Engagement in Practice: Engaging with the Community One Bike at a Time

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Dr. Jacquelyn K. Nagel is an Assistant Professor in the Department of Engineering at James Madison University. She has eight years of diversified engineering design experience, both in academia and industry, and has experienced engineering design in a range of contexts, including product design, bio-inspired design, electrical and control system design, manufacturing system design, and design for the factory floor. Dr. Nagel earned her Ph.D. in mechanical engineering from Oregon State University and her M.S. and B.S. in manufacturing engineering and electrical engineering, respectively, from the Missouri University of Science and Technology. Dr. Nagel's long-term goal is to drive engineering innovation by applying her multidisciplinary engineering expertise to instrumentation and manufacturing challenges.

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Jason Forsyth is an Assistant Professor of Engineering at James Madison University. He received his PhD from Virginia Tech in May 2015. His major research interests are in wearable/ubiquitous computing and engineering education.

His wearable computing work develops safety systems that provide continuous monitoring and sensing to protect human life. Previous work examined the role of wearable pulse oximetry in protecting construction workers from carbon monoxide poisoning and developing a warning system for road-side workers and emergency personnel to estimate potential vehicle strikes. His current research interests focus on on-body human activity recognition and interactive machine learning for physical therapy patients and practitioners to increase exercise adherence and clinical evaluation.

Dr. Shraddha Joshi, James Madison University

Shraddha Joshi earned her Ph.D. in Mechanical Engineering from Clemson University with her research focused on understanding the role of requirements in engineering design by novices. Dr. Joshi received her MS in mechanical engineering from Clemson University and her BE in mechanical engineering from Nirma University, India. At Clemson, Dr. Joshi has worked on multiple industry sponsored research projects (Michelin tweel –low rolling resistance for non-pneumatic tires, IFAI ballast friction testing project). She was actively involved in mentoring and advising Capstone design projects. She has advised over 10 different design projects –BMW, Rotary, TTi and mentored over 100 students. While at Clemson, Dr. Joshi was also awarded endowed teaching fellowship as a part of which she has taught a sophomore class on Foundations of Mechanical Systems for 2 semesters.

Dr. Joshi worked as a Post-Doctoral Fellow with Professor Jonathan Cagan at Carnegie Mellon University. She investigated the avenues of internet of things and connected products. While at Carnegie Mellon University, Dr. Joshi was also instructor for classes such as Mechanical Engineering Seminar, Capstone Design and Storytelling with Machines

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Dr. Joshi's areas of interest include requirements in design, conceptual design, engineering education, design representations, development of design tools and design research methods, internet of things and connected products.

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Dr. Kyle Gipson is an Associate Professor at James Madison University (United States) in the Department of Engineering (Madison Engineering). He has taught courses pertaining to topics for first-year engineering, materials science and engineering, engineering design, systems thinking and engineering leadership development. Currently, he holds the following positions: Director of the Madison Engineering Leadership Program and a Co-Director of the Center for STEM Education and Outreach. He has a PhD in Polymer, Fiber Science from Clemson University. His research background is in the synthesis of polymer nanocomposites and engineering education. He was trained as a Manufacturing Process Specialist within the textile industry, which was part of an eleven-year career that spanned textile manufacturing to product development.

Introduction

At James Madison University, community engagement is integrated in the culture of our departmental community. First-year students are asked to explore the citizen science aspects of measuring local environmental phenomena via weather balloons and connecting that information to the needs of local stakeholders. In the second year, students design, develop, and deliver human-powered vehicles for local community members with disabilities. Finally, in the two-year junior/senior capstone, all of our students are encouraged to work with faculty and staff to identify local community members to engage with through the project. These are just the curricular projects! For example, students currently may opt into an engineering elective course focused on building a bridge over Mossy Creek which includes a partnership with the local community to redesign and build a pedestrian foot bridge that was washed out during recent flooding.

In particular, this Engagement in Practice paper will focus on the second-year project. This project, building human-powered vehicles for a member of the local community, is in its 10th year and is a required, year-long, client-based, design project interwoven with instruction in a two-course design sequence. The course sequence incorporates experiential, problem-based learning and active learning pedagogies to teach sophomore engineering students engineering design fundamentals. The course project experience focuses on the design, development, and construction of a human-powered vehicle for an individual with special needs. Through the course, students not only learn about the engineering design process, but also, they learn about themselves as budding engineers and their future role as an engineer in society.

