WHY Lab: Discovering Engineering

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Abstract— The intention of the WHY Lab is to foster a scientific approach to acquiring knowledge by encouraging students to observe the world around them. We are proposing an Introduction to Engineering course that will lead the prospective engineering students to discover their engineering vocation based on experiments representative of the engineering applications. To instill the idea that engineering is about "doing" and not just learning "equations, heuristics and theories". The Lab's approach fosters a student confidence to design experiments and observe the outcomes. The new experiments become part of the catalogue of explorations. The new experiments focus on issues relevant to the student interests and keep the lab's mission current.

The internet and the pedagogy of engineering education has led to a system of accepted principles from which you could deduce an explanation for what you observed. Engineering program's reliance on testing and homework results in codifying mathematics and scientific principles. Further, student reliance on the Internet to find facts, solutions, and generalizations, avoids the need for critical thinking or the use of an experimental approach. These factors lead to a rigid system with very little room for innovation or new thought.

Keyword—Experiential Learning, Freshman Recruiting, Student Development, Collaboration with Education and Technology Partners, Engineering Education,

I. INTRODUCTION

University of New Mexico has been collaborating with education and technology partners such as Quanser, Inc. and National Instruments to develop pioneering techniques to prepare the engineering students to prepare for the challenges of the future. This initiative has been in line with the role of laboratory in engineering education which has gone through a shift towards constructivist/experiential pedagogy where learners gain knowledge through hands-on experience [1]. Traditional laboratory courses, or brick-and-mortar laboratory courses and those offered in the traditional sense, which involves student participating in and conducting hands-on experiments in a physical laboratory. Traditional laboratory courses provide learners the opportunity to practice and experiment with the hands-on skills and knowledge to harness and change matter and energy. As such, traditional laboratories play an important role in engineering education [2].

These lab experiments are well structured and/or scripted to ensure that the desired set of outcomes occurs. Most students do not put much thought into the experimental design. Typically they attend the lab and follow the instructions, analyze the data and confirm a topic in the textbook. The students are not given the opportunity to design their own experiments or to exercise their curiosity.

In a constructivist/experiential approach, learners are encouraged to exercise their curiosity by designing additional experimental content. Learning how to observe different aspects of the physical phenomena or exploring limitations in the ability to observe phenomena. This exploration engenders a sense of ownership/permanence of the information gained and not just a temporary use of information needed to pass a class.

In his seminal book, Kolb [3] presented his theory on experiential learning, which is based on previous work by John Dewey, Kurt Lewin, and Jean Piaget. Using psychology and philosophy, Kolb proposed a model for the process of learning and discussed the role of experiential learning in higher education and lifelong learning, especially they way it pertains to adult learners. Engineering education is an applied science by nature and thus laboratory skills can play an imperative role in strengthening the learner's understanding of various engineering topics. However, engineering education since the 19th century has taken a more theoretical approach with a pedagogical emphasis on classroom and lecture-based learning [1]. More recently engineering schools have started to rethink the role of laboratory courses in engineering education and many have started to experiment with redesigning laboratories with a constructivist pedagogical approach. The problem of many traditional laboratory courses is that they do not construct knowledge, because learners are often too busy with the technical aspects of running a laboratory and therefore lack the time to reflect on the topic that is being experimented on [1].

As technology evolves, engineers are facing the need to "study and learn" new systems of thought that spawns new technologies. This process is not accompanied by new training or a traditional classroom environment. Engineers often learn on the fly or as things evolve. Therefore, future engineers need to be equipped with the tools needed to compete in this environment. The primary questions they need to be asking and answering on their own are "What" does the new technology do; "How" does it do these things and "Why" should we be using this technology. These may sound like trivial questions, but the answers are sometimes difficult to get at. Usually the "what" and "how" are partially addressed by the supporting information. In most cases, there is some aspect that has been overlooked that may lead to unintended consequences for the consumers or producers using the technology. The "why" question leads to broader engineering issues dealing with economics, the environment, safety, and welfare of societies.

We are developing a WHY lab program as part of UNM's Electrical and Computer Engineering program to get students to start to think is these terms, WHY is an acronym for the three questions posed above.

II. BACKGROUND

A. Economic Diversity

The student population at the University of New Mexico is not typical for a state university in the United States. The state of New Mexico has an open scholarship grant available to any student who graduates from a New Mexico high school in good standing. This promotes a student population with greater economic diversity. The engineering program tends to attract students whose families are not necessarily from a middle-class background where their parents have a college education. In the past, most engineering students came from families where at least one parent was an engineer or worked closely with engineers.

