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Development of an open and free robotics course

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1 Abstract

Science, Technology, Engineering, and Math (STEM) education is essential to the development of Sub-Saharan Africa. Robotics in the High School education system is one of the best ways to get students interested in pursuing future education in a STEM field. This project involved developing an open and free robotics course that incorporates videos, sample problems, surveys, labs, and quizzes to help developing countries teach robotics. During the IQP our current modules were tested with both Sub-Saharan African teachers and United States High School students. In addition to the course, a low cost robotics kit was designed and built.

2 Acknowledgments

We would like to thank our advisers, Nicholas Bertozzi and Brad Miller, for their support and guidance throughout the project. Additional thanks go to Jason Leboeuf from Worcester Technical High School, who gave us invaluable feedback for the Power Transmission module that was tested with his class. Furthermore, we would like to thank those who organized and attended the the Math and Science for Sub-Saharan Africa (MS4SSA) conference. Special thanks to the translators, who helped us communicate and improve the attendees personal engagement during the MS4SSA conference. Lastly, we would like to thank Neil Heffernan for providing ASSISTments as a tool to improve our canvas modules. Without the guidance, support and time commitment from all these people, these modules would have not been properly developed.

3 Executive Summary

This report is the result of an Interactive Qualifying Project (IQP) to develop an open and free robotics course for use anywhere in the world. This report describes the final result of the research component, the deliverables and actions taken to complete this IQP, and provides a detailed account of the process that was ultimately followed to shape the outcome of this project.

During this project we discovered a lack of robotics content in other countries, primarily in Sub-Saharan Africa. Leading to the involvement with the MS4SSA in order to get useful feedback from Sub-Saharan Africa representatives. The MS4SSA was first organized by the World Bank in 2016 as a resource to revamp mathematics and science education in Sub-Saharan Africa education system. Additionally, it aspires to increase adequate faculty in Africa's education system. As a result, there will be a significant enhancement in STEM field job qualification, a more adept workforce, and exceptional preparedness for post-secondary STEM education in Sub-Saharan Africa.

At the MS4SSA conference, we also learned that many countries in the region had a great lack of resources and content for STEM education. Which results in an obstacle for a more proficient educational system, leading to poor economic and social transformation in Sub-Saharan Africa. However, regardless of their current circumstances and certain concerns such as money, Internet and language barrier, the Sub-Saharan representatives were eager to learn and incorporate the Power transmission and Sensor Programming labs that were shown during the conference into their education system. Lastly, we shared pedagogical practices and teaching materials as resources to be used in any classroom. As a result of the conference, we were able to improve our current and future modules for a more useful tool and resource to others.

In order to get useful feedback from student, we also introduced Worcester Technical High School into a beta version of our current modules for teaching purposes. Additionally, we introduced the school into the learning management system canvas and ASSISTments as resources to teach the modules. The beta version included, outlines for various modules,videos, practice problems, and labs as resources for teaching.

After analyzing the given feedback from the school, we found that students were having concerns with the duration of the videos, the length of the module's labs, and the lack of a pacing guide for students with limited prior experience on the topic to be taught. As a result, the school provided significant feedback for future modules architecture and the addition of a pacing guide for students with different backgrounds and limitations.

This information led us to begin the creation of a series of robotics modules, starting with the Power transmission Module leading up to the conference. At the conference, we realized after speaking with the representatives that the cost of existing robot kits is too high an investment for many of them. The two kits specifically that we looked at were the VEX kit ($450 - $800) and the Lego Mindstorm kit ($350 - $470). As a result we developed a low cost (<$50) kit that they would be able to implement. The intention of the kit was that it would serve as a replacement for one of the pre-existing kits in our courses. We wanted a solution that anyone would be able to manufacture and assemble therefore requiring that it is affordable. The kit when designed is a drivable platform with a detachable arm that is able to communicate wireless through bluetooth to many devices including cellphones. There are also many sensors included in the bill of materials such as IR line sensors and an ultrasonic sensor to make it so that the robot is able to operate autonomously. With the included bill of materials all of the labs in our course would be able to be completed.

4 Authorship

Below is a list showing who was the primary author of each section. We all worked on revising the whole paper and most section had some involvement of all members.

Section	Primary Author	Editor
Abstract	Jeff	Jeff, Keion, Augusto
Acknowledgements	Augusto	Jeff, Keion, Augusto
Executive Summary	Keion	Jeff, Keion, Augusto
Introduction	Jeff	Jeff, Keion, Augusto
Background Research	Jeff	Jeff, Keion, Augusto
Deployment	Keion	Jeff, Keion, Augusto
Robotics Kit	Keion	Jeff, Keion, Augusto
MS4SSA Conference	Augusto	Jeff, Keion, Augusto
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Course Architecture	Jeff	Jeff, Keion, Augusto
Results and Analysis	Keion	Jeff, Keion, Augusto
Conclusion	Augusto	Jeff, Keion, Augusto

Contents

5 Introduction

STEM education is one of the most important aspects of sustainable economic growth within countries because it leads to improved infrastructure and increased competitiveness in global markets. According to the World Economic Forums biannual Africa Competitiveness Report "there is no African country achieving a strong performance in infrastructure, higher education, technological readiness, or innovation"[1] which are key factors in global competitiveness. There is a huge need for investment in higher education in Africa to create a globally competitive workforce. This IQP focuses on getting high school students interested in higher education through the robotics field.

Robotics is an extremely useful tool for educators to get students interested in STEM fields. A study conducted by FIRST [2], which stands for For Inspiration and Recognition of Science and Technology. showed that 87-88 percent of students that participated in their robotics competitions were more interested in doing well in school, with 84-90 percent saying they were going to take more STEM related classes. The result of the FIRST program on students shows that robotics is a great way to motivate and inspire students to go into STEM. It is this technical curriculum which this IQP seeks to generate so that inspired students can get the robotics education they want. In particular, this IQP looks at the deployment of this type of curriculum in Sub-Sahara Africa in collaboration with WPI and The World

Bank's MS4SSA project.

There are three main groups that overlap our objectives: FIRST, VEX, and AFRON. FIRST primarily focuses on inspiring students in addition they do have documentation that helps teams get started with building robots. However, this content wasn't designed to teach robotics. VEX Robotics is both a company and a host of other high school level robotics competitions. VEX is more focused on the educational side of robotics releasing a much more in depth curriculum that overlaps many of the topics covered in the course this IQP is creating.[3] The course this project creates isn't based around the VEX EDR kit which costs approximately $440. [4] This high cost makes it limiting to many schools around the world which is why this IQP also designed a robotics kit that is low cost ($50). The last major organization related to introducing robotics in Sub-Sahara Africa is the African Robotics Network (AFRON). AFRON focuses primarily on deploying existing competitions and course materials to schools in Africa, not on content creation.

One of the major weaknesses of all the existing robotics content was that none of it incorporated online assessments that allowed for quick student feedback and targeted teaching. VEX provides assessments with its curriculum, but they are PDFs that have to be printed out and manually graded. [5] There was also a gap in the availability of low cost ($50) robotics kits that had enough functionality to teach a full introductory robotics course.

The goals of this IQP were to provide a framework for using hands-on lab experiences to improve student understanding of concepts and to create an open and free online robotics course that covers the introductory topics of robotics that are taught in RBE 1001 (More information about RBE 1001 can be found in appendix C). Another goal was to ensure that this course would have online assessments that allow students and teachers to instantly assess the students understanding and what they need to focus on. Alongside the online course, there needs to be a low cost robotics kit that is easily sourced and built by students. The combination of a low cost kit and a free online course will enable students in developing worlds to learn robotics while getting inspired to go into STEM fields.

6 Background Research

At the start of the IQP there were several topics that needed to be researched before creating the robotics course. There was research into what content already existed, how the content should be delivered, and whether it was worth incorporating WPI ASSISTments.

6.1 Existing Content Research

It was decided that all the content used would be WPI content to ensure that WPI would control all aspects of the course and to minimize the possibility of a resource becoming unavailable. Research and analysis of what WPI content already existed was needed before the IQP group could plan out what content to create. There are three main sources of existing WPI robotics content: videos on YouTube, RBE lecture slides, and RBE lab documentation.

The WPI Robotics department has published several videos related to the RBE 1001 course over the years. A list of videos that existed before the IQP is in appendix B. In addition to simply researching what videos existed previously, the IQP involved going through the RBE 1001 slides by lecture and created a list showing what skills are covered in each lecture. The list is in appendix C. This list was used in the process of creating the course road map in the Course Architecture section. After reviewing the existing RBE 1001 labs it was decided that they all needed to be modified for high school student. For example during the power transmission module students have to run robots on a straight ramp whereas the original RBE 1001 lab involved a curved ramp that increased incline, The research into existing content helped maximize the number of modules that could be finished during the 7 week IQP by allowing for the creation of the sensor module without creating additional videos.

6.2 Learning Management Systems (LMS) Research

The main gap in robotics curriculum this IQP is filling is the need for an online course with assessments. Because of this it was decided that the content was going to be delivered via a Learning Management System (LMS). LMS are designed to be deployed by a school and allow teachers to have online courses. While most schools in the United States use LMS, there are far less schools in developing countries that use them. It was important to research what the advantages and disadvantages of various LMS were before creating content because in many of the places this course will be deployed this will be the schools first experience with a LMS.

