Multidisciplinary College-Industry Collaboration on Biometric-Controlled Electrical-Assist Bicycles

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Abstract

Collaboration between industry partners and collegiate faculty/students is often a complicated undertaking. In projects that cross departments and include numerous independent groups, the complexity of the overall undertaken tasks can grow significantly. Students and faculty may be involved for various portions of the project that span across multiple courses and semesters. Throughout, independent student roles may vary from small parts on up to central roles in the overall project development. This presents numerous challenges from both academic and logistical standpoints.

For this study, the project goal was to take an existing, commercially available electric-assist bicycle and adapt it to include physiological feedback from biometric sensors, in order to prevent injury to the rider. If the identified sensors detect the user may be at risk of injury, through an array of predetermined medical constraints, the bike's motor would automatically take over to limit the physical exertion of the user. Because of the interdisciplinary facets of the project, student groups from different backgrounds were recruited and assigned to specific tasks. In the completion of the prescribed tasks, many obstacles and issues arose.

Over three academic semesters beginning in May of 2016, overlapping cohorts of students (17 students total) and faculty (12 faculty members) at Wentworth Institute of Technology entered into a partnership with RRT eBikes. The work presented here describes their roles in a large industrial/collegiate collaboration and provides insights into what worked, what didn't, and the reasons for each. In particular, setting student and faculty roles and maintaining direction with a large cross-disciplinary team proved to have unique challenges. After the initial semester, the team worked to improve the process based on feedback gathered during the intercession. This work describes the iterative process and provides insight into what worked and what didn't in this large-scale interdisciplinary project. It provides tips and tricks for people pursuing similar large scale projects for undergraduate programs, interdisciplinary teams, and/or industry partnerships.

1 Introduction

College-industry partnerships are an ever-present component of project-based learning in colleges across the world. These projects require a delicate balance between the constraints of the classroom and college experience and the demands of the needs of the industry partner to produce tangible results for manufacturing and marketability. While not all projects will fall into the parameters described, in this work, we will examine this environment in the effort to develop a biometrically-adaptive electric bicycle, beginning in the spring and summer of 2016. We will explore the interactions between students, faculty, industry partners, and the various methods of involvement (*e.g.*, classroom, extra-curricular projects, co-op employment).

Wentworth Institute of Technology focuses primarily on undergraduate engineering education, specifically with hands-on, project-based, and interdisciplinary studies. Students have numerous opportunities to get involved in both purely academic and academic-industry-collaborative projects. These projects are typically integrated into the curriculum as full-semester projects for design courses, as small projects within a technical course, as work for a co-op employee, and/or as an extra-curricular project. Each of these methods was utilized as a part of this particular project, as will be discussed in future sections. It is also worth noting that Wentworth has three full semesters, fall, spring, and summer, each of which is 15 weeks.

RRT eBikes, the industry partner, produces an electrically-assisted bicycle. It is a small, local company, focusing on a narrow, but growing, application-space for their e-bikes, including hobbyists, police departments, and now, rehabilitation patients. RRT eBikes came to the faculty at Wentworth to help develop a biometric feedback and control mechanism to their electric bike. At the start of this collaborative effort, the bicycle was already capable of regeneration of the battery, electrically-assisted pedaling, multiple gears and power modes, and basic tracking functions (*e.g.*, distance, time).

The collaborative product was an expansion on the existing components, targeting a product that could adapt to biometric feedback from a variety of sensors, including heart-beat sensors, blood oxygen levels, torque/force applied by particular muscles and joints, as well as the ability to expand to other sensor inputs in the future. In the end, the product would be used by patients who wanted to get outdoor exercise without endangering themselves. For example, if a patient had a heart-attack prior to engaging in a rehabilitation regiment, the pulse-meter would track their heart rate. If the pulse rose over a specified threshold, the bike would increase the power delivered to the motor, decreasing the exertion by the patient. The same could be done for patients suffering from knee-injuries through the use of torque and pressure sensors. In the end, the type of injury and rehabilitation could be paired with a particular sensor or group of sensors. The bike's controller would ensure patients are doing the appropriate level and amount of exercise for their individual needs, while limiting the risk of further injury as a result of over exertion.