The broader spectrum of economic diversity means that some of the students do not appreciate what engineering is. The other more traditional students do not appreciate how technically diverse the engineering field has become as a result of the rapid technological applications growth. The personal experience of one of the authors from 40 years ago was that students could typically cross train in multiple fields of engineering. When he returned 15 years later to earn a master's degree, students only had time to learn one field of engineering. Now students are being asked to pick an area of specialization within a field. The UNM ECE department refers to these areas as tracks.

B. Educational Challenges

Primarily, the department is looking at issue of undergraduate retention. Retention involves keeping an engineering student in the program until they graduate. It is unfortunate, that when a student starts a program, the student has no idea of what they are committing to. As stated above students who have a parent who is an engineer have observed this first hand and consequently have a mentor they can identify with. They are the lucky ones. Another issue is not having a clear understanding of what the end goal is. It is interesting to work with academic seniors in the program who have spent the last three years learning all the facts and knowledge of engineering. They have been discovering how to use them for purposes other than passing an exam or completing a lab. The final issue deals with the question of whether they feel they were prepared to compete in the world outside of school as an engineer. This is a difficult question, because of the rapidly developing technologies and a global market. Unless they are part of the processes creating the changes, their greatest asset is to know how to think, analyze, and self-learn. This concept is a touchy subject with students especially if they have made it to their senior year.

The retention issue is best addressed by helping students discover an area of interest. The how to use what they know is best illustrated with an experiential program that helps to shape their expectations of what to learn. The last issue is best addressed by fostering an approach to learning that encourages discovery and experimentation and asking questions.

III. WHY LAB, HOW DOES IT WORK?

WHY is the question that needs to be answered by engineering students from picking an area of concentration to learning how to master with new systems and advancing technologies. Many students are faced with their first choice "an area of concentration" with no background or experience to fall back on. They may read about the tracks in the course catalogue or ask other students for advice.

We are proposing an initiative to help freshman engineering students gain a better understanding of what Electrical and Computer Engineering (ECE) is and help them find a place in the community of ECE students. The Why lab gets its name from the answer to these three primary questions, "What" ECE Engineers do; "How" engineers do things and "Why" you need an introduction to ECE like this in the first place.

In a more general sense, these questions also need to be addressed in the context of a definition of Engineering. Engineering applies science and mathematics to make the environment and indirectly society a better place for human beings. This implies a responsibility to society that what you are doing does not cause harm to people or damage the environment.

Since the students have not been in an engineering program, they know very little about engineering and its applications. To overcome this, we use an existing working solution and adopt a systems engineering approach, one that focuses on cohesive conglomeration of interrelated and interdependent components. As such, the WHY lab gives students a chance to explore existing working applications and develop an appreciation of some of the solutions and their limitations.

A. Desired Outcomes

The key outcomes are (a) motivation, (a) skills, and (c) engineering literacy. These outcomes map to the key outcomes defined by ABET for ENG 101 type courses. The Lab will attempt to motivate students by applying a system-level treatment to a series of motivating autonomous vehicle applications. Starting from a simple remote control application, to using tele-operations, to autonomous behaviors such as path following, occupancy/object mapping, radio homing, and auto-parking. By motivating students we aim to answer questions such as “Why do I need course X, Y, Z?” and the takeaway being the top one or two ideas in each theme.

We also hope to develop an appreciation for what skill sets it takes to perform these tasks and work with application. The need to select the correct tools, develop critical problem-solving, and the need for complexity management. Gaining this perspective will lead to asking what course of study is needed to work the interesting problems.

Engineering literacy refers to the development of competent formal vocabulary as it pertains to engineering formalisms, methodologies, workflows, and tools.

We wish to have the students understand that Engineering is the application of Science and Mathematics to make society a better place for human society. It is an approach and not a collection of facts and formulas. That the approach consists of

a) Identifying the information that is available
b) Evaluating what you know and don’t know
c) Develop an understanding of what you don’t know and assimilating the need information
d) Applying your knowledge to the problem
e) Verifying that the resulting solution really works given what you know about the situation.

The main tools of the approach include Observation (experimental design); Analysis (mathematics & science); communication (learning how to ask the right question, explaining what you are doing, selling someone on your solution or approach.); Application Development (using hardware & programming to make your solution come to life); Patience and Persistence (exploring different solutions and discovering the one that makes the most amount of sense. One Size does not fit all.); and Intuition & Confidence develops over time (doing homework and projects).