Moodle

Moodle is the most widely used Learning Management System (LMS) in the world with over 90 million users.[6] This is the primary reason that Moodle was the first LMS researched as part of this IQP. It is open source and community driven, which guarantees that it remains free forever with regular updates. In addition to being widely used and free there are also hundreds of plugins that have been developed to allow a wide range of functionality.[6] During the MS4SSA conference the use of LMS was discussed with participants. It was clear that Moodle was the most widely used because many participants had experience with it. There is also free web hosting available for Moodle.[7] The result of researching Moodle was that it became an important requirement that the course was available to Moodle users.

Canvas

Canvas is a relatively new LMS developed by Instructure in 2011.[8] It is open source like Moodle but isn't community driven development which means it will only be supported as long as Instructure continues to work on it. There is also free hosting available for Canvas but with limited functionality.[9] Canvas is also the LMS WPI uses for campus which means students and professors are familiar with it and there are IT staff on campus who know how to fix any problems that arise down the road. It is this familiarity and support, which leads to the use of Canvas as our central content delivery system for this IQP. Another reason Canvas was chosen as the primary LMS for this project is Canvas Commons. Canvas Commons is a place for teachers in the community to share their classes.[10]

6.3 ASSISTments

ASSISTments is an application developed within WPI for online assessment. It also follows the LTI standard set by IMS Global.[11] ASSISTments use of the LTI standard means it integrates into both Moodle and Canvas. This is important for this IQP project because Moodle compatibility is a major priority. It also has support for Google Classroom which is a very new LMS. It was because of this compatibility that ASSISTments became the center of the courses online assessments. ASSISTments is also unique in that it allows teachers to create hints and related questions so when students have trouble they can get help immediately. As a side bonus to this IQP using ASSISTments, it also helps those at WPI working on ASSISTments by providing a larger user base for their research.

7 Deployment

7.1 Canvas Commons

Canvas Commons is a free learning object repository that enables educators to find, import, and share resources[10]. Commons allows for an easy and efficient means of distribution of our course. The Canvas Commons export file type. IMSCC can easily be imported into any existing Canvas LMS with all content, files and quizzes copying without errors. When attempting to import into the Moodle LMS we were able to successfully copy all the content and files with no errors however there were many problems copying quizzes. Despite this canvas commons is still the easiest means of course distribution as all verification and file management is done by the Canvas LMS group.

7.2 ASSISTments

After discovering problems importing Canvas Commons quizzes into other learning management systems we looked into ASSISTments as an alternate solution. Our decision to integrate ASSISTments into our course was primarily as the means of quiz distribution. ASSISTments is integrated into both LMS platforms and serves as a means by which quiz and assessment questions can be accessed. The ASSISTments group has a set of questions related to a specific topic that can be compiled into a quiz or assessment. The use of ASSISTments fixes the compatibility problems encountered previously.

8 Robotics Kit

8.1 Goals

During this IQP we aimed to provide robotics content to a large number of people, however throughout the project we discovered the cost of pre-existing robotics kits such as those sold by LEGO and VEX was very high ($400 - $800). In combination to the price these kits were drastically different to the kits used at WPI, being that in the case of the Lego Mind Storm kit the Java programming language is used instead of variants of C used in the Vex robotics kit and those used at WPI. To resolve this we decided to create our own low cost 3D printable platform based around the Arduino micro controller. We targeted a sub $50 system including all components and hardware required to have a fully working robot.

8.2 Method

When designing our robot we had to develop a way to create the chassis out of a low cost and durable material with an easy means of manufacturing. This led us to use 3D printing because the cost of consumer grade printers has fallen drastically in recent times making them the most affordable means of making these. Our other options would have been CNC machining and laser cutting, however these processes would have been much more expensive to setup. When designing for 3D printing, many things have to be taken into consideration, including the strength of the layers and the direction they're printed, avoiding any overhanging, importantly the tolerances and size limitations of 3D printers.

For our main controller we chose to use an Arduino micro controller, specifically the Arduino nano. We chose this platform due to the sheer amount of available information and support available on the Internet. The Arduino is one of the most popular consumer grade microprocessor platforms on the market. The use of an Arduino also gives those using our system an introduction to embedded programming skills which is very common in higher level robotics applications.

WPI's classes use a custom shield that is not commercially available. We had to find an inexpensive and readily available replacement. We decided to get an Arduino nano breakout shield which provides headers with VCC (5v), Gnd and signal pins which work perfectly for common motors and sensors.

When deciding which sensors to incorporate in our design, we looked at the introductory robotics course at WPI, RBE 1001. We decided that we would use 3 IR reflectance sensors to be able to do a line following challenge, an ultrasonic sensor in order to be able to demonstrate PID control, and a potentiometer to be used to keep the position of an arm once again to demonstrate PID control in another perspective.

When searching for motors we were looking for a simple integrated system so as to not have to handle motor drivers separate to the motors, this led us to find continuous rotation servo motors. The chosen motors are low cost, light weight motors.

8.3 Feedback

The whole design process for the robot spanned across about two weeks, this included the brainstorming phase, choosing and sourcing components, initial design, test prints, alterations, and re-prints. In this time we met with our advisors to discuss the design a number of times. After the initial design we showed our advisors and we discussed all the mechanical limitations of our current design as well as improvements that could be made. These concepts were incorporated into the design. These included adding idler bearings for support as to not apply too much axial load to the motors as well as other design changes. We then did our first print of all the parts.

Once we had completed the first full print of all the parts we assembled it as far as possible, however we discovered there were a number of issues we had not realized. Such things included the gap for the motor wires being too small, the offsets from the motors being too small causing the to fit too tight, and holes not aligning correctly. However, this did give us many ideas as to improvements we could make such as to split the axle away from our gears and print them in a different orientation as to improve their strength characteristics.

We took the things we learned from this process and made all necessary alterations to our files and ran a final print of all the components, these took about 25 total hour of print time.

8.4 Results

In the end, we were able to Develop an affordable 3D printable robot with a sub $50 price tag. All of the components total up to approximately $43 not including shipping costs as they will vary. The total cost, including filament for the 3D printer should sum to approximately $50 per robot.

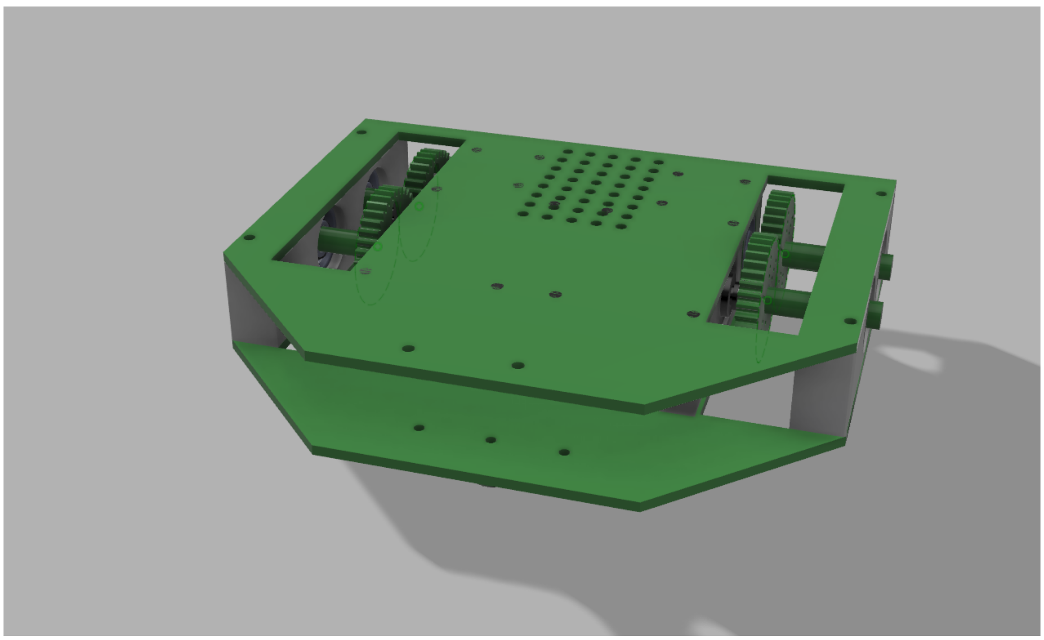

Figure 1: Rendering of Robot chassis

9 Mathematics and Science for School in Sub-Saharan Africa (MS4SSA) Conference

9.1 Goals

The MS4SSA was launched by the World Bank in 2016 as an initiative to improve and strengthen math and science education in Sub-Saharan Africa education systems. Furthermore, by improving their weak foundations in these subjects there will be an improvement in job qualification in modernizing economies as well as preparedness for post-secondary STEM education. MS4SSA aims to increase the number of qualified faculty in Africa's education system and to encourage future development of a more adept workforce for Africa's economic and social transformation [12].

Over the course of one day, Worcester Polytechnic Institute was able to introduce the Sub-Saharan representatives to the broad field of Robotics through a series of two labs. The goals of the labs were to engage Sub-Saharan African representatives using robotics and to show them a new world of opportunities. Additionally we shared content knowledge, pedagogical practices, teaching materials, and tools for use in a robotics class. [12].