In this work, we describe the collaborative efforts between Wentworth Institute of Technology and RRT eBikes in their efforts to create the biometrically-adaptive electric bicycle, while maintaining the academic focus of the institutional needs. In Section 2, we present existing related work. In Section 3, relevant technical details regarding the project are presented. Section 4 presents the process and how it evolved over three academic semesters. Section 5 presents description and analysis of student feedback. Section 6 presents the overall recommendations for any group pursuing similar efforts and concludes.

2 Related Work

Industry-academia collaborations are popular among engineering programs. Previous works have addressed the guidelines of these experiences, providing insight into the best practices from an industry and/or collegiate perspective. For example, the University of Hartford's Ward College of Technology and New Horizons described the importance of identifying industry-specific needs, developing an appropriate plan, establishing a mutual agreement, and assessing the model in order to make continuous improvement to the partnership and project[1]. This process created a project that could make mutually beneficial progress. In another example, Gannon University's graduate program incorporates the academic program with application-based training of key real-world industry problems[2]. In explaining their success, the authors describe communication as the key to success, and an annual review meeting provided a way to reflect and improve the program. Our work developed similar conclusions. In a survey done to characterize programs collaborating with industry partners across the country, it was noted that in most cases these collaborations lead to success, but warrant further discussion and investigation[3]. Industry-academia collaborations also find a place in accreditation guidelines which makes it even more attractive to both academic and industry partners[4]. Similar observations and experiences have been discussed in additional prior work as well[5,6,7,8], echoing many of the conclusions reached in our present work.

Many of the academia-industry collaborations revolve around the senior design or capstone project experience, where an industry partner sponsors individual projects and works with the student teams to develop a design. At Penn State University, the 15-week capstone design course placed interdisciplinary design teams with various industry partners to engage in industry-led design projects. This mutually beneficial effort allowed students to gain valuable experience in real-world design environments while providing real solutions for industry partners, similar to the efforts described above[1]. Many of the designs that were developed through these collaborations were implemented to provide cost savings and/or quality improvements for the industry partners[9]. At Howard University, a similar interdisciplinary effort was performed through a formal collaboration with General Motors. Along with the mutually beneficial aspect, the industry partner was able to provide students with projects in which the company would otherwise be unable to engage due to time limitations. This model for capstone design presented additional challenges in that it required collaboration between faculty at Howard University that traditionally would not collaborate. In addition to the challenges on the academic side, considerations had to be made for ownership of rights to the final design projects, which ultimately resided with the industry partner[10]. Other efforts in external collaboration through capstone design projects have been explored that include working with community partners[11], interdisciplinary design challenges[12], and cooperative education experiences in conjunction with capstone design[13]. All of these efforts have proven to be valuable experiences for both the students and the industry partners, yet they provide an array of challenges that are not present in the traditional capstone design model. Our work echoes many of the benefits and challenges found in the existing papers, but goes beyond senior projects, engaging juniors, co-ops, extra-curricular project, or small course work. Similarly, some existing work discusses industry collaboration that includes graduate students[13,14], but as Wentworth Institute of Technology has no graduate students, these comparisons are only considered where appropriate.

The co-op experience is pivotal to the collaboration between Wentworth and RRT eBikes, as two students were used as a centerpiece to the design experience. The co-op experience is also well-documented as being a proven asset to students entering the work-force, as well as providing a natural mechanism of industry-academia collaboration[12,13].

There are a number of existing published experiences describing scholarship programs[13,14] and individual case studies[8,15,16,17], each providing valuable insight into collaborative efforts. While some conclusions overlap with the lessons learned with our work, the design environment varies, thus providing a new perspective. For example, while RRT eBikes provided funds to pay for equipment, faculty and student teams received no compensation, and involvement in our project was less formalized and structured than scholarship programs. Similarly, the multidisciplinary and on-going aspects of our work differs from many of the previously published works.