Project Design & Execution

The teaching team has written on the course structure, project design, and project execution [1-4], thus it would be repetitive to describe these in detail herein. There are, though, some critical elements of the course sequence that should be shared herein for clarity.

First, the second-year design experience is a two-course sequence: Engineering Design I and Engineering Design II. The course's outcomes and course description do not explicitly state that the courses require engagement with a member of the local community for completion of the course project. Instead, the courses are focused on teaching students the engineering design process and design tools that may be used during the engineering design process through the semester. It may be noted that while such engagement is not mentioned as a primary focus of the courses in the syllabus, it is an important element of the courses, and the project lends itself to allowing the students to engage with the community through the partner program Overcoming Barriers to develop empathy. Through this connection students may realize the broader impact of their engineering education on the lives of the people in the community.

During the first semester, students learn the engineering design phases of project definition and conceptual design, which includes the following design tools: team contracts, interviewing customers, listening to stakeholders (i.e., peers, clients, etc.), design objectives, constraints, functional modeling, sketching, morphological matrices, Pugh charts, decision matrices, and mock-up prototyping. During the second semester, students learn the engineering design phases of preliminary design, detailed design, and final design reporting. This second semester includes design tools such as design analysis, proof-of-concept prototyping, bill of materials, engineering drawings, design communication, testing and refinement, and alpha and beta prototypes. Through both courses, connections are drawn to physics and statics course work, helping the students to make models estimating force output requirements (and expected output), estimate forces in frame members, determine mass, locate center of mass, and perform a tip/flip analysis in various riding situations; these calculations inform conceptual and preliminary design decisions made by teams.

The project of designing and building the human-powered vehicle is interwoven into the course content and used throughout for in-class individual and team work. Students learn and practice course topics during class meeting times, and then must complete the activities for the project on their own outside of class. Often this means meeting with the final design recipient (client and/or user), members of support staff (e.g., the university machinist, department lab manager, or local bike mechanic) or using material learned in other courses (e.g., MatLab and SolidWorks). As the course progresses, the students must transition from being assigned weekly deliverables which walk the students through the design project to being able to manage large assignments that require longer term planning. Team size from 3 to 4 in the Fall increases to 6 to 8 in the Spring. In the Fall semester, the students are primarily working on gathering the requirements and developing initial concepts, thus smaller teams of 3 to 4 are sufficient for this semester. In the spring semester, however, the students start prototyping, building proof of concepts and ultimately fabricating the alpha and beta prototypes, thus the increase in team size in the Spring. This also allows the students to apply project management course work to the management of the team and project as it is challenging to work in larger teams.

Since the course focus is on the engineering design process and design tools, the goal is for students to arrive at completed beta prototypes that can be trialed by the recipient but are not the final deliverable given to the final design recipient. Instead, we hire a student through the summer to build a final design borrowing the best ideas from the beta prototypes trialed at the end of the Spring semester. Our typical timeline for project execution is August through October of the following year with some years ending much earlier and others ending many months later depending on the complexity of the final design (e.g., not complex - *upright trike with standard propulsion* versus complex - *tandem with recumbent and upright positions, and independent, unique propulsion, braking, and steering systems*).

Partnership Development

Critical to the success of the course sequence are course partners. Course partners (both internal and external to the university) have helped to make the course a success and are critical to not only meeting the course outcomes, but also, creating an enriching course experience.

The course project began with the first partner (who is also a faculty member at our University) discussing a project idea with two faculty members in our nascent engineering program – creating a human-powered vehicle, specialized for his cerebral palsy, so that he could ride in his first 5K. The sophomore engineering design courses had not yet been offered, so the opportunity presented was to design the courses with the project already known. This conversation became the genesis for subsequent course offerings as this first partner, following receipt of his human-powered vehicle, became the facilitator for identifying all future recipients. In the second year, this first partner was asked to identify a second recipient, and he chose his long-time mentee – a student in the local high school. The second year, he went to the local high school for a recipient, and in this year, we had our only recipient that did not receive a human-powered vehicle. We have continued this trend of identifying course partners each year through our original "partner". This relationship is beneficial as he maintains a community-based research program for persons with disabilities and thus has a known pool of future partners that we can explore.