9.2 Method

Lab 1: Power Transmission

The goal of this lab was to introduce accurate representations of free-body diagrams (FBD), drive line speed/torque transmission effects, optimal transmission ratio given design objectives, and utilization of motor curves to predict drive line performance. The lab consisted of a series of questions as well as hands on experience to determine the kinetic coefficient of friction between a wooden block and a wooden ramp and between the base bot and the wooden ramp. Finally, a 1:1 and 5:1 gear ratios were introduced in order to understand their performance to choose the optimal option as needed for the desired design. Through this lab the Sub-Saharan representatives could assimilate and sharpen the skills mentioned.

Lab 2: Sensor Programming

The goal of this lab was to have a brief introduction to basic programming concepts, turning performance of 2WD robots, discerning limitations of dead reckoning autonomous robot operations and a clear introduction to proportional control. The lab had a brief introduction, which explained the platforms and software to be used in the lab, in this case Arduino. During this lab, they were asked to program the robot to make a square, additionally they modified the constant proportional coefficient (Kp) to make the robot drive forward and stop 10in away from a wall through the use of a proportional control. Through this lab the representatives could engage and learn the new skills mentioned.

Given the language barrier and the large size, the Sub-Saharan representatives were broken down into three groups: all French, all English, and half French and English to improve personalized engagement on the topics discussed. Each lab lasted approximately two hours, and was accompanied by the student body to guide and support them as needed during the tasks. All the labs started with a brief introduction of the subject, followed by hands on experience where most seem to be more engaged.

9.3 Feedback

To better understand how to improve our modules, we designed a survey to gather further information about their experience and struggles with the labs. Additionally by attending to all the labs, we were also able to catch a glimpse of their major concerns about the robotics field and its development into the African education system. After analyzing the data given by the survey and the conference we could discern in what areas people are having the most complications. Some of these areas are: Money Barrier, Internet Barrier, Language Barrier, and Time constrains.

Internet Barrier

At the conference some representatives were angst of the usefulness of the modules and its content because a part of their schools don't even have Internet access. We highly considered Rachel servers, which did not required Internet connection in order to use the canvas modules. However, ASSISTments requires internet and therefore Rachel servers were not the right solution for our current modules. Further development must be made in order to tackle such problem.

Language Barrier

During the labs the language barrier seems to have a sizable effect on communication, interaction, engagement and understanding for the Sub-Saharan representatives. Additionally, the poor automatic translation to French on the published videos limits their understanding and engagement on the topic being taught. We realized that the language barrier limits the interaction, feedback and even the usefulness of the modules and labs being taught.

Time Constraint

Throughout the labs, several representatives seem to have difficulty following along with the labs given its broad content. They complained about how the lack of time and broad topics were a barrier to fully comprehend the discussed topics. Additionally, they argued that they did not have enough time to even finish the lab on time and that their content was too complex to be understood in two hours. Therefore, these problems lead to less efficient modules and labs, as well as limited learning capabilities.

To assess these problems, a pacing guide was developed. Students need a simple, interactive, consistent but also manageable way to learn something new. With the use of this guide, students will be efficiently able to grasp the basic knowledge of robotics at their own pace given their current background. As explained before, if students feel overwhelmed by the robotics content, they might believe that they are not capable of understanding such a complex subject. Therefore better manageable labs, assignment, and videos must be developed and incorporated into the modules.

9.4 Results

The conference contributed to constructive results and feedback to improve our outlines for future modules and labs. As a clear result, Sub-Saharan representatives had a more in depth experience in the field of robotics. Additionally, they realized that anyone could design, build and program a robot with proper guidance. During the lab sessions it was clear that the labs' content was too broad to be taught over such a short period of time and therefore must be broken down into smaller sections to improve future experiences. Nevertheless, all the Sub-Saharan representatives seem engaged in the topic, therefore successfully introducing over 100 representatives in the field of robotics.

10 Worcester Technical High School

10.1 Goals

Worcester Technical High School is a vocational-technical high school and a member of the Worcester Public Schools district [13]. It has over twenty-three different trades from four different academies from which students can choose. Offering students a high school Diploma and Technical certification of accelerated academic courses and education for equity in both the classroom and the workplace [13]. Moreover, helping students grow academically and socially for future success.

After deliberate consideration, Worcester Technical High School expressed an interest in applying the Robotics modules to their freshmen students. The goal was to introduce the school into a beta version of our modules and a full version of the Power Transmission module for teaching purposes. As well, to introduce the school into the learning management system canvas as a resource to teach the modules. Likewise, gather required feedback for future modules and their content, as well as evaluating our current Power Transmission module and its content. Lastly, we were planning to provide a correct representation of a Worcester Polytechnic Institute student lifestyle.

10.2 Method

As a means of education, we provided Jason Leboeuf with a teacher email account, password and unique canvas website for their freshmen students with our most updated modules and their content. Furthermore, we provided a video as a brief introduction to canvas, on top of instructions on how to add students into the robotics course and its modules.

The course included, but was not limited to outlines for various modules, videos, practice problems, and labs as resources for teaching. Leboeuf implemented the Power Transmission module over a period of three days, where he assigned videos and practice problems. During the third day, we made an appearance at Worcester Technical High School to give an overview on how to teach the first lab along with the required materials. Thereafter, answer any questions they might have about Worcester Polytechnic Institute, along with providing some advises on how to succeed in college.

Power Transmission Lab I

The goal of this lab was to provide a clear overview on how to teach subsequent labs and modules for exceeding results. Not to mention, introduce free-body diagrams, drive line speed/torque transmission effects, optimal transmission ratio, and utilization of motor torque, power, and speed curves to predict drive line performance. For this lab, we focused on the hands on experience sections to determine the coefficient of friction between the wooden block and the wooden ramp through pulleys, along with speed test given different gear ratios on the base bot. Through this lab the freshmen students were easily introduced into the broad field of robotics.

10.3 Feedback

To have a more useful feedback, we decided to be present during the execution of the Power Transmission Lab I. All along we were gathering meaningful information to further develop our current modules to improve future results. After meticulously analyzing the given information, we could distinguish the areas that caused the most problems for the students and their learning capabilities. Some of these areas are: duration of the videos, length of the Power Transmission lab, and a lack of a pacing guide.

Length of the Power Transmission Lab

In the same manner that the Sub-Saharan representatives were struggling to finish the Power Transmission lab on time, the freshmen students seem to be facing the same exact results. Leboeuf complained about how the lab covered too many topics over such a limited period of time. The excess of content leads to an undoubtedly lack of concentration from the students. Consequently, the lab seems to have lost its purpose and usefulness as a teaching tool. Therefore leading to impractical modules for the education system.

To take measures to this problem, simple more concise labs must be developed and further analyzed. Our current labs must be broken down into smaller sections easier to follow for High School students. Furthermore, future research must be done to estimate how many topics should be taught in each lab in order to optimize results and keep students engrossed in the topic being taught.

Duration of the videos

At the end of our visit to Worcester technical High School, Leboeuf gave us verbal feedback about the extent of our current videos. It seems that students have a short retention period and our current 15-30 minute videos overwhelm the students and their learning proficiency. Furthermore, students do not want videos that resemble school power points because these could be taught and better explained during class.

To appropriately deal with this problem, future videos must provide a distinct alternative to enhance passion on the topic being taught. Our current videos might have worked for college students, but we identified that learning proficiency differs from high school students and college students. Therefore, these high school students need a shorter and interactive way to learn a new topic. Smaller and more concise videos must be recorded, as well as including animations for visual learners. Further research must be developed, to understand the most convenient way to introduce students into a new subject without affecting their learning competence. Consequently, by following these directions future modules would be more satisfactory and useful for students.

Lack of a pacing guide

Given the lack of time between the MS4SSA conference and the high school Power Transmission pilot program, we were not able to update the modules as needed before providing it to Worcester Technical High School. Therefore a pacing guide was missing, and according to Leboeuf the module was hard to follow given their students' background. Each module has an expected suggested preparation, which must be taken into consideration before starting a module, but it seems that different backgrounds also need different paces to teach the modules in a more adequate manner. Consequently, this shows that developing a pacing guide is a must in order to successfully teach the modules and furthermore implement them in the education system.

10.4 Results

The visit to Worcester Technical High School has provided beneficial results and feedback for future modules. During this visit we were able to recognize different ways to enhance our current module, along with future module development. Additionally, as a result of our visit students convey the impression of engaging the new field of robotics, often overlooked. Not to mention, that regardless of the minor disadvantages in the Power Transmission module, it is a useful and engaging module for high school students.