3 Project Description

3.1 Commercially Available Product

RRT eBikes entered into the collaboration with an existing commercially available project. This bicycle is equipped with advanced technical capabilities as listed below:

- *Motor & Control*: The existing motor is 3-phase and is able to both drive the rider or regenerate the battery given rider-induced power generation.
- *Battery & Regeneration*: The battery is made up of 12 Lithium-ion cells, in total capable of 48V and 280Wh. It can be plugged in to recharge or can be recharged by the person by switching to a particular power mode. The existing system is capable of 11-12 miles of non-regenerated power at top speed, or roughly 30 minutes of riding (approximately 22 mph, flat surface, with a 150 lb. rider).
- *Interface*: The handlebars contain a user interface with speed/gear control, current speed read-out, battery charge information, a diagnostic menu, and an optional throttle.
- *Emergency Features*: The motor has an emergency cut-off when the user pedals backwards or applies the brakes, to ensure the bike's motor does not propel the user into danger.

The bike is currently available for purchase, and thus, is a closed package. The current system was designed, manufactured, and tested by people all over the world. This motivated us to have tasks that enhance the current system, rather than creating a brand new system. However, this also created issues related to both intellectual property and the lack of proper documentation throughout the prior design process. These challenges discussed further in Section 4.1.

3.2 Expected Overall Outcomes

Starting with the existing e-bike, the engineering design team set a number of short and long term goals which, over the subsequent semesters, were adapted and edited to better serve the students and industry partner.

The team's overall engineering goals:

- Create a biometrically integrated and adaptive electric-assist bicycle, based on the existing product.
  - Select and integrate sensors to gather a variety of data, including pulse, oxygen-level, torque, applied pressure, etc. These sensors should be as open-source as possible to facilitate integration.
  - Test and verify sensor data to maintain precision and accuracy.
  - Replace or enhance the bicycle's existing microcontroller to include a rehabilitation mode, in which it would read bike and biometric data. This controller could include multiple chips or could be incorporated in a single chip.
  - Create a communication infrastructure for sensor, bike, controllers.
- Create a mobile application and web-based database to track and analyze biometric, distance, and speed data. The data could be shared with a medical professional (*e.g.*, a doctor or physical therapist) to facilitate a tuned work-out for rehabilitation patients.
  - Mobile application should be designed for both Android and iOS
  - The application should track GPS, distance, speed, biometric data, as well as user feedback (*e.g.*, how they feel after a ride).
  - Communicate the data from the user/bike to a medical professional, when appropriate.
  - Allow a medical professional to create a structured work-out for the rider.
  - Maintain HIPAA compliance to ensure medical and personal data is protected.
  - Determine communication infrastructure of the bike to the mobile application and to the database.
- Better characterize the existing product to understand its motor, battery, and control mechanisms in order to better inform the engineering design decisions.
  - Understand the existing gear and power mode sensors and their integration with the motor.
  - Characterize the battery discharge and recharge times for better understanding of the range.
- Maintain the general structure of the existing bicycle with as many non-invasive changes to the product for easy manufacturability.
  - Gather and interpret existing documentation on various bicycle parts.
  - Stay in contact with manufacturers and RRT eBikes.

In addition to the technical goals, there were a number of academic goals in this collaboration. The overall goal is to ensure students: 1) apply the knowledge they have gained in their coursework, 2) acquire new knowledge, and 3) work in a real-world, interdisciplinary environment.

4 Semester Breakdown

4.1 Spring 2016: Preparation Semester

4.1.1 Academic Preparations

In the spring semester of 2016, RRT eBikes approached faculty and staff at Wentworth Institute of Technology to serve as a consulting/designing institution in the next evolution of their product. The semester was used to organize and prepare faculty and students alike to the coming tasks.

