of an ongoing effort to incorporate entrepreneurship topics throughout the curriculum at Binghamton University, their Office of Technology Transfer and Innovation Partnerships and the New York State Center of Excellence have sponsored a new Entrepreneurship Across the Curriculum (ExC) initiative. This resulted in the development of new or revised courses with an emphasis on entrepreneurship. A workshop was held to educate their faculty about the program which served as an opportunity to develop additional course proposals. One of their recent surveys suggest that over half of today’s
college students have a major career goal of owning a business however few of these students will choose to pursue a major in entrepreneurship. On the other hand, they found majority of their students all across campus in diverse programs such as music, art, the sciences, health care, education, history, religion, English, etc. Therefore, they found it essential that entrepreneurship courses are easily accessible if these programs hope to attract students from across the campus. One of the other barriers to this diversity can be pre-requisites to take the entrepreneurship courses. Therefore, many programs around the country were able to overcome this obstacle by creating entrepreneurship courses that do not have other business or technical courses as pre-requisites. It is thus essential that entrepreneurship courses are easily accessible if these programs hope to attract students from across the campus.

Offering minors in entrepreneurship has also become a popular way for entrepreneurship programs to reach students who choose to major in other studies, for example, Belmont College. Entrepreneurship minors help students learn valuable skills they can use throughout their major and their lives. The minor is usually a combination of entrepreneurship and other business courses, such as accounting and marketing. On another note, one of the barriers to attracting students from across campus into entrepreneurship courses can be pre-requisites. Almost all of Belmont’s courses are experiential in nature in the sense that their students work on projects directly related to their businesses, their ideas for businesses, or from their area of interest, such as music, art, health sciences, history, English.

At Belmont, entrepreneurship programs reach students across campus by offering specialized lectures and even specific courses within various programs. Their professors often integrate assignments in their classes around the entrepreneurship topics covered in these guest lectures, thus helping them along the way to create successful start-up businesses. As is well known, starting one’s own business or working in a start-up is not easy as it requires knowledge and skills in practically all areas of business. Entrepreneurship minors and other across-campus entrepreneurship programs are a great way for students to gain basic business skills and to begin to understand the complex world of entrepreneurship.

One of the goals of a college education is to prepare students to compete for the best jobs available and to give them the skills and information they need to succeed. As a liberal arts college, Lake Erie offers students a broad education that can be applied to every field of work. The Center for Entrepreneurship, established in 2007, adds a new dimension, giving the students an outlet to apply business thinking to any major and help them form businesses about which they are passionate. They currently offer majors in entrepreneurship and equine entrepreneurship as well as a minor in entrepreneurship. More than 5% of their students have chosen to either major or minor in entrepreneurship studies. They organize monthly speaker series including Future Entrepreneurs, which brings experts to campus, and D.E.S.K. (Developing Entrepreneurial Skills and Knowledge), which highlights more than 24 of their faculty and staff research grants that have been funded by the center, opens up the discussion and investigation of entrepreneurship to the entire campus. Besides the in class and on campus programs, community networking events allow their students to interact with local and in some cases foreign country entrepreneurs that are often supplemented by entrepreneurship internships.
NC State University provides opportunities to their student entrepreneurs from any discipline with a venue to showcase their innovations. Unlike the traditional business plan competition for entrepreneurial students, NC State offers a program called “eGames” to celebrate the spirit of student entrepreneurship across all colleges and disciplines. The idea is to provide student entrepreneurs from any discipline with a venue to showcase their innovations. The competition features eight award categories that range from the most innovative use of an everyday product to an extreme website makeover for a nonprofit to an investor presentation judged by local venture capitalists. Several of these award categories emphasize service through sustainability. Once a student decides to enter the eGames, valuable resources such as workshops and feedback from experts are provided along the way to the final competition. This helps assure that everybody who enters comes out a winner, regardless of the outcome of the competition. NC State, like many universities including Kettering University believes that the students don’t wait for graduation to launch businesses and explore radical new ideas.