Setting up canvas for free

For schools and groups without a setup canvas hosting server, there is a free alternative provided by the Canvas lms group. This can be accessed by selecting teacher from this address, `https://canvas.instructure.com/register_from_website` . Once selected you should be redirected to this screen;

Once here, fill in all required sections of the displayed window. Once com-

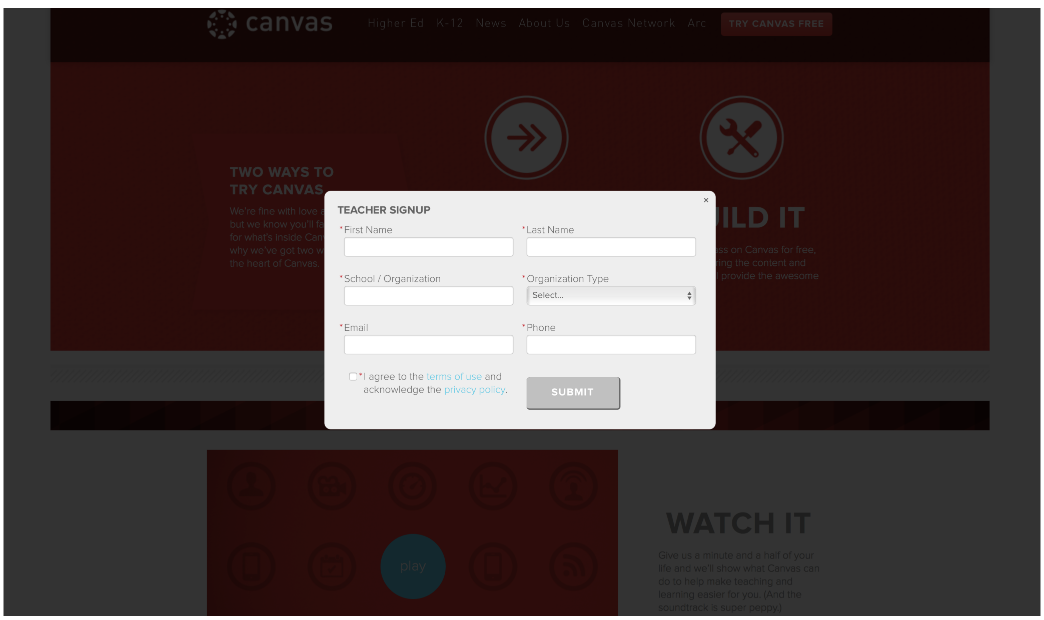

Figure 2: Sign up screen for Canvas LMS

pleted an email will be sent to your provided email containing the website, username and password for the admin/teacher account.

11 Course Architecture

The development of the robotics curriculum for the course will occur as an IQP series. In order to facilitate continuity with future groups there was a need for a course road map that described what modules would eventually be created and what topics each would cover. An analysis of all the RBE 1001 lecture slides was done to determine what topics were covered in RBE 1001. Then these topics were grouped into bit size modules that could be taught as a course. There are eight modules in total in the course road map that was created. In addition to the course road map there was a need for a module outline which lays out what each individual module will look like.

11.1 Course Road map

Force Analysis Module

Originally basic force analysis was incorporated into the Power Transmission Module but while at Worcester Technical High School testing the module it became clear that there was a need for a module that covers basic force analysis. The force analysis module will cover how to create a Free Body Diagrams (FBD) and how to analyze the forces and torques using complex numbers and vectors. The goal is that by the end students will be able to analyze skid steering torque problems on ramps. The background knowledge required for this course is basic physics, basic trig, and an understanding of complex numbers.

Power Transmission Module

The power transmission module is primarily focused on teaching the relationship between torque, speed, and power within various transmissions. It also covers related topics like chains, worm gears, and power transmission efficiencies. This lab builds on the force analysis module heavily, but also requires a background knowledge of how DC motors work. By the end of the module, students should be able to design power transmissions for a variety of robotic applications taking into consideration efficiencies and motor power requirements.

Basic Programming Module

The basic programming module is designed to teach students the basics of programming so they have the background required for later modules. This module covers how and why to create functions, how variables and variable types work, how code flow control works, and the difference between behavioral programming and state machines. There is no expectation of prior programming experience. This module is based around VEX pros, a programming language developed by Purdue university for use on the VEX controller.

Intermediate Programming Module

The intermediate programming module builds on the basics taught in the basic programming module by introducing students to arrays, pointers, and classes. These topics are very useful for students to learn because it allows them to utilize object oriented programming. This module also introduces students to Arduino. The reason Arduino is taught instead of continuing with VEX pros is that it gives inspired students the knowledge required to utilize low cost Arduino micro controllers in their own projects, whereas the VEX controller price limits them to the classroom for many students.

Basic Electronics Module

The primary goal of the basic electronics module is to introduce the concepts around Kirchhoff's laws and to give students experience analyzing DC resistor networks. This module also introduces students to photo-resistors and the applications in which voltage dividers are useful. By the end of the module, students should not only be able to analyze resistor networks, but design voltage dividers for various applications. There is no required background for this module, but understanding matrices will help with solving systems of linear equations.

Intermediate Electronics Module

After the student have completed the Basic Electronics Module they can progress onto the Intermediate Electronics Module. The Intermediate Electronics Module is primarily focused on introducing students to basic DC operational amplifier circuits. The goal is to get students to the point where they can build their own line sensors using photo-resistors and operational amplifiers. In addition to covering operational amplifiers there will also be information covering PWM and diodes. The decision to put these two additional topics in the intermediate module was based around the goal of covering the equivalent content taught in WPI's RBE 1001 course.

Controls Module

The controls module builds on the knowledge of the basic programming module and the basic electronics module to introduce students to the concept of using sensors in closed loop control systems. The module goes over several very common sensors such as potentiometers, ultrasonic range finders, infrared range finders, encoders, etc. This module also covers the PID controller. By the end of the module, students should be able to control the position of the RBE 1001 robot arm and control distance to a wall using the ultrasonic range finder. In addition to having completed the basic programming and basic electronics modules it is recommended that students have a base understanding of how derivatives and integrals work. Note this basic calculus background is recommended not required because students can understand generally how PID works without fully understanding these calculus concepts, but their understanding is improved if they can understand how the math of a PID controller works.

Pneumatics Module

Pneumatics is briefly covered in RBE 1001 but for completeness of the curriculum, it also gets a module. This module, like the RBE 1001 slides, is short but covers an overview of various pneumatic parts and their uses. It also covers the basic equations used to compute how much force or pressure an actuator needs to complete a given task. As this module is much shorter than the other modules and because the kits don't include pneumatics there is no specific lab for this module.

11.2 Module Outline

The module outline is designed to create a template for what each module should have in it. It is important to note that this is just a template and specific modules might have to deviate slightly.

Module contents

- Overview page
- Pacing guide
- Content video(s) with accompanying assessments
- Practice problems with worked out solutions
- Lab Instructions/Setup guide
- Lab worksheet and solutions
- Lab Videos

Overview Page

The overview page is suppose to be a single page that a teacher and student can look at and understand what's involved in the module. It should include the learning objectives, an outline of what the module includes, and it should include an overview of what background knowledge is needed. It is important that this document be short and well organized because teachers will likely use it to assess if they want to teach a module.

Pacing Guide

Each module should include a pacing guide which helps teachers adapt the course for their specific students. This guide has a suggested speed the content should be taught given a specific student level. This is important because the content being created might be taught to high school freshman or high school seniors. Seniors can go through the content at almost the same rate as WPI students whereas high school freshman will need to go much slower so the understand. Many teachers will not have gone through the module themselves so they don't know how fast they can cover the content, this is where the pacing guide helps them.

Content Videos and Assessments

Each module covers a set list of topics. Each topic should get its own video covering it. These videos should be no more than 10 minutes but ideally they are around 5 minutes. Each video should also have an associated assessment that verifies that students understanding of the topic presented. These assessments will be online using WPI ASSISTments. They should also have hints for students when they get the problem wrong on their first attempt. It is important that there is feedback for students because it lets them know what they need to study more. In addition, it allows teachers to focus on problem areas by giving them an overview of what problems students had in the class.

Practice Problems

In addition to the video assessments, each module also includes practice problems. These practice problems cover more than a single topic and are more application problems that show students how the information they just learned is useful. These problems also come with worked out solutions for the teachers so they can help students better understand where they go wrong when solving the problems. It is important to recognize that the video assessments are to make sure students understand the content of a single video whereas the practice problems are to make sure they understand the entire module. Ideally these problems will relate directly to the labs so students can continue to build off their prior work.

Lab Instructions/Setup Guide

Each module has a lab associated with it to engage students and to give them hands on experience. Each module includes a lab instructions guide which covers how to setup the lab, how to run the lab, and what is required for the lab. When creating this document it is important to remember that many of the teachers will not have any robotics experience prior to teaching the course and as such need a lot of guidance on how to run a robotics lab.

Lab Worksheet and Solutions

The lab worksheet and solution included in each module provide questions and guidance for students while they complete the lab. It forces students to focus on the engineering aspects of the lab. It also guides students to better understand how the robots behaviors relate to the topics they learned in the modules. The lab solutions also need to show worked out solutions like the practice problems so students know what the correct answers are. It is important to emphasize to student that their results will vary from the solution because they are collecting experimental data.

Lab Videos

Each module should include lab videos which serve to provide instruction for the lab. The videos basically serve to visually show how the lab is suppose to work and might even include example results (depends on the module). While testing the modules at the on campus MS4SSA conference these videos became even more important because they helped bridge the language gap and also they helped with the limited time because it allowed the teachers to see how the lab was suppose to work.

12 Results and Analysis

The course of this project led us in many different directions, we began creating solely introductory content for robotics, we then went onto developing an entire course that could be packaged and given to teachers and groups that wanted to use the course, to finally developing our own platform that could be used to compliment the content in our course.

In the original development of the power transmission course we made many discoveries, such as that a lot of the pre-existing content that the WPI Robotics Engineering department had previously made relied heavily on the RBE 1001 course to compliment it. Additionally, we had to develop many videos to compliment the content explaining things such as gear ratios, transmissions and how to actually complete the labs in the module.

While assisting with the lab sections at the MS4SSA conference we saw that many of those who had not watched the videos had difficulties completing the labs. When we talked to many of them we learned that a lot of the content was still complicated to them despite the fact that they are teachers of subjects like math and physics. We spoke with them some more about the content and learned that they like the videos and their style however they needed more explanations of the basics and even some more detail of the content in some of the sections.