In the context of this course, this process of discovery or learning about the current solution is called getting orientated or orientation. The analysis portion deals with discovering limitations and proposing ways to work around them. Analysis is the key to fostering innovation and initiative. We will encourage using their newly acquired understanding of the existing solutions to extend the solution to handle new situations or provide a new ability.

B. Organization

The class is designed to run in half a semester. Each week the class meets for a theory lecture and a lab day. As the semester progresses, emphasis is placed on lab time and lab team interview/instruction rather than the lecture. As such, the lecture component consists of 50% or less of the time for a week. The remaining time is divided up between the teams. During the team time, the instructor allows each team a minimum of 5 to 10 minutes to review the implementations and talk about their observations. (Learning the idea of teamwork and leadership by example).

The lecture component may be 50% for the first 3 weeks. Initially, the time will be spent discussing how the Lab works and the safety concerns. This is followed by a discussion of how to do each project and the ideas behind the projects. Possibly having a demonstration of a working project.

We will divide the class into teams of 3 and assign a project. When assigning groups members, we are mindful of the diversity among students [4]: students have different attitudes toward learning and different responses to specific classroom environments and instructional practices. Therefore the aim is to assign groups consisting students who exhibit a deep approach as well as those who exhibit a surface approach to learning.

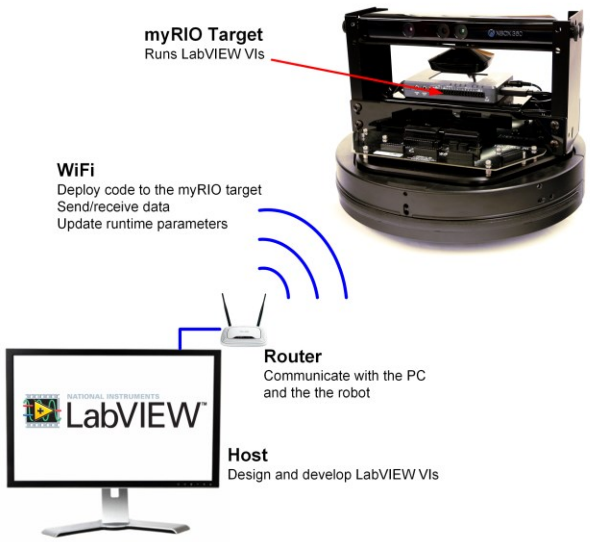

Figure 1: QBot 2 myRIO configuration.

C. Series of Problems and Solutions

We are proposing an Introduction to Electrical and Computer Engineering course that will lead the prospective engineering students to discover their areas of concentration in ECE based on “doing” experiments representative of the field’s applications. Using different robot navigation techniques as an overarching topics, the WHY Lab course consists of 8 exploration that collectively focus on the following seven tracks or areas of concentration within ECE:

1) Control Systems and Robotics
2) Communications and Radio Antenna Applications
3) Signals and Systems
4) Microprocessor and semiconductors
5) Computing and Programming
6) Circuits and Electronics
7) Power and Energy

The "Experiments" use a Qbot2 myRIO system [5] as the primary platform for the experiments. The Quanser QBot 2 myRIO is an innovative autonomous ground robot system incorporating a robust educational ground vehicle with the Microsoft Kinect and a National Instruments (NI) myRIO embedded device. The QBot 2 myRIO is equipped with a complete sensors suite including an accelerometer, gyroscope, depth/RGB sensors, bump sensors, and encoders. Controllers are developed using the LabVIEW programming environment [6] on a host PC and deployed over a WiFi connection to the embedded myRIO device. A schematic diagram of the system's configuration is shown in Figure 1. The LabVIEW environment is a graphical programing environment that allows the rapid development and deployment of software used for interfacing with sensors, instruments and general hardware. A LabVIEW Virtual Instrument, or VI, is composed of 2 elements – a Front Panel and a Block Diagram. The *Front Panel* acts as a Graphical user Interface (GUI) which the user interacts with by means of controls, indicators and waveform scopes. The *Block Diagram* consists of the program's logic, variables, and wires which direct the flow of data. A VI is akin to a laboratory instrument, albeit a virtual one, where the user interacts with the outer portion of the device using knobs, buttons and LCD screen, while the electrical components and wires are contained to inside of the instrument.

Each week, we will present the students with a problem and a working solution. We will ask them to work with the solution and discover its limitations. A summary of the lab experiments is provided below.