In 2004, the University of North Carolina at Chapel Hill created the Carolina Entrepreneurial Initiative with seed funding from the Kauffman Foundation. Their multi-million dollar initiative has reached thousands of students, faculty, staff, alumni and partners with programs that extend from the top-ranked offerings of their Business School across campus to students in the College of Arts and Sciences and professional schools. Their goal is to infuse entrepreneurship education throughout every aspect of education, research and outreach at North Carolina. They define entrepreneurship broadly to include not only commercial ventures but also social, artistic and scientific enterprises and activities. This supports the aspirations of their students 70 percent of whom say they hope to start a business one day. It also reinforces the university’s public-service mission, encouraging students to use their entrepreneurial skills and expertise to create sustainable new companies and nonprofit organizations that address pressing societal needs. Of particular interest is their initiative to offer experiential education and venture to encourage Women's Entrepreneurship Network which offers regular discussions and networking for women enrolled in the minor in entrepreneurship to share knowledge and experiences and connect with successful female entrepreneurs and business executives.

Kauffman Entrepreneurial Year (KEY) program funded Syracuse University students to accept students in to their multi-year entrepreneurship program tuition-free. If needed, they spend an additional year on campus pursuing an entrepreneurial endeavor. One of the KEY graduates who dual majored in history and anthropology, created an afterschool youth development program for at-risk students. The program integrates tutoring, athletics, community service, and ethics. A team of recently accepted KEY students with chemical engineering majors launched a sustainability consulting firm. They have already secured their first clients - the University of Rochester’s Admissions and Financial Aid Offices. University of Rochester also offers other diverse options for entrepreneurship learning, and non-traditional entrepreneurship education on their campus. Rong, et al discussed a very successful entrepreneurship program by integrating innovation and entrepreneurship in senior design projects some of which resulted in start up businesses.

From the brief literature mentioned above, it can be observed that entrepreneurship education is offered to a great extent by the Business Department of a university. Also, topics such as innovation and sustainability are covered with a necessary outcome to open a business. However,
the outcome of education on entrepreneurship and innovation should perhaps be the development of a mindset in students, particularly in technical fields, to appreciate open-endedness and ambiguity of requirements in designing the engineering products. With this in mind, in this paper, innovation and entrepreneurship principles, and NABC analysis have been integrated in the Machine Design course taught by the author. Students’ assessment has been carried out through a survey. The survey is about how integration of these topics might have helped them understand innovation principles.

At Kettering University\(^{11}\), we have developed the intellectual and practical capacity to shift our learning from the needs of a knowledge economy paradigm to an entrepreneur and innovation paradigm. The EAC drive involves the professional development of our entire faculty and staff. It is hoped that the results will be a learning experience through the entire academic experience for all our students. Our program plans to develop a graduate who sees the world not only as a technical expert, but also as an innovator. This program is supported by a grant from the Kern Family Foundation. To this end, the university's cohort of around 40 faculty and 20 staff members recently completed the EAC workshop that promises to be a national model for other universities. As mentioned before, these faculty members will teach a module within a class that incorporates the workshop's concepts, followed by an assessment of student learning from the module. Our vision is to continue the workshops until the majority of faculty and staff members are covered, and hopefully a mindset is developed in due course of time.

Mechanical Engineering Design or Machine Design course is taught after the students take Physics, Statics and Mechanics of Materials as well as Calculus sequence and Differential Equations. This course involves application of concepts and principles learned in these courses and apply those to the analysis and design of mechanical components and sub-assemblies used in automotive, aerospace and other industrial applications and devices. The principles and concepts used in these courses include solution of simple algebraic and differential equations, static equilibrium of rigid bodies, stress and deflection analysis of deformable bodies and other miscellaneous topics from Mathematics and Physics. The design components include transmission shafts, bearings, bolts, and miscellaneous torque and normal load transmitting components that are mounted on the shaft such as couplings, gears and pulleys which are secured to the shaft by keys and pins. Other miscellaneous machine elements such as springs and power screws are also covered in this course. The main challenge though is that this course requires a basic understanding of how a particular mechanical device (for example, a gearbox) works and the role of each machine component (both function and form) within that mechanical device. This seems to be a major challenge for many students as they seem to lack sufficient exposure to such devices from an engineering perspective. One would expect that co-op experience if any or observation of engineering products should help but this seems to be not necessarily true for many students. To partially address this deficiency, few instructors:

1. Draw sketches of components on the board, use textbooks and internet resources to show them the pictures and videos of components either in good condition or those that have failed during normal operations or in service.
2. Bring real components (whether failed or in good condition) as educational aids to the classroom. This is not always possible as some components may be heavy to carry.
3. Divide students in small groups and bring each group into a laboratory that contains machinery (for example, pumps, presses, metal cutting machinery, etc., or to an automotive lab) to demonstrate how the load bearing components are assembled in those devices (including an understanding of the role of their function and form).