During the third year, challenges were faced with engagement, strained relationships, and differences in expectations between the recipient, the recipients' family, and our program. Through these challenges, recognizing the importance of having "the right" recipient for the human-powered vehicle, we began to formalize processes for selecting recipients. Formalizing the process meant establishing clear roles for partners and establishing a legal framework for the course project. Key partner development efforts include:

- Work with University legal-council to develop a contract to be agreed to by the legal representative of the recipient of the human-powered vehicle.
- Formalize partnership relationships: Faculty course coordinator performs project management tasks for course project; recipient becomes known as the *user*; the recipient(s)' legal representative becomes known as the *client*; and the first partner is the *partner coordinator*.
- Vet all users *and* clients through their engagement in the Overcoming Barriers program run by the partner coordinator through the academic year. Users *and* clients are chosen by prior commitment in the Overcoming Barriers program, and agreement to at least one year of forthcoming commitment during the design-build process of the human-powered vehicle.
- Establish expectations prior to beginning project work for all users and clients, and establish critical meeting schedules during the first week or two of each semester year for the user and design students. Ensure that the user and client understand our time line for project completion as well as our expectations for their availability during this timeline.

Since establishing this legal framework, these partnership formalizations, and expectations, all human-powered vehicles have been delivered to our user. In total, seven successful hand-offs, one near competition, and one that was not handed-off. All human-powered vehicles have been completed; three have been returned, and the three returned are on loan to a physical education program at a local high school.

As a direct result of the formal partnerships with the user and client, through the course, students have open opportunities to meet with their users and their users' parents (clients) on their own time as needed due to the arraignment with the Overcoming Barriers program. Through this partnership, users receive the strength and flexibility training that they will need to ride the human powered vehicle that they will eventually receive. Students are often able to see the users' strength and physical abilities improve through the users' participation in the Overcoming Barriers program. And through the semester, students work to create a design that plays to the users' strengths such that the user will be able to ride the human powered vehicle as independently as possible once completed.

Additional partners required for success include: a local bicycle expert, the University machinist, the Department lab manager (who is also a professional welder), University surplus, and the departmental administrative assistant. Each plays a critical role in the course:

- The local bicycle expert has 40 years of professional bicycle experience in racing, sales and fitting, as an Original Equipment Manufacturer (OEM,) and is a hobbyist airplane builder. He attends class twice during the Fall semester, helping the students to learn traditional techniques for bicycle fitting and how to modify those techniques to be applicable to a wide range of bicycle and tricycle types, as well define the design, structure, and mechanics of a "common" bicycle.   He attends all major presentations, maintains studio hours during the Spring semester, and provides the critical safety sign-off for the beta prototype final deliverable.
- The University machinist runs lathe and mill training for all students in the program during the Fall and Spring semester which creates an entry point for the Machinist Apprentice Program where students have the opportunity to work on personal, Department, and University machining jobs under the apprenticeship of the University machinist.
- The Department lab manager helps to maintain the studios, ensure tools are properly prepared for student use, employ shop assistants, and keep the spaces open. He runs welding training for students who want to complete their own welding, and he assists those that do not. He assists with any machining tasks or prototyping tasks that the students have yet to master, and he is critical to us having a final deliverable that we can be proud to hand off to the partner family.
- Monetary resources have luckily not been a challenge; each team is given $400 dollars which may be spent at one time based on their final bill of materials submitted to the department administrative assistant. Many bicycle parts are obtained through University surplus after the bicycles have been left behind on campus the following summer.

Successes & Challenges

The most important element to success is ensuring a strong relationship between our program with the user and the client. We have found that when this relationship is strong, then the course can keep moving forward, and the students can meet the course outcomes. When this relationship is tested, it can become difficult to meet the course outcomes without continually, creatively rearranging the course schedule. Because we can never be sure at the start of a year how well the relationship with the client and user will unfold, we warn the students that all schedules posted in the syllabus are tentative, and every year we have had to adjust through the semester with some years needing an adjustment almost every other week.

Interestingly, while the strength of relationships may test the schedule of the course and the course coordinator's ability to meet course outcomes, it has never appeared to impact students' development (or lack of development) of empathy for the user. For many students, meeting with the client and the user, knowing that they have an opportunity to positively impact the client's and user's lives, and having the opportunity to work with the client and user for a year, creates a magical bond between the students and the user that develops into a strong sense of empathy. This acts as a catalyst, as motivation and as drive. Yet, while we do not assess empathy among our students, it appears to exist on a gradient with some students expressing little to no empathy towards the user.