Week One: First-day Motivation

The first week exploration focuses on introducing the Qbot 2 myRIO platform as the primary experimental platform for the course which getting students excited about the prospect of using a high-fidelity platform to explore various areas of ECE throughout the semester. Students are required to unpack the robot and follow instructions provided in the user manual to partially assemble the robot, setup the network infrastructure, and configure the LabVIEW project required to operate the system. Using a pre-programmed LabVIEW VI, students tele-operate the QBot 2 using the keyboard of the host PC within the laboratory environment.

Week Two: Embedded Systems & Programming

Topics covered during the second week include a closer look at embedded systems and LabVIEW programming and how they are used to improve robot navigation. As noted earlier, each week students are presented with a problem faced in the previous exploration and presented with a working solution. During this week students are presented with the following problem: what if the operator cannot observe robot while driving it? Using the VIs from the previous week, students are asked to operate the QBot from a starting point inside the lab then attempt to drive it outside of the laboratory along a long corridor, turn around, and attempt to navigate it back to its starting position within the lab. Most of them quickly realize that once the Qbot is out of the operator's sight, it is cumbersome if not impossible to tele-operate the robot. As a solution, they are introduced to vision system and the visual feedback that can be obtained from the robot's built-in RGB camera. They are then asked to use a modified VI (shown in Figure 2) which incorporates RGB feedback from the Kinect sensor to re-attempt last week's navigation. Students are encouraged to discuss the advantages and disadvantages of using visual-only feedback for tele-operation.

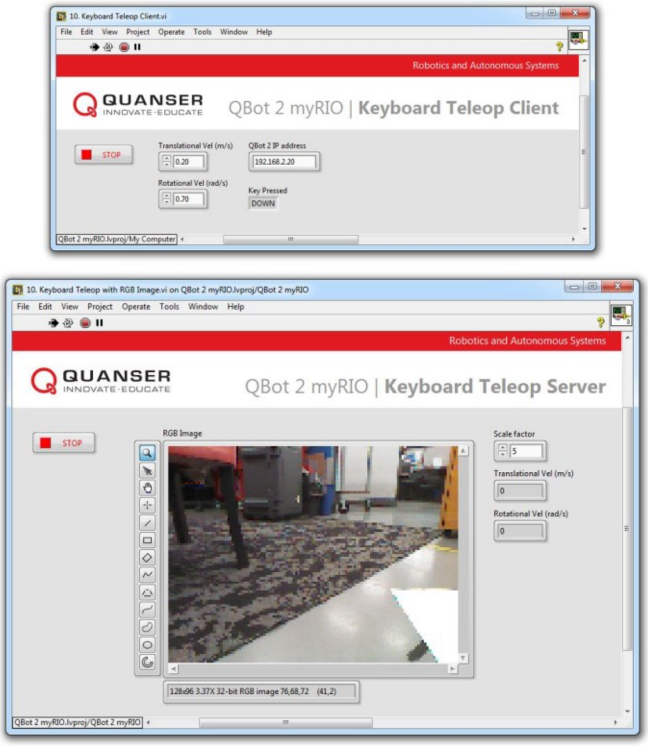

Figure 2: Keyboard teleop with visual feedback

Week Three: Circuits and Analog Electronics

The primary theme for week three includes an introduction to sensors, filtering, analog/digital conversion, and analog electronics. This week's proposed problem is autonomous navigation of the robot as opposed to being tele-operated by a user. Students implement a simple wall-following approach using an infrared distance sensor. After integrating the IR sensor and necessary signal conditioning circuitry, they attempt to follow a long hallway with doors or corridors and observe how well this strategy works. The day includes a class discussion about the advantages and disadvantages of wall following, e.g. what happens when you get to a doorway versus a corridor and you want to go straight ahead instead of turning, and how OptoElectronics is involved in the solution.