4. Engage students to do research on an existing engineering case study and present it to the class for discussion. This method helps both in motivating and involving students to learn the subject well as it applies to real-world. It also helps to relate design with current and contemporary issues and how the overall design of a component or a system impacts the society as a whole. This is one of the most powerful methods of innovative instructions.

5. Bring industry speakers to make presentations on a current area of application or research related to the class. This is another effective way of instruction.

Using such methods does not necessarily challenge the students to understand the load calculations (how much load each individual component bears within the assembly). Reengineering is one method used to help the students. An example of this can be to analyze the reason for failure of a component using the yield criteria principle of static and fatigue failure theories discussed in the machine design course. Thus, in machine design course, the students are expected to carry out an inspection and evaluation of the several alternative designs that seem to fulfill the same or similar input-output design requirements. The design alternatives in this course mainly focus on how innovative selection of different sizes and shape of cross section of members, and the use of various engineering materials (mostly metals) affect the strength of a load bearing component. Knowing the source and the magnitude of load acting on a member is obviously not an easy task since in real life, different types of load (axial, bending and torsion) act simultaneously in the form of combined loads. Understanding and developing an appreciation for modeling and analyzing complex systems is important. Further, students are taught to make simplified and realistic engineering assumptions while identifying the significant loads acting on the component. This is done by a discussion of how to choose safety factors in design calculations, which adds to the list of the other three basic design parameters, namely, the geometry, load and the material. Closed form solution is obtained if any three out of the four design parameters are known. The design becomes open ended if more than one unknown is involved, which in turn helps in making engineering judgment to propose a solution.

The above discussions often involve critical thinking and an appreciation for open-ended and sometimes ambiguous requirements of design specifications or design parameters. ‘What if’ scenarios help a lot in this course just like in any other course that facilitates critical thinking skills. Product design is not complete unless many other constraints are satisfied. These include for example, innovative ideas to reduce mass, cost, time to manufacture and marketing of the 'designed' components. Can we accomplish all this in a single course? Probably not; however, is it possible to do something to address these issues to help the students critically think more when they take their capstone courses? Possibly yes, but how? Evaluation of the several design alternatives to study how the lower-bound and upper-bound values of the four design variables (geometry, load, material and safety factor) affect the weight (volume times the material density), manufacturability (coarse and/or fine machined, forged, ground finish, etc.) and the cost to market the component. Use of simple math tools such as Excel spreadsheet helps carry out these ‘What if’ scenarios to a great extent. Starting a business based on the product and process design is yet another issue that needs other criteria to discuss that depends on the nature of the
application of the product and its working environment. The final design of a product based on these constraints would not only be optimal but also innovative.

In the light of the above mentioned background, philosophy and discussion of what can be done to enhance students’ innovative thinking, following was what was planned and accomplished:

- The students were informed from early on and throughout the course about the framework of how the course is being taught from a different perspective addressing innovation while not sacrificing the coverage of the fundamental knowledge and topics of machine design course. Students were given handouts on NABC analysis from Carlson’s book and the personal entrepreneurial behaviors and mindset from a Business Department professor’s lectures.
- Brought several within campus or outside speakers to make presentations on design optimization (topological or topographical), synthesis and analysis topics as they pertain to this class. This also included an innovative demonstration of how mathematics and machine design can be integrated using an example of contact fatigue of rolling bearings.
- We discussed simple case studies of failed components and reengineered or redesigned the components.
- Students were constantly encouraged to critically think and to appreciate open-endedness and the ambiguity of the design requirements. Example of the design and analysis of a gearbox used for windmill is assigned as a term project. The students are expected to propose several alternative designs (mostly by changing the geometry, load, materials and safety factor). They are also expected to study how these designs affect the weight, manufacturability and cost of the gearbox.
- Students were assigned homework and mini-projects based on real life situations of components or subsystems that currently exist, or new or those that have failed during operation, to carry out both strength and NABC analysis and to produce various design alternatives using math tool such as Excel.
- As mentioned above, students were asked to do NABC analysis for as many home works, class works and mini- and term projects as possible.