Beyond these, other challenges that we have faced include: (1) formal assessment to really understand the impact for students and for project deliverable recipients, and (2) differences in maturity of students.

It is important that the students have a maturity level that allows them to be fully engaged in a community-engagement course, but it is a challenge to address how to nurture students through their required personal growth to be successful. Often this manifests itself as actions that may best be summarized by "not knowing how to act around the user and the client". Early on in the development of this project, we would have the classes as a whole meet with the user in a local gym to guarantee that all students would have an opportunity to meet with the user. This did not work; one, it was overwhelming for many (not all) of the users, and two, it was challenging for a number of our students due to their perceived discomfort in interfacing with people with disabilities. We have since provided discussion in the course on behaviors appropriate around minors (the majority of the users have been children) and these are customized depending on the disability. We have also stopped mandating that all students interact with the user and the user's family. This allows students to be driven by whatever it is that directs them toward their individual definition for success.

Finally, it is important to consider the faculty members that have taught the course, and how this course has changed them. We have all had the opportunity to teach portions of this course sequence, but for some of us, this is the first time that the engineering design process has been presented in a formalized manner because of our vastly different backgrounds. It is relatively easy to deliver a lecture on course content; however, a goal of all instructors is to bring real world relevance to the content and having the project run concurrently with course content allows for instructors to place great emphasis on relevance and importance. Additionally, having the opportunity to learn more about community members and course partners is an excellent opportunity for instructors to become more engaged in the community as well. Community engagement deepens the relationships that enrich the curricular content and make the project and course more meaningful. Further, this course provides a unique opportunity to teach students the broad impacts of their engineering education in the lives of the people in the community. Lastly, since the client and user are new every year, the instructor is on the journey through the project just as much as the students which builds an extremely strong relationship between instructor and student. Engaging in this type of relationship is a fundamental mission of James Madison University, and builds an expectation for how the adviser, capstone team relationship will be established in the following year.

Transferability to Other Institutions

There are the obvious elements that can be transferred such as stakeholders, cost, spaces, equipment...etc., but one key element that hereto-now has only been mentioned is the timeline for the course, and this is critical for the success in this course. The course meets once a week for 100 minutes. Classes are run with a mixture of lecture and workshop. Students leave class with multiple assignments – individual and team. A lot of the work happens outside of the classroom and requires *time*. Having two semesters is critical to our success, and even with two semesters, students argue that they are working harder for these cumulative four credits than they do for any other credits they have taken. To build a human powered vehicle, with students who generally have no idea how a bike works, for a client that has never ridden a traditional bike before, in fabrication spaces that are being shared with other courses, and with stakeholders who have many other job responsibilities, takes time.

Our program was in its second year when this course sequence was first offered. It is our understanding that this course sequence was not even originally considered as a course sequence, so for us, it was serendipity. For others wanting to implement a project as described herein, be cautious. Consider how long students will take to complete the project meaningfully (and probably double or triple) that time. Then use backward course design principles to map the timeline to the semester.

Concluding Thoughts

Students frequently refer to this course sequence as the most meaningful experience of their engineering studies at James Madison University during exit interviews. For recipients, the results have been equally powerful from breaking down in tears after riding their first ever 5K, to obtaining a learner's permit after thinking that they would never be able to operate any sort of vehicle. We have given a young child an opportunity to participate in recess activities when they previously had to sit out, and we gave two families of active cyclists opportunities to go on long trail rides after thinking they could never do this again as a family. Many clients have come back to campus year-after-year with their bikes for the following year's handoff. Overall, this course sequence provides a foundational experience for all of our engineering students that sets the tone, expectations, and trajectory for their future engineering work.

References

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[4] O. Pierrakos, R. Nagel, E. Pappas, J. Nagel, T. Moran, E. Barrella, and M. Panizo, "A Mixed-Methods Study of Cognitive and Affective Learning During Problem-based Service Learning," *International Journal of Service Learning in Engineering - Humanitarian Engineering and Social Entrepreneurship, Special Issue: Opportunities and Barriers to Integrating Service Learning into Engineering Education,* pp. 1-28, 2014.