RRT eBikes introduced the faculty and staff of Wentworth to an array of their existing products and provided the opportunity for the potential investigators to use the bicycle and learn of its features. Faculty were also invited to visit the office of RRT eBikes to discuss the potential directions and gather information about the existing design and company infrastructure. At this point, the pool of interested faculty narrowed and plans were made for how to integrate the research and development into the classrooms of the various faculty. Planning ahead for the subsequent semesters, it was determined that the project work would be initially incorporated into the following courses:

- Summer 2016: Co-op student employed by the industry partner; Co-op student employed by a professor at Wentworth; Engineering Senior Design; Software Engineering; Junior Design;
- Fall 2016: Co-op student employed by RRT; Electromechanical Senior Design; Independent Study;
- Spring 2017: Electromechanical Senior Design (continuing); Engineering Senior Design (new); Software Engineering; Independent Study; Co-op students employed by faculty;
- Summer 2017 (if necessary): Senior Design (new and continuing); Independent Study;

Faculty were recruited based on their expertise and their course assignments in various capacities (*e.g.*, advisors, consultant, instructors, managers). Students were recruited from the course rosters of the faculty courses or by volunteering for a particular task or set of tasks specified by the professor.

The goals of the project were to be accomplished approximately one year after the beginning of the work. This put the end date in spring and summer of 2017 with a ready-to-manufacture design delivered to the industry partner.

4.1.2 Internal Logistics

To formalize the agreement between the industry and academic collaborators, a number of legal agreements were created. First, a memorandum of understanding (MOU) was created to clarify the roles of the involved parties. This included the expected goals of the project, the roles of the industry partner in financing and engineering, and at least one Principal Investigator from Wentworth.

Additionally, it was necessary to protect existing and future intellectual property (IP) for the industry partner. RRT eBikes already holds patents on unique bicycle technologies, and if possible, the Wentworth team would work within those patents or produce patentable technology, which would then be the property of RRT eBikes. Similarly, students, faculty, and staff were all required to sign a non-disclosure agreement (NDA) before being allowed to participate. It was also agreed that Wentworth Institute of Technology would be able to publish and advertise as needed with permission from RRT eBikes on all materials.

4.2 Summer 2016: First Working Semester

4.2.1 Semester Progress and Outcomes

In the summer of 2016, there were four faculty directly involved on a day-to-day basis. There were an additional four consultants, some of whom were acting as technical experts for students, some of whom were the instructors of record for a particular course. Students were involved in five separate capacities, originally all given a certain subset of tasks, as shown in Table 1.

Some of these students/projects were intended as terminal, as many students graduate or move to new classes, but some students were able to stay through to subsequent semesters, providing continuity. It is worth noting that while these tasks were the ones assigned at the beginning of the semester to the students, there were gaps in the required accomplishments from the overall goals, as well as unintentional and intentional redundancy. This will be discussed in the following subsections.

Students in each of these classes met regularly with their professor of record, with semi-frequent updates to the faculty PI. As with many classes, the real technical aspects did not start until a few weeks into the semester, so there was approximately a month of work being done independently with no synchronization or calibration. Faculty and students largely communicated in informal and undocumented ways, which led to some significant conflicts later in the semester, as some student teams usurped tasks from others and some tasks went unaccomplished.

A month into the project, all student groups, as well as available faculty, met to synchronize the

Course	*Student Majors*	*Tasks*
Co-op (Employed by RRT eBikes)	Electrical Engineering	Overall management, motor and control characterization, control algorithm, microcontroller, documentation
Senior Design	Electrical Engineering & Computer Engineering Technology	Microcontroller and control algorithm
Software Engineering	Computer Science and Networking	Microcontroller and control algorithm
Junior Design	Mechanical Engineering	Sensor choice, characterization, and implementation
Co-op (Employed by professor at Wentworth)	Electromechanical Engineering	Design of torque sensor

Table 1: Breakdown of courses, majors, and tasks for summer 2016.

efforts. During the meeting, students gained a better understanding of their tasks, as well as shared their contact information with the other teams, leading to a better communication structure among the student teams. Specifically, the students used an online communication messaging platform to maintain constant updates across the teams.

Towards the end of the semester, RRT eBikes's CEO made frequent stops at the laboratory, observing demonstrations, asking questions, and ensuring the work was being done properly and on time.

The co-op student, employed by RRT eBikes, served as a centerpiece to much of the progress in the semester. The student was part manager and part engineer, and without this student, it is likely little would have been accomplished. Faculty and students alike relied on the co-op, as was reflected in the student surveys (see Section 6).