At the end of the term, Innovation Assessment for the class of 41 students has been conducted. The analysis is mostly based on the survey questions as shown in charts 1 thru 3. The students are asked to give their feedback on to what extent if any, the machine design course and the lectures addressed the attributes such as Attitude towards innovation, Creativity, and Tasks given to them as homework. For each one of these three attributes, the students are asked to give their feedback whether the entrepreneurship and innovation topics are useful and to what extent. These are indicated on the x-axis as Exposure, Thoughtful, Applicable, Integral and Immersion. The survey as outlined in these charts indicates:
Figure 1: Students’ perception of Attitude versus the extent to which it is covered

Figure 2: Students’ perception of Creativity versus the extent to which it is covered
• All charts, with a minor degree of variation indicate that all students seem to agree that the class encouraged Attitude, Creativity and Tasks from not only an exposure perspective but also to an applicable level. Only a few students agreed that creativity was integral part of the class. This aspect has been addressed to some extent while assigning the final project and will also be kept in mind in the future attempts of embedding EAC into the classes.

![Chart](tasks_chart.png)

Figure 3: Students’ perception of Tasks versus the extent to which it is covered

• The charts on Attitude and Tasks also indicate similar feedback as the chart on Creativity in that the students realized the exposure to applicable levels but not in the other two areas (integral and immersion).
• One of the comments given by few students is the time given to fill out the survey form based on which the charts have been developed.

Based on another version of the survey form called “Innovative Assessment”, following observations were made.

**Creativity:** A total of at least 5 to 8 classes were spent on discussing new ideas that are perceived to generate inventive thinking and those that displays an inquisitive nature. This is done through classwork, homework and mini- and term end projects. They involved generating several alternative designs by varying the four design parameters and studying the how they affect the product design. More than one out-of-class activity has been given.

**Attitude:** As mentioned above, in addition to classwork, more than one outside class activity (homework and projects) gave the students an opportunity to accept risk in product design through ambiguous and challenging design requirements that required individual or team-based effort.
Tasks: Although the students completed the projects and homework involving component design, and cost analysis to some extent, little could be accomplished to address the business aspects of marketing and legal issues of the product.

As an example of the partial successes of integrating innovation and entrepreneurship in Machine Design and other courses at Kettering is demonstrated by the feedback from a recent graduate student, who is planning to become a partner of a startup company – Aerospoke Trike\textsuperscript{12}. This company manufactures wheels for bicycles and for three wheel trikes. The student’s feedback is included in Appendix – 1. In the last 5 years, through Kettering University TechWorks\textsuperscript{11} (http://www.ku-tw.com/), approximately 30 Kettering students have started entrepreneurial ventures while as undergraduates. About 25 have taken part in TechWorks technology entrepreneurship training classes. While some came in teams, others came to just get an experience but do not start businesses. Finally, TechWorks coached about 20 KES (Kettering Entrepreneur Society) student entrepreneurs with companies or sincere plans to launch.

In summary, in the Machine Design course taught during Fall 2009, the students were asked to think innovatively and to appreciate the open-ended characteristics that are typical for real life problems. Several opportunities were given to encourage the development of a mindset for this. As an example, two industry speakers were invited to the class to make presentations. One of them dealt with open-ended and ambiguous design requirements, while the other speaker discussed design optimization using finite element analysis/design, embedded with innovative design ideas. Another speaker from math department made presentations to reinstate how statistics concepts that they learned can be used to think innovatively and apply those to the design of machine components. The idea is to discuss how math and engineering should be integrated while understanding and modeling contact fatigue problems, in this particular case, the contact fatigue of rolling bearings (ball and roller bearings). They were showed exhibits of failed bearings in service due to high cycle contact fatigue and due to other failure modes, such as pitting and corrosion under fatigue loading conditions. A discussion of how alternative materials and alternative designs of the bearing assemblies can enhance the life of the bearings followed these lectures. Taking ‘risks’ to innovatively think and to apply those to the design of components in a traditional machine design course seem to be certainly a challenging task, particularly due to time constraints. More attempts will be made in the future to systematically address each issue, one at a time to seamlessly integrate the innovation and entrepreneurship principles in to traditional engineering courses such as machine design and capstone design courses.