We took the feed back from the conference and applied it to our over all course that we had gone further into the development of. We then went to Worcester Technical High school and presented the content to a class of 12 freshman students aging from approximately 14-16, many of whom had not yet taken classes such as trigonometry which our course relied heavily on. Despite this the students enjoyed they way the course was setup and had fun while learning it. After the class we spoke with Jason Leboeuf who had shown the students the videos of the module the day before. His feedback was overall positive however he had a very important point which was to keep the videos as short as possible if our target demographic was high school students. His recommendations were to keep the length of the videos to about 10 minutes as to keep the students entertained and attentive. in addition he suggested breaking the videos down into multiple sections that could be assigned to the students over multiple days.

After analyzing the collected data, we decided that our best option would be to further develop the platform on which the course would be developed in the future. This is because when trying to decide which modules, every existing platform uses its own means of programming, its proprietary set of sensors and is likely to have something changed int the near future. Due to this we decided to go forward designing our own robot kit for as lower cost in order to make it as accessible as possible. The original target was at most $100 price tag however strove to keep the cost below $50 in order to make it as feasible as possible.

Once we had our platform laid out we were able to use the existing WPI Robotics content for sensors and create a sensor module for our course. We tested our guidelines for module creation by following them. We discovered they were well laid out and made the process a lot simpler than doing everything at once figuring out how to do each thing. We made two lab documents to follow for an implementation of the lessons learned in the videos. The module was applicable to both our developed platform as well as any other existing platform. The only aspects that will not transfer directly would be the code and coding guidelines. The

Overall as a project we successfully completed what we set out to do, we created a means to spread robotics content to the masses. We did stray away from our original project however in the end we have successfully created a very good starting platform on which other groups can easily develop content for. We intend that this project will persist and that future IQP groups will further develop content for this course.

13 Conclusion and recommendations

In conclusion, over a seven week period we have developed the foundations of an open and free robotics course that pursues to improve the educational system of under-developed countries. This course currently contains two modules, that were fully developed and tested through the MS4SSA representatives and Worcester Technical High School's freshmen students.

Due to the short length of this seven week project, we were not able to thoroughly incorporate and enhance our modules or develop more modules for future educational purposes. Nevertheless, we were able to organize various modules' outlines that could be easily developed in the near future. Additionally, we developed a basic robotics kit for under $50 for schools in Africa that could not easily afford a Vex Robotics kit that ranges form $450-800. However, our kit must be further developed and tested in order to be able to incorporate it into course's modules. Lastly, in order to maintain the course quality, constant research and pilot tests must be carried out in the future to provide a useful and engaging course for everyone that needs it.

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[17] WPI Robotics. Op amps playlist. https://www.youtube.com/playlist?list=PLg88X7N-g5bxL45k2MRRreXkL1TK2DsZo, June 2017.

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[19] Brad Miller. Robot controls playlist. https://www.youtube.com/playlist?list=PL8BLGj0RyhMzNXX9gHBosWPRbqqn0gJUQ, June 2017.

15 Appendix A: MS4SSA Survey

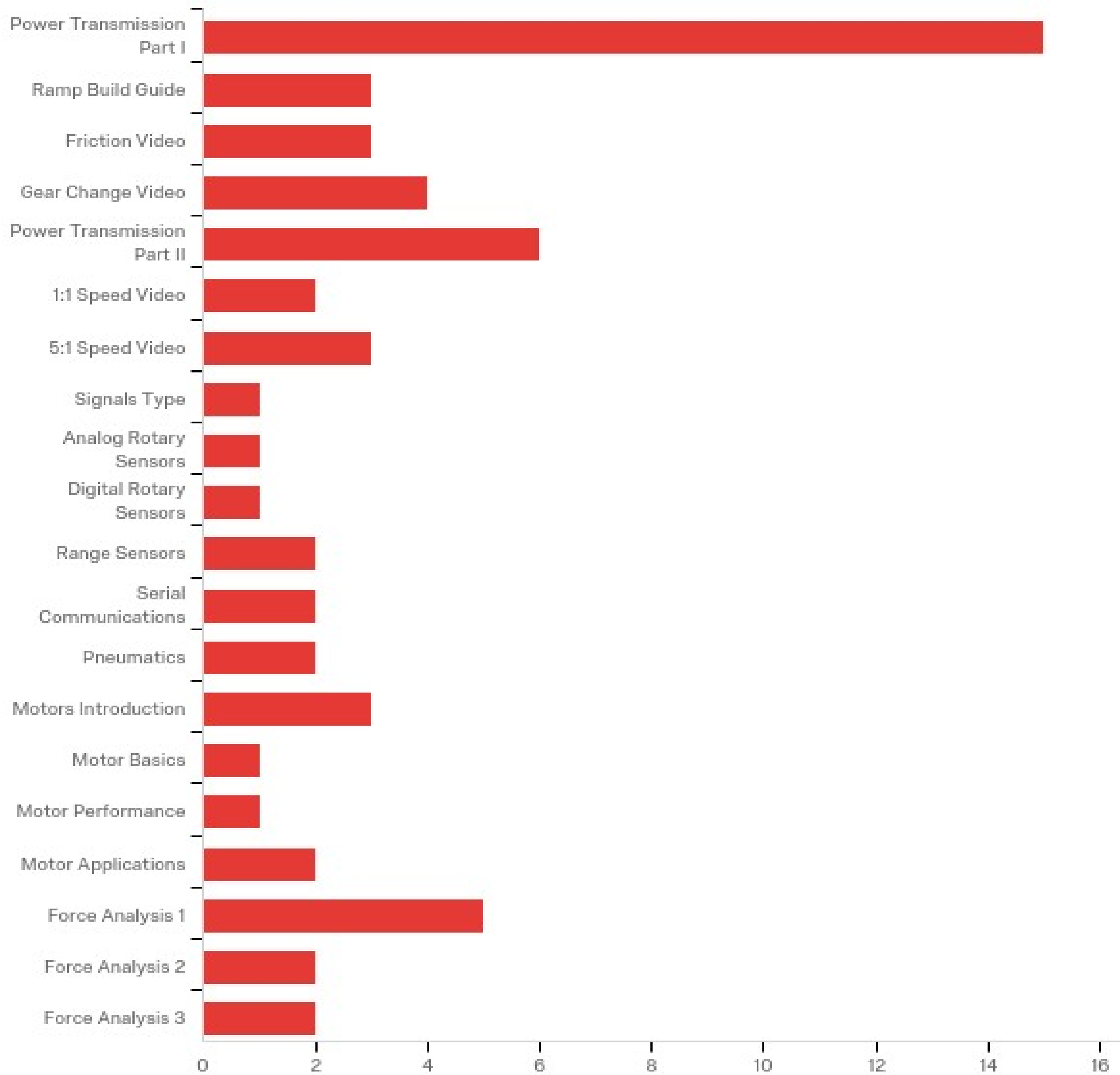
A survey was given after the MS4SSA conference workshops. Below are the results of the survey. It is important to know that during the workshop participants watched the Power Transmissions Part 1 video, which explains why that video was the most viewed in the survey. Additionally, all the questions asking about video feedback (Example Q6) only appeared if participants had watched the video, and therefore those videos that were not watched have little to no feedback.

Default Report

IQP-Conference Robotics Module Feedback

June 23rd 2017, 6:37 am EDT

Q5 - Which video(s) did you watch?



#	Answer	%	Count
1	Power Transmission Part I	24.59%	15

2	Ramp Build Guide	4.92%	3
4	Friction Video	4.92%	3
5	Gear Change Video	6.56%	4
3	Power Transmission Part II	9.84%	6
6	1:1 Speed Video	3.28%	2
7	5:1 Speed Video	4.92%	3
8	Signals Type	1.64%	1
9	Analog Rotary Sensors	1.64%	1
10	Digital Rotary Sensors	1.64%	1
11	Range Sensors	3.28%	2
12	Serial Communications	3.28%	2
13	Pneumatics	3.28%	2
14	Motors Introduction	4.92%	3
15	Motor Basics	1.64%	1
16	Motor Performance	1.64%	1
17	Motor Applications	3.28%	2
18	Force Analysis 1	8.20%	5
19	Force Analysis 2	3.28%	2
20	Force Analysis 3	3.28%	2
	Total	100%	61

Q6 - Power Transmission part I video feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Video Quality	60.00	100.00	85.00	12.21	149.20	10
Usefulness	70.00	100.00	88.70	10.97	120.41	10
Translation Quality (if applicable)	52.00	100.00	76.17	16.46	270.81	6

Q7 - Ramp Build Guide feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	0.00	0.00	0.00	0.00	0.00	0
Usefulness	0.00	0.00	0.00	0.00	0.00	0
Translation Quality (if applicable)	0.00	0.00	0.00	0.00	0.00	0

Q8 - Power Transmission Part II feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	49.00	100.00	80.67	22.57	509.56	3
Usefulness	61.00	100.00	84.67	16.98	288.22	3
Translation Quality (if applicable)	50.00	50.00	50.00	0.00	0.00	1

Q17 - 1:1 Speed Video feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	51.00	51.00	51.00	0.00	0.00	1
Usefulness	71.00	71.00	71.00	0.00	0.00	1
Translation Quality (if applicable)	52.00	52.00	52.00	0.00	0.00	1