4.2.2 What was Successful?

At the end of the summer semester in 2016, students demonstrated their working designs in a senior poster exposition, with fully functioning motor/wheel prototype. The student teams were able to successfully control the motor and wheel of the bicycle using a function generator and external power source, which could then be replaced by the sensor input and a separate microcontroller. Further technical details are removed, subject to the NDA.

One student also took it upon oneself to design the basic mobile application, although it was not an assigned task. The lack of an application was not noticed until late in the semester (as will be discussed in the next section). The fact it was attempted was a testament to that student's forward thinking and tenacity, as it was not that student's job, but needed to be done.

The students were also able to create a basic functioning database for user login. This would later form the infrastructure for a user-tracking and data-tracking database.

The team designing the sensors successfully found, tested, and installed the sensors. These sensors and the lessons learned helped to inform the next iteration's choices.

Besides successful completion of the above milestones, there is one standout conclusion: the co-op was the most important component to the work done in this initial semester. It is highly recommended, when possible, to include a student who can dedicate all of their attention to the project. A co-op provides exactly that, working 30 hours without classes taking time away from the project. Also, the co-op acted as an intermediary, making communication with the industry partner simpler. While it is important to pick the "right" student, the collaboration between industry and academia in this project would not have been successful without that cornerstone.

4.2.3 What Needed Improvement?

The largest problem was a lack of communication and infrastructure at the faculty level. Faculty took tasks from the list and then did not communicate these choices until a month into the semester. At that point, students were already accomplishing portions of their tasks. This type of redundancy was in some cases intentional as students would be able to experiment with their own design and then the design team could collectively choose what worked best. Unfortunately, these intentional overlaps were unclear to the students, who then mistook it as a possible competition for work. Students communicated that they felt left out of the discussion when another team succeeded in a shared task. Additionally, because the faculty did not have a clear separation of tasks, some tasks, including the mobile application, were left undone until the end. This was only rectified when a student completed a basic working mobile application with a faculty consultant.

The design team was hoping to have a fully integrated product, albeit with some gaps, at the end of the semester. Unfortunately, a lack of insight into the control board (caused by a lack of information and documentation regarding the original product design) and a lack of initial communication prevented the teams from accomplishing this.

Similarly, the lack of infrastructure and communication led to a dearth of proper documentation to pass onto the next generation of students. Fortunately, remaining participants were able to keep in touch with those that had graduated, and there were still three students that remained at Wentworth in the subsequent semester. This gave some continuity, but did mark a need for a better structure of inter-semester communication. This is of particular importance for the teams approaching graduation, as it is more difficult to keep students motivated after they have left the institution.

At the beginning of the semester, the teams lacked shared collaborative physical space. While the availability was resolved mid-semester, at the beginning it was unclear where students could all work together with the necessary technical equipment.

4.2.4 Overall Lessons Learned

Collecting the successes and failures from the summer 2016 semester, the faculty synchronized and attempted to restructure the procedures and policies for the fall semester. They are listed below as recommendations.

- Improve faculty communication and interaction. This should be done before the semester starts and frequently throughout the semester.
- Use shared communication medium (*e.g.*, chat, messaging) to supplement email.
- Use shared documentation saved in a cloud or local server to improve accessibility and continuity across teams and semesters.
- Explicitly structure the tasks being clear about redundancy and overlap where appropriate. This includes faculty synchronization and open communication with students throughout the semester.
- Isolate the day-to-day tasks of the students, allowing them to make progress even in the presence of overlap.
- Find a dedicated space large enough for multiple student teams with the necessary equipment that can be accessed only by the teams.

Course	*Student Majors*	*Tasks*
Co-op	Computer Engineering	Overall management, mobile app templating, microcontroller choices, sensor choice and purchase, documentation
Senior Design	Electromechanical Engineering	Battery and motor characterization
Senior Design (continuing students)	Electrical Engineering	Motor and control, documentation
Work study	Electromechanical Engineering	Sensor choice, purchase, and testing; Medical-compatibility planning
Extra-curricular (continuing student)	Electromechanical Engineering	Sensor choice, purchasing, and testing

Table 2: Breakdown of courses, majors, and tasks for fall 2016.