Conclusions

In this paper, a brief review of literature has been included on EAC and how integrating topics on innovation and entrepreneurship, together with NABC analysis may be useful while teaching engineering courses such as Machine Design. If each engineering course incorporates these principles, it is believed that eventually, many students and faculty will develop an appreciation for product design and design to market mindset. Assessment results presented in the form survey and charts indicate an overall encouragement and agreement that a discussion of these
topics within engineering courses benefit the student mindset development to seriously think and to incorporate innovative ideas in their careers. Over the last 1.5 years, roughly 1,500 students taking different courses with different ‘EAC Faculty Fellows’ at Kettering University were introduced the innovation and entrepreneurship principles as a part of their regular course studies in engineering, math, sciences and business.

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Design and analysis of Aerospoke wheels

Need

Aerospoke Inc. wants to expand the market for their composite injection molded wheels. One target market of interest is trikes (see Figure A1 at the end), which mainly utilizes metal spoke wheels. Aerospoke’s present wheel hub design only allows their wheels to be mounted onto fixed-end axle designs such as bicycle forks. However, trikes incorporate a cantilevered axle design for their front wheels. In order for Aerospoke to mount their wheels onto cantilevered axles, they will need to redesign their current hub. The differences in axle setups requiring the redesign are:

- Axle outer-diameter
- Method to fixture the hub onto the axle

Approach

Aerospoke Inc. did not have any additional requirements for this hub beyond having it fit onto cantilevered axles. This lack of constraint and overall ambiguity of the project allowed us to be creative and entrepreneurial with our approach. The design of the composite wheel cavity where the hub mates with the wheel created its own unique set of design challenges. However, because of the open-endedness of the project, we were able to forgo using a standard hub design, and instead developed a 3 piece hub. This 3 piece hub design allowed us to move the bearings outside of the wheel cavity, which was necessary to account for the increased axle outer-diameter of cantilevered axles (the wheel cavity for the hub was not large enough to fit the larger bearings needed for the larger axle). It also allowed us to avoid using two different hub designs for the left and right wheels due to the nonsymmetrical nature of the spokes, as well as the nonsymmetrical keying feature which mates the wheel to the hub.

Benefits

The use of the 3 piece hub approach eliminated the need for Aerospoke to make costly modifications to their wheel molds. More so, with this new hub design Aerospoke Inc. can now market their wheels to trike users and manufacturers as well as other products utilizing cantilevered axles, allowing for increased profits and further company growth. In turn, trike users now have an option to purchase lightweight composite wheels which have an aerodynamic design and aesthetic appeal to them.

Competition
Aerospoke Inc. has a unique and patented wheel design which is superior to other wheel manufacturers based on their aerodynamic design, weight, and aesthetic appeal. They offer a large amount of different paint designs which allows the trike users to customize their trike, ability that metal spoke wheel manufacturers and many other composite wheel manufacturers do not offer. These differences should make Aerospoke Inc. competitive in the trike market for years to come.

**Innovative Mindset Development**

“I believe my personal background along with my academic and cooperative employment experiences are the factors which have helped me develop an innovative mindset.”

“My ability to draw and sketch, along with my math and science skills had led me to want to become an engineer. Kettering University helped me to further develop these skills, as well as develop a mechanical aptitude and overall become more analytical with my problem solving. This was supplemented by my co-op experience, where I was able to take a more hands-on approach when it came to designing and fabricating tooling for manufacturing equipment. This hands-on learning experience really taught me the basics of machine design with regards to how components come together, and how to design for manufacturability. Overall, my positive experiences at Kettering University and during my co-op employment helped me to develop my potential, gave me the confidence to seek unique solutions, and the knowledge to make the solutions feasible.” – Andrew Pokoyoway

“The initial design parameters of the trike hub project required a creative solution to be implemented. What really allowed us to develop the creative solution was a personal understanding and drive that things can always be better, and that there can be multiple solutions to a problem. I feel this understanding and drive is something that is developed overtime and is a product of a positive and creative environment (such as those created by Universities and employers).” – Andrew Pokoyoway

![Figure A1: Terratrike Trike with the aerospoke wheels](image-url)