Q18 - 5:1 Speed Video feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	50.00	69.00	59.50	9.50	90.25	2
Usefulness	40.00	77.00	58.50	18.50	342.25	2
Translation Quality (if applicable)	40.00	61.00	50.50	10.50	110.25	2

Q19 - Signal Types feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	0.00	0.00	0.00	0.00	0.00	0
Usefulness	0.00	0.00	0.00	0.00	0.00	0
Translation Quality (if applicable)	0.00	0.00	0.00	0.00	0.00	0

Q20 - Analog Rotary Sensor video feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	0.00	0.00	0.00	0.00	0.00	0
Usefulness	0.00	0.00	0.00	0.00	0.00	0
Translation Quality (if applicable)	0.00	0.00	0.00	0.00	0.00	0

Q21 - Digital Rotary Sensors feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	0.00	0.00	0.00	0.00	0.00	0
Usefulness	0.00	0.00	0.00	0.00	0.00	0
Translation Quality (if applicable)	0.00	0.00	0.00	0.00	0.00	0

Q22 - Range Sensors feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	0.00	0.00	0.00	0.00	0.00	0
Usefulness	0.00	0.00	0.00	0.00	0.00	0
Translation Quality (if applicable)	0.00	0.00	0.00	0.00	0.00	0

Q23 - Serial Communications feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	83.00	83.00	83.00	0.00	0.00	1
Usefulness	85.00	85.00	85.00	0.00	0.00	1
Translation Quality (if applicable)	0.00	0.00	0.00	0.00	0.00	0

Q24 - Pneumatics feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	49.00	49.00	49.00	0.00	0.00	1
Usefulness	59.00	59.00	59.00	0.00	0.00	1
Translation Quality (if applicable)	9.00	9.00	9.00	0.00	0.00	1

Q25 - Motors Introduction feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	93.00	93.00	93.00	0.00	0.00	1
Usefulness	58.00	58.00	58.00	0.00	0.00	1
Translation Quality (if applicable)	12.00	12.00	12.00	0.00	0.00	1

Q26 - Motor Basics feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	0.00	0.00	0.00	0.00	0.00	0
Usefulness	0.00	0.00	0.00	0.00	0.00	0
Translation Quality (if applicable)	0.00	0.00	0.00	0.00	0.00	0

Q27 - Motor Performance feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	0.00	0.00	0.00	0.00	0.00	0
Usefulness	0.00	0.00	0.00	0.00	0.00	0
Translation Quality (if applicable)	0.00	0.00	0.00	0.00	0.00	0

Q28 - Motor Applications feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	0.00	0.00	0.00	0.00	0.00	0
Usefulness	0.00	0.00	0.00	0.00	0.00	0
Translation Quality (if applicable)	0.00	0.00	0.00	0.00	0.00	0

Q29 - Force Analysis 1 feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	51.00	89.00	72.25	13.74	188.69	4
Usefulness	72.00	80.00	76.00	2.92	8.50	4
Translation Quality (if applicable)	12.00	78.00	50.75	24.61	605.69	4

Q30 - Force Analysis 2 feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	81.00	81.00	81.00	0.00	0.00	1
Usefulness	81.00	81.00	81.00	0.00	0.00	1
Translation Quality (if applicable)	82.00	82.00	82.00	0.00	0.00	1

Q31 - Force Analysis 3 feedback
(0 is worst and 100 is best)

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	75.00	75.00	75.00	0.00	0.00	1
Usefulness	76.00	76.00	76.00	0.00	0.00	1
Translation Quality (if applicable)	76.00	76.00	76.00	0.00	0.00	1

Q14 - Lab Feedback

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
How did the lab go overall? (0 is worst, 100 is best)	60.00	100.00	84.14	12.65	159.98	14
How difficult was the lab? (100 is hardest)	10.00	100.00	61.79	22.56	508.74	14
How much did the videos help with the lab? (100 most helpful)	11.00	100.00	63.15	25.79	665.05	13

Q2 - Overall feedback from the robot workshops

Set the slider to indicate your response. 0 is worst and 100 is best.

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
Overall Quality	64.00	97.00	83.55	11.03	121.70	11
Usefulness	62.00	100.00	86.18	12.79	163.60	11
Ease of use	40.00	97.00	62.09	18.25	333.17	11

Q9 - What do you think went well with the workshops and the modules?

What do you think went well with the workshops and the modules?
Tout c'est bien passe.
je pense queles videos sont tres utiles pour apprendre fqcilement
Mon temps d appropriation est inssufissante
programmation des robots
The videos were well concieved, the audio quality was also good. The presentation was lucid and clear. It was easy to relate to the videos, since the course materials were readily avialable.
The lectures and the facilitators were good enough to motivate and make the contents clear to the participants
(1) The presentation on introduction to robotics: The SWOT analysis assisted us to reflect on aspects of our action plan (2)   The practical activities on robotics: It was quite exciting and captivating
La programmation s'est bien passée. Au niveau mécanique, il y eu plus de difficultés à entrer dans le site cel a entrainé un suivi difficile des explications.
Friendly use
The explanations were clear and we could do it.

Q10 - What improvements would make the workshops more successful?

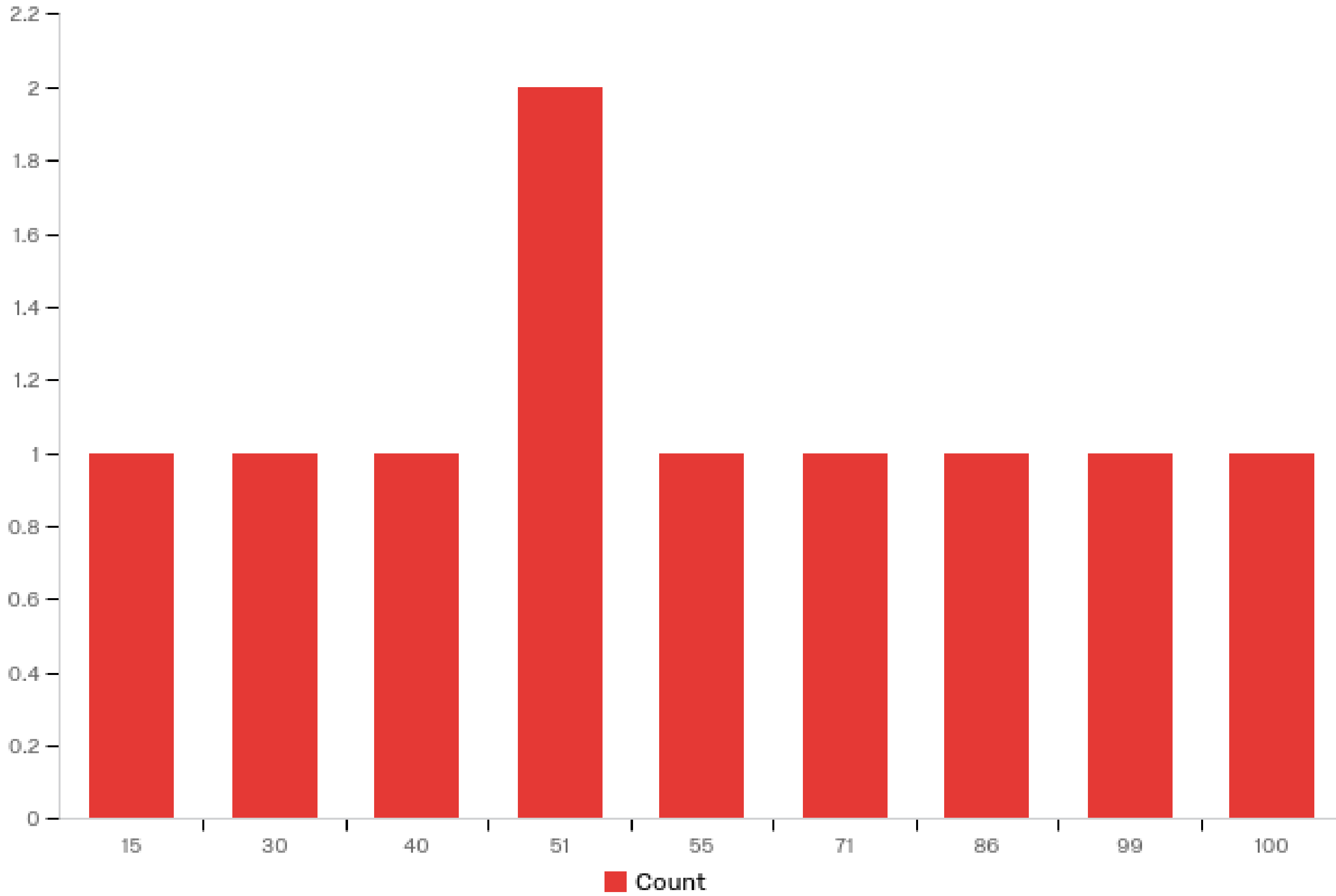
What improvements would make the workshops more successful?
Non
non on a bien parle dans les modules
Peut etre oui
There can always be room to improve the simplifying of the examples. It is very simple yet, full of relevant content.
Increase the time. Most of the participants seemed to wish to continue with the sessions
(1) We need more of practical sessions. A lot of time should be devoted to this. Exposure to the facilities makes us appreciate more the relevance of the training materials
Les ateliers sont formidables car bien propres et bien entrenus et spacieux ce qui est favorable aux apprentissages.
I loved above all the programming part. Longer period should have been allocated to this.
Go step by step and wait for all the participants to be on the same page; otherwise some are still at the back. Please check the login and password before the start of the session. It did not work for some of the computers and we had to change place.

