2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #34078

Robotics Retrofit: Filling the Gap in Robotics and Automation Curriculum

Mr. Gregory Lyman, Central Washington University

Associate Professor and Program Coordinator of Electronics Engineering Technology at Central Washington University. On the web at: www.cwu.edu/engineering/eet

Mr. Rowdy A. Sanford, University of Idaho

B.S. in Electronics Engineering Technology, from Central Washington University class of 2020. Currently a graduate student studying Electrical Engineering at the University of Idaho.

Mr. Jeff R. Wilcox, Central Washington University

Lecturer and EET program Engineering Technician. He holds a MS in Physical Chemistry an MS in Industrial Engineering and a BS in Electrical Engineering Technology.

Dr. Timothy L. Sorey, Central Washington University

Timothy L. Sorey, PhD. is a science educator who is a full professor at Central Washington University - Ellensburg. He has a dual appointment with the Chemistry Department and Science and Mathematics Education Department. Please visit his departmental website for more information (https://www.cwu.edu/chemistry/tim-sorey).

Robotics Retrofit: Filling the Gap in Robotics and Automation Curriculum

Abstract

Many engineering technology programs are implementing robotics and automation platforms into their undergraduate curriculums. However, presenting students with an industry-applicable and budget-friendly platform for such a curriculum can be a surprisingly difficult challenge. Program faculty have reviewed a plethora of robotics platforms and determined that most readily-available robotics platforms fall into two categories: robotics toys and industrial robotics. Both categories can