4.3 Fall 2016: Second Working Semester

4.3.1 Semester Progress and Outcomes

Fall of 2016 was the second full semester of technical work. Three students were able to remain active in the project, providing some continuity, as described in Table 2. Specifically, the summer co-op student that worked directly for RRT eBikes was able to join a Senior Design team, along with a student who had done the first semester as a Senior Design participant. These students, being the most familiar with the technical details of the project were tasked with continuing their work on the motor and control system, as well as providing complete documentation of their experiments and how to recreate the results. This was a reaction to the lack of proper continuous documentation from the previous semester.

Further, as also described in Table 2, a few new students, largely focusing on the electromechanical and biometric sensor concepts, were added to the team.

In this semester, four faculty were in charge of the five different teams (three from the previous semester, including the PI, and one additional person). These faculty were more communicative with each other and with the students, specifically with the scope of the individual team goals. This communication was focused on a more isolated approach to each of the technical tasks. Student groups were given non-overlapping portions of the project and thus were able to accomplish their task without being concerned with infringing on someone else's responsibilities.

In the first semester, the team at Wentworth was given a budget to complete its tasks. Unfortunately, but perhaps predictably, as new teams were added, directions were changed, and new problems arose, the budget needed to be increased. In particular, the motor and battery characterization and the sensor kit would cost more than the initial budget would allow. Thus, RRT eBikes was given new budgetary requests, after teams did their due diligence to find alternative solutions at a lower cost. This is part of most real-world design projects, but did create a minor obstacle to progress.

Before this semester, documents were not kept in a shared repository, but that was in progress. The documentation needed to be available to all people involved, but must adhere to IP and NDA agreements. A variety of options were explored by the co-op employer. Microsoft tools were determined to be an acceptable option, as the institute had internal license agreements and documents could remain private to the PIs without losing IP to the host service.

Aside from the existing technical goals of the semester, RRT eBikes asked the co-op and faculty to explore a new line of design. The system being designed prior to the fall of 2016 was meant specifically for the bicycle they sold as a complete product. The new direction included keeping the biometric feedback, sensors, and microcontroller, all paired with the mobile application and database, but remove the bicycle and make the system portable to all exercise equipment, such as treadmills, stationary bikes, or rowing machines. When first proposed, the idea seemed compatible with the on-going efforts. In retrospect, this change of scope gave the co-op, who was in charge of all aspects of the project, too many variables to balance, preventing timely and informed decisions. This resulted in both a slowdown and dissatisfaction of the co-op student. Approximately halfway through the semester, the PI and CEO met, along with other involved students and faculty, and it was decided the dual paths were untenable and only one could be done at a time, simplifying the project's scope.

4.4 What was Successful?

The co-op again proved invaluable to keeping the project on track. The former co-op (from summer 2016) remained involved as a senior design student and a new co-op was hired full-time. The former co-op provided technical and managerial continuity, while the new co-op brought a fresh perspective. The co-op again served as a central hub for communication between faculty, students, and the industry partner. Moving forward, it will be necessary to have a central point of decision making, either from a co-op or a faculty member.

The continuity provided by involving the same students and faculty was the instrumental to much of the progress in the semester. Students were able to continue their previous work while providing a much needed support for students who were just added to the project. The continuity from semester to semester will be targeted each semester going forward.

This semester featured less students than the previous semester. This proved positive because 1) students developed a closer working relationship and 2) tasks could be more specifically assigned, creating a better isolation, which was one of the goals in this semester. In the future, the number of students (and faculty) will remain similarly small to ensure similar success.

In addition to the technical and on-demand tasks, the co-op also helped to set-up documentation and code-sharing policies, which will provide invaluable for the next generation of participants.

4.4.1 What Needed Improvement?

In this semester, the largest issue was an unforeseen shift in the final goals. The dual paths - the original bike system and the additional portable exercise system - created a more difficult design landscape. While the faculty and the industry partners agreed the new landscape was a valid and desirable path in the long-term, in the short-term this made design decisions more difficult, particularly with sensor purchasing and mobile application design.

To remedy this, faculty met with the industry partners and decided on a short-term path for the next semester or two. In the future, Wentworth will create a more explicit agreement with industry partners to ensure students have a stable and achievable goal in the time allotted. This issue arose largely from a fundamental difference between industry and academic goals.

In industry, it is necessary to move fast and think big, in order to stay relevant in the marketplace. However, in academic institutions, particularly with students involved for short durations of time, it is better to have realistic goals and more constrained visions, as only 3-4 months are given per semester. A clearer contract at the beginning of each semester would help to compromise between the two worlds, but requires a balance between flexibility (to allow changes) and constraints (to guide students).

In order to protect student teams from too much redundancy and interference from one another, there was a conscious effort on the part of the faculty to explicitly isolate the teams' efforts. Unfortunately, that led to a lack of broader perspective, as the various design teams lost sight of how their piece fit into the larger puzzle. While this didn't necessarily hurt the design effort, students expressed dissatisfaction with a lack of larger perspective. In the future, faculty will strive for a balance between big picture and individual student work.

Because there was a number of isolated teams, it was also easier to identify what was and wasn't working across the student characteristics. One key piece was that students who were dedicated full-time or for significant portions of the semester (work-study and senior design) were more likely to accomplish their tasks. This seems intuitive, as students who have the time and external motivators (*e.g.*, grades, pay) are more likely to accomplish their tasks.

Similarly, faculty who were working on the project intermittently expressed concern with being left out of decision-making, while those working on it more consistently were forced to make quick day-to-day decisions. Thus, it was determined the project team needed to formalize a process and decision-making hierarchy for those involved in the project. To do that, a slight reorganization was proposed where the PI of the project along with two other faculty would form a faculty committee to oversee what faculty are involved, what students are chosen, and in what capacity they would be working. In the beginning, this form of hierarchy was avoided to give freedom to faculty and students. At this stage, the freedom was detracting from the project goals, so the hierarchy was seen as more of a necessity.

4.4.2 Overall Lessons Learned

At the end of the second semester of student involvement, as with the previous semester, faculty and students made some minor changes to help improve the overall project. Below are the lessons learned from the fall semester (second semester of student work).

- It is important to have clear and concrete goals for the project, particularly between the faculty and the industry partner. This should be determined at the beginning of the project and re-evaluated each semester *before* students begin their work.

- A smaller set of teams working on semi-isolated problems helps to improve overall efficiency. Maintain communication, and have all those involved better understand their place in the large project.
- A hierarchical approach to decision-making helps improve day-to-day tasks.
- As with the previous semester, a good communication structure between groups and between semesters is important for forward progress. Digital repositories, meetings, and group chats/emails should be used to ensure everyone is informed.
- Maintaining continuity between cohorts shortens the ramp-up time for new students and projects.
- The co-op student again proved to be a valuable asset to the team. While this year's co-op did more project management than the previous one, that was the need of the group. It is strongly suggested that someone on the team is able to dedicate the time and effort to the project, whether student or faculty.

4.5 Spring 2017: Third Working Semester

4.5.1 Academic Involvement

Course	*Student Majors*	*Tasks*
Senior Design (continuing)	Electromechanical Engineering	Battery and motor characterization
Senior Design (continuing)	Electrical Engineering	Motor and control, documentation
Work study (continuing)	Electromechanical Engineering	Sensor choice, purchase, and testing; Medical-compatibility planning
Co-ops (employed by professor at Wentworth)	Computer Science and Computer Engineering	Application and Database Design

Table 3: Breakdown of courses, majors, and tasks for spring 2017.

Students have been recruited and assigned tasks, as described in Table 3. The new faculty decision-making hierarchy is put into place, small teams will be used, and frequent meetings will be held to keep everyone on track, both with individual tasks and the big-picture decisions. At the time of submission, no significant conclusions can be drawn, but indications are that the teams will complete their tasks and the progress has been much more consistent.

5 Student Survey Results

At the end of the summer and fall semesters of 2016, students were encouraged to fill out a short survey regarding their experience. The surveys used both multiple choice and short answer questions. Because of the limited number students in each cohort, the quantitative numbers are from a small sample size, and thus revealed little.

Overall, students agreed that the project was interesting, successful, and worthwhile. They also agreed the success came from an improving communication structure and the ability to rely on the full-time co-op student. However, students did respond that the beginning of the semester was “chaotic,” particularly as “there were students who I did not know were even involved in the project until [the mid-semester] meeting.”

Additionally, students in the redundant or overlapping portions were dissatisfied, as some felt they had less to do and others felt over-burdened. One student wrote, “I was under the impression that the project was much smaller in scope.”

Students gave some suggestions, such as “early team assembly, fewer teams, bi-weekly [...] meetings, a co-op fully dedicated ...” Many students also suggested only allowing students in junior or senior-level project design courses to put everyone on equal footing. In the second semester, changing project goals left a few of the students believing there was a “decrease in productivity.”

Many of the insights gained from student feedback were also noticed by faculty and changes were put into place, as described by the previous sections. Faculty did not participate in the survey, but volunteered information to each other less formally. Nonetheless, changes were made each semester based on both student and faculty observation and feedback.

6 Overall Recommendations and Conclusions

While this project and the institutions involved are unique, the lessons learned and recommendations given are applicable to all collaborative projects, particularly interdisciplinary projects between academia and industry. After a full year of planning and executing the collaborative project with the industry partner, the faculty involved with the design of the e-bike have compiled the overall recommendations for similar academia-industry collaboration. These recommendations have been described in previous sections, but will be listed and described again here.

Guidelines and Goals: It is recommended that the industry and academic partners have a firm, yet flexible description of the project’s deliverables and timeline. These guidelines should be detailed enough to ensure students and faculty working on the project have clear goals, allowing them to partition the project tasks appropriately. The timeline of the industry partner is often more accelerated than that of student projects, which creates a conflict between project teams and the industry partner.

Decision-Making: In order to make decisions, it is helpful to have a project manager who can act as a representative of both industry and academia. It is recommended that a principal investigator be assigned, who should have the authority to steer individual projects along with a small cohort of faculty members. This becomes a necessity if the faculty team grows beyond just a few, because a democratized decision process across large numbers of faculty has the potential for delay, which could be problematic and hard to manage. The PI must, of course, remain open to input from all involved faculty and students.

Student Involvement: Once the faculty and industry partner have delineated the goals and tasks of the project, students must be recruited. For an undergraduate institution, as is the case here, that could mean involvement from a variety of classes, including small and large projects, co-ops, etc. From the experience in this project, there are two recommendations. First, limit involvement to students that can dedicate a significant portion of time and effort to the project. Small-scale projects, for example, a 3-week final project worth a percentage of a grade, cannot demand the same commitment as a 15-week project worth a significant portion of the final grade. Second, if possible, hire or recruit a dedicated student (or more than one) to work full-time on the project. This allows teams working part-time to rely on a resource beyond the faculty. Additionally, the faculty can rely on someone to make forward progress, without having to divide their time with other jobs, classes, and commitments. If possible, a co-op student can and should act as both a project manager and a technical expert for the tasks at hand.

Communication: Open and frequent communication is critical to the success of any project. It is recommended that each team has a clear understanding of their individual tasks and their place in the big picture. Any overlap or redundancy should be explained or minimized. Use group emails, shared document repositories, and frequent meetings to help maintain order and facilitate progress. Ideally this infrastructure would be put in place early in the process.

Continuity: Lastly, as students graduate or move on to new semesters, maintaining continuity becomes an issue. It is recommended that, if possible, at least one student remain active across semesters to help maintain momentum. This allows incoming students to rely on the experience and guidance of the veteran participants.

Wentworth Institute of Technology and RRT eBikes embarked on an interdisciplinary, collaborative project involving the enhancement of an existing electric bicycle with biometric feedback and control. A large number of students and faculty were and continue to be involved. However, as the project progressed, inefficiencies and issues arose and were addressed that helped to shape the current state of the project and its infrastructure. In this paper, the lessons learned, changed made, and insights gained were described, including suggestions for communication infrastructure, hiring and recruitment, and the decision-making hierarchy. While the project itself and the partners involved are all unique, the recommendations given apply to a broader audience of academia-industry partnerships and collaborations.

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