Q11 - List any suggestions you have

List any suggestions you have
C'est une bonne experience.
traduire mieux en francais introduire par ce qui est plus simple
une meilleure appropriation me permettrait d etre plus objectif
None
increase of the time
As in the above
- Prendre tout le temps d'expliquer les différentes étapes avant de commencer les exercices. Cette remarque est valable aussi bien pour la programmation que pour l'atelier de mécanique.
Check everything works properly prior to the session. But this is minor and does not affect overall satisfaction.

Q12 - How likely are you to use this course? (0 - never using it, 100-definitely using it)

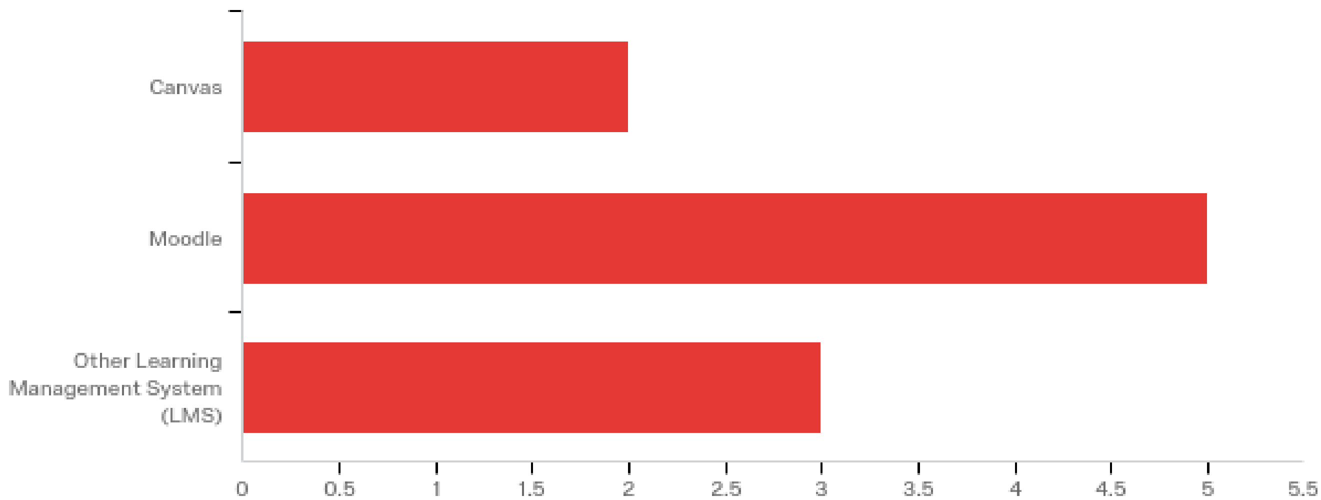
Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
How likely are you to use this course?	15.00	100.00	59.80	27.26	742.96	10



Q13 - Enter contact information below if you would like to receive the Canvas/Moodle module via email

Name	Email
MADOUGOU	nassara01@yahoo.fr
Oumar	galoba2001@yahoo.fr
Dr. Olushola Odusanya	shola2@hotmail.com
Sarifa Fagilde	samfagilde@hotmail.com
Mathias January	mathiasjanuary@yahoo.com
Kuilbila	samkuil20@gmail.com
Hari	Hrasolonjatovoan@worldbank.org
Ajay Ramful	a.ramful@mieonline.org

Q32 - Which of the following have you used before?



#	Answer	%	Count
1	Canvas	20.00%	2
2	Moodle	50.00%	5
3	Other Learning Management System (LMS)	30.00%	3
	Total	100%	10

16 Appendix B: Existing Video List

1. Sensing and Sensor Videos [14]
    - Signal Types
    - Analog Rotary Sensors
    - Digital Rotary Sensors
    - Range Sensors
    - Serial Communications
2. Power Transmission [15]
    - Power Transmissions I
    - Power Transmissions II
3. Force Analysis [16]
    - Force Analysis 1
    - Force Analysis 2
    - Force Analysis 3
4. Op Amps [17]
    - Op Amp 1
    - Op Amp 2
    - Op Amp 3

- Op Amp 4
- Op Amp 5
- Op Amp 6
- Op Amp 7

5. Motors for Robotics Applications [18]
    - Motors Introduction
    - 1 - Motor Basics
    - 2 - Motor Performance
    - 3 - Motor Application
6. Robot Controls [19]
    - Introduction to Controls
    - PID Control

17 Appendix C: RBE 1001 Lecture Breakdown

This is a breakdown of the RBE 1001 lectures and what's covered in them.

- Programming 1
  - How PWM works
  - How C functions work
  - Example of writing basic servo program in arduino IDE
- Programming 2
  - Functions
  - variables/assignments
  - if statements
  - rational expressions
  - Pull up resistors
  - logic expressions
  - while loops
  - for loops
  - break/continue
- Programming 3

  - Arrays/multidimensional arrays
  - Pointers
  - Structs/classes

- Behavioral Programming
  - Def of behavioral programming
  - Roomba Example
  - Practice example

- State Machine Programming
  - Sequential coding
  - State Diagram
  - Switch cases
  - Examples

- Circuits 1
  - Intro to def of voltage, current, power, and charge
  - DC versus AC, super basic level not complex
  - What nodes are in circuits
  - Current loops
  - Series versus parallel

  - KCL, KVL
  - voltage sources, current sources, gnd, resistors
  - p=vi,v=ir
  - Passive sign convention
  - Equivalent resistance in series and parallel
  - voltage dividing with circuits
- Circuits 2
  - LEDs
  - Photo Resistors
  - Op Amps intro
  - Line Follow Circuit Design
- Circuits 3
  - Diodes: Forward bias and reverse breakdown
  - Opamp practice problem
- OpAmp and Gain
  - Basics of opamp symbol (inverting versus non inverting)
  - Comparator Config
  - Ideal versus non ideal config

  - Inverting Amplifier circuit
  - Voltage follower configuration

- Sensors
  - Why you want to use sensors
  - Example of open loop control
  - using limit switch as control for motor stop
  - Using a potentiometer with P control

- PID Control
  - what is system, controller, plant
  - open versus closed loop control
  - PID math definition
  - Casual versus formal tuning
  - How each term impacts response generally

- Power Transmissions 1-2
  - Gear train equation relating speed ratios, torque, and efficiency
  - Spur gear dimensions and terminology
  - ANSI chain parameters
  - considerations when using chain such as chain wrap and engagement angles

  - Worm gears
  - Power transmission example problem
- Motors
  - Basically a set of practice problems given you have watched the motor videos that ken made Pneumatics
- Force Analysis 1
  - Center of Mass problems
  - Basic static trust problems with equations of equilibrium and FBD
  - Problem determining max slope given friction coefficient before slip
- Force Analysis 2
  - Skid steering analysis
  - Skid steering on slope analysis
- Mechanisms 2
  - Lifters
    * Screwdrives
    * Telescopic Elevator
    * Rack and Pinion

- Pneumatics
  - Force = Pressure*Area
  - Pneumatic Circuit with part labels
  - Where to use pneumatics
  - Misc robot building tips

18 Appendix D: Robotics Kit

18.1 Bill of Materials

General name	Item	Quantity	Cost per item	Total Cost
Motors	JX Servo PS-4806HB	3	$6.29	$18.87
Line sensor	TCRT5000	3	$0.34	$1.02
Ultrasonic Sensor	HC-SR04 Ultrasonic Module	1	$1.50	$1.50
Breadboard	Breadboard	1	$0.95	$0.95
Hookup wires	Dupont connectors	1	$2.50	$2.50
Bluetooth Module	HC-05	1	$2.47	$2.47
Wheels	servo wheel	2	$2.99	$5.98
Battery Pack	Holder for 6 x AA	1	$2.78	$2.78
Arduino nano	Arduino Nano	1	$2.49	$2.49
Breakout board	Shield For Arduino Nano	1	$1.62	$1.62
Potentiometer	10K OHM Potentiometer	1	$0.13	$0.13
Bearings	608 Bearings 8pcs/set	1	$3.00	$3.00
			Subtotal	$42.31

Appendix E: Project Evaluation Criteria and Rubrics

1. Formulate and complete a project that addresses a combination of social, cultural, humanistic, and technical issues				
IQP learning outcomes: 1-5, 9; *Sources of evidence:* Meetings, presentations, report, and project implementation in general				
	Excellent (A)	**Good (B)**	**Fair, Acceptable (C)**	**Comments**
Goal and objectives	Project has a well-conceived and clearly stated goal and objectives, and the goal is achieved.	Project has a stated goal and objectives, and the goal is achieved.	Project has a stated goal and objectives, and the goal is partially achieved.*	
Background and project context	A sophisticated understanding of social, cultural, and technical issues related to the project is evident throughout the students' work, and demonstrate background research with both breadth and depth.	Shows a good understanding of social, cultural, and technical issues related to the project, demonstrating appropriate background research.	Does not consider some important social, cultural, and/or technical issues related to the project or shows a poor understanding of them, limiting project outcomes and credibility.	
Methodology	Students select and implement a sound methodology to achieve the goal, understanding and communicating their limitations.	Students select a reasonable methodology, and implementation of methods is mostly sound. Limitations are acknowledged.	Weaknesses in methodology are often unrecognized or could have been anticipated and addressed, or students do not approach project systematically.	
Analytical thinking	Students analyze data or design alternatives systematically, in-depth, and with creativity and critical thinking	Data or design alternatives are analyzed mostly systematically. Critical thinking is usually evident.	Little evidence that a systematic process was used to analyze data or design alternatives. Critical thinking is often weak.	
Recommendations or other deliverables	Delivers clear, comprehensive recommendations to the sponsor that are well	Delivers useful recommendations to the sponsor that are supported by	Recommendations may not be useful to sponsor or are weakly supported by project	

	supported by project findings	project findings	findings	

**Sometimes the project goal is not entirely achieved for reasons that are beyond the students' control. Advisors evaluate only what is within the students' control.*

2. Communicate the process and outcomes of the project persuasively and professionally both in written and oral form				
IQP learning outcomes: 7,8; *Sources of evidence:* Presentations, report				
	Excellent (A)	**Good (B)**	**Fair/Acceptable (C)**	**Comments**
		Team Products		
Use of guidelines and feedback	Students clearly make use of writing guidelines, such that each section clearly meets its expected purpose. Students learn from advisor feedback such that advisors' role in writing improvement decreases as project progresses.	Students attempt to make use of writing guidelines, and each section/chapter mostly meets its expected purpose. Reliance on advisor feedback for writing improvements may be steady throughout the project.	Students often do not make use of writing guidelines. Report requires high levels of advisor effort to make it acceptable.	
Persuasion and use of evidence	Writing and presentations reflect critical thinking: claims are persuasive because they are supported by credible evidence, using high quality sources of information, and because they are qualified appropriately.	Clear progress is shown in making writing and presentations more persuasive. Most claims are supported by credible evidence and are qualified appropriately, but some are overstated or exaggerated.	Some progress is shown in making writing and presentations more persuasive, but many claims are still not supported by credible evidence or qualified appropriately.	
Organization and coherence	Writing and presentations are logically organized with a coherent line of reasoning. Formatting assists in conveying structure of paper or presentation. Paragraphs feature clear topic sentences and are tightly written about that point. Almost all transitions are smooth.	Writing and presentations are usually logically organized with a coherent line of reasoning. Formatting usually conveys structure of paper or presentation. Readers occasionally struggle through wandering paragraphs or unclear transitions.	Writing and presentations don't show much improvement in organization and coherence, and readers often struggle to identify a line of reasoning.	
Clarity and writing mechanics	Writing is mostly clear and concise. Active constructions and a "research voice" is used throughout. Mostly free of errors in writing mechanics (e.g., grammar, spelling, punctuation, sentence structure). Word usage is almost always varied and appropriate.	Writing is usually clear and concise. Passive constructions may occasionally obscure meaning, and some writing may be conversational in tone. Most elements of writing mechanics are correct, and errors do not obscure meaning. Word choice sometimes does not convey intended meaning.	Frequent writing errors begin to obstruct meaning or cast doubt on the credibility of the authors. Overuse of passive constructions may obscure meaning and make reading hard to follow. Word choice often does not convey intended meaning. Conversational tone may not be consistent with credible research.	
Visual aids	Visual aids are creative, engaging, and convey messages effectively to diverse audiences.	Visual aids are professional and add value beyond spoken remarks.	Visual aids are professional but do not add much value beyond spoken remarks.	
		Individual Products		

Quality and extent of writing contributions	Authorship page indicates a substantial writing contribution. Produces writing of good quality that requires minimal revision and editing by team members.	Authorship indicates a reasonable amount of writing contribution. Produces writing of sufficient quality that team members can proceed with reasonable levels of revision and editing.	Authorship indicates few writing contributions. Or produces writing of insufficient quality such that it cannot be used without substantial revision from team members.	
Presentation skills	Demonstrates professional presentation skills. Clearly prepared and succeeds in engaging the audience.	Shows noticeable effort and improvement in presentations skills. Clearly prepared and attempts to engage the audience.	Shows some effort and improvement in presentation skills. Sometimes does not seem prepared or is unable to engage the audience.	

3. Work productively as a team, make effective use of all person-power, and reflect critically and constructively on group process				
IQP learning outcome: 6; *Sources of evidence:* Teamwork assessments, meetings, report authorship				
	Excellent (A)	**Good (B)**	**Fair/Acceptable (C)**	**Comments**
		Team as a whole		
Teamwork monitoring	Our team can identify specific processes, norms, and/or guidelines we use to work effectively and respectfully together. We regularly monitor our group processes along with individuals' ideas, feelings, and contributions. We can identify actions or adjustments made as a result.	Our team can identify processes, norms, and guidelines used to work effectively and respectfully together. We regularly monitor our group processes along with individuals' ideas, feelings, and contributions. We may have some difficulty showing useful, tangible outcomes and actions from that monitoring.	Our team attempted to develop processes, norms, or guidelines to work effectively and respectfully together. We tried to monitor our group processes but often did not succeed in making adjustments. We tried but did not always succeed in monitoring individuals' ideas, feelings, and contributions.	A: The teams use of a Gantt chart allowed monitoring of project progress as well as distribution of work.
Team critique and conflict identification	Our team reflects critically on its effectiveness and communicates with each other and with advisors regarding challenges it is facing and how it has responded effectively to those challenges.	Team reflects on its effectiveness and attempts to communicate with each other and with advisors regarding challenges it is facing and how it has attempted to respond to those challenges.	Team does not critically reflect on its effectiveness or does not communicate with each other or with advisors regarding challenges it is facing. Conflict avoidance.	A: The team was able to handle critique in a professional manor.
		Individuals		
Reliability, effort, quality of work	Partners would say that I am always reliable, and deliver my best effort and high quality work.	Partners would say that I am almost always reliable and deliver solid effort and good quality work.	Partners would say I am inconsistently reliable and don't always deliver solid effort. Quality of work sometimes suffers.	Keion - A Jeff - A Augusto - A
Openness to feedback	When partners or advisors target an issue that relates to me, I am not defensive and always open to discussion. I try to resolve the issue promptly and succeed in doing so.	When partners or advisors target an issue that relates to me, I am usually not defensive and am usually open to discussion. I try to resolve the issue promptly and usually succeed.	When partners or advisors target an issue that related to me, I sometimes am defensive or not always open to discussion. I still try to improve the situation satisfactorily.	Keion - A Jeff - A Augusto - A

Self-assessment and response to feedback	I show critical introspection in identifying my strengths and weaknesses as a team member from the perspective of diverse others. I can identify specific actions I have taken to modify my behavior.	I can identify my strengths and weaknesses as a team member from others' perspectives. I can identify some general ways in which I have attempted to modify my behavior.	I can identify some of my strengths and weaknesses as a team member but not always from others' perspectives. I have difficulty showing evidence of actions I took that led to noticeable improvement.	Keion - A Jeff - A Augusto - A
Support for other team members	I regularly share my feelings and opinions and elicit those of others. I give constructive, actionable feedback to team members and support their efforts to improve.	I usually share my feelings and opinions and consider those of others. I show attempts to give constructive feedback to team members and support their efforts to improve.	I occasionally share my feelings and opinions and sometimes disregard those of others. I show little progress in learning to give constructive feedback to team members.	Keion - A Jeff - A Augusto - A

4. Show professionalism				
IQP learning outcomes: All, but especially 6 ; *Sources of information:* Project implementation, meetings, development of report and presentations				
	Excellent (A)	**Good (B)**	**Fair/Acceptable (C)**	**Comments**
Conduct of meetings	Meetings between the team and advisors/liaisons are useful and productive. The team is always well prepared, and all team members have a meaningful role in meetings.	Most meetings between the team and advisors/liaisons are useful and productive. The team is almost always well prepared, and all team members usually play a role.	Team often comes to meetings unprepared, or not all members are engaged. Advisors often step in to ensure that important and useful discussion occurs during meetings.	
Initiative	Students take the lead in project formulation and implementation. They are proactive and take initiative. They become increasingly self-directed with positive outcomes.	Students become more self-directed and less reliant on advisors as the project progresses. They are usually proactive, take initiative, and show some independent thinking.	Students are often reliant on direction from advisors to deliver a quality project. They do not show much initiative or original independent thinking that is sound.	
Overall use of feedback	Students respect feedback from advisors and liaisons, critically reflect on it, ask for clarification when necessary, and always respond to the feedback in recognizable ways.	Students respect feedback from advisors and liaisons and attempt to critically reflect on it. They usually ask for clarification when necessary and respond to the feedback in recognizable ways.	Students don’t always value feedback from advisors and liaisons and may not reflect critically on it. Feedback that isn’t understood is often ignored, or team does not respond to feedback in recognizable ways.	
Attitude	The team always responds with a positive attitude to unexpected changes in the project. They consistently show flexibility and adaptability.	The team usually responds with a positive attitude to unexpected changes in the project. They attempt to be flexible and adaptable.	The team has difficulty responding positively to unexpected changes and tends to get bogged down by them.	

Commitment	The team is always in “continuous improvement” mode, shows intrinsic motivation to deliver the best project they can, and shows a commitment to learning.	The team is clearly committed to delivering a high quality product. May rely on advisors’ evaluations in deciding how much effort to expend.	The team does what is necessary to deliver an acceptable project.	