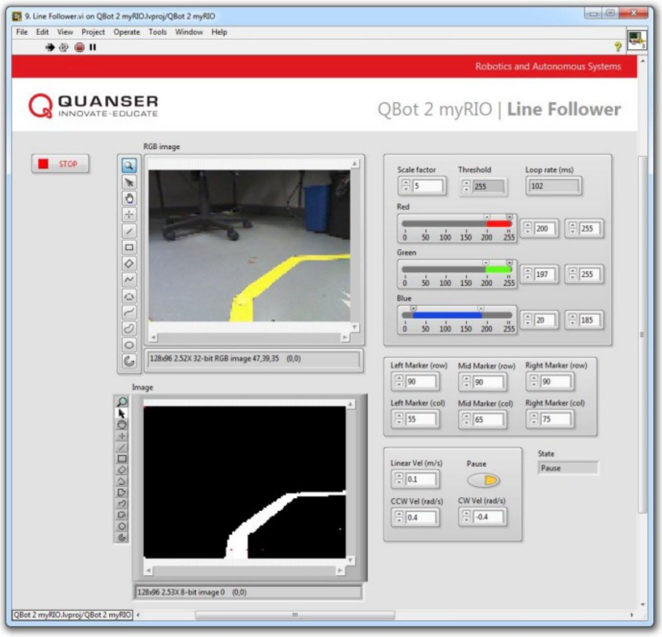

Figure 3: Line following application

Week Four: Digital Signal Processing

Week four focuses on digital signal processing and in particular vision, image processing, and thresholding. This week's proposed challenge is an autonomous robot in a manufacturing facility that wants to travel the same path every time. Students are then presented with vision-based navigation techniques using such as line following. Students are required to develop a line following algorithm by implementing a state machine that enables the QBot 2 myRIO to follow a colored path on the floor. The RGB image of the Kinect sensor is used to "see" the path. First, students must threshold the RGB image to filter out everything except for the colored path (see Figure 3). The VI implements a state-machine that either drives the Kobuki base forward, turns it left, turns it right, or pauses the base depending on the position of three user-defined markers. Class discussions include advantages and disadvantages of following a colored piece of tape, as well as RGB vs HSL thresholding.

Week Five: Signals and Systems

Week five introduces signals and system using the concept of odometry with optical encoders and how they aid the process of dead reckoning and occupancy grid development; two key concepts pertaining to autonomous vehicles. Dead Reckoning, also known as odometric localization, is the estimation of the robot's position based on the measured or estimated motion of the robot's wheels. In the case of the Quanser QBot 2 platform, the procedure for odometric localization involves estimating the amount of wheel displacements based on encoder data and determining the robot's pose using the built-in gyro. The data is used to determine the relationship between the independent motion of the two wheels and the motion of the overall robot. As part of the exploration, students are required to first follow an irregularly shaped space (Hexagon, parallelogram, trapezoid) using a series of known waypoints. They then expand localization to a basic occupancy gird example where the depth sensor of the Kinect camera is used to build a map of a confined space within the lab. The week includes a class discussion about the advantages and disadvantages of using odometry such as knowing your position relative to the robot versus knowing your position relative to North and East coordinates, gyroscopic drift, and a how microelectronics is involved in the solution.

Week Six: Controls & Robotics

During this week students are introduced to general controls concepts that pertain to autonomous vehicles. They take on a system level approach view of the robot and explore more advanced concepts such as obstacle avoidance. In particular they examine and how depth feedback from the Kinect sensor can be combine with steering, odometry, and video in order to avoid obstacles. They specifically discuss how systems and controls are used in defining and solving this problem.

Week Seven: Communications & RF

Week seven activities focus on RF and software defined radios. Students are provided with an overview of a custom built RF tracking sensors integrated with the QBot and how it works. Using a direction finding antenna, they attempt to find a walkie talkie transmitter. The weekly discussion includes advantages and disadvantages of using RF direction finding and the role that electromagnetics plays in our daily lives (wifi, cell phones, radar systems for self-steering cars, etc.).

Week Eight: Power & Energy

The final week of explorations focuses on power and energy. Students are provided with an overview of the robot's lithium battery and onboard charging system. By integrating a shunt resistor in series with the main battery, they examine power consumption under various operating conditions and tasks.

IV. Conclusion

The approach of being presented with a problem and finding a working solution is the main reason for employment of engineers. The idea that we have a working product and that the product needs to be improved or re-invented to take advantage of new technologies drives a large number of corporations. Their concern focused on maintaining market share or profitability. It is also important to teach that problems are not always solved by applying some theorem or use of an algorithm.

An engineer needs to follow a WHY methodology. The primary questions they need to be asking and answering on their own are "What" does the new technology do; "How" does it do these things and "Why" should we be using this technology. The personal engineering process should stress that the approach consists of:

a) Identifying the information that is available
b) Evaluating what you know and don't know
c) Develop an understanding of what you don't know and assimilating the need information
d) Applying your knowledge to the problem
e) Verifying that the resulting solution really works given what you know about the situation.

We are hoping that general approach will foster retention by developing a set of skills needed for continuous professional as well as academic growth. It is also hoped that the development of this skill set will help them to face the challenges of learning how to think like an engineer and apply what they know in the undergraduate program. We are also hoping that they will have a better picture of the interesting and hopefully inspiring applications they can create given they complete their course of study. These factors should boost the retention of students and provide motivation to stay with the program.

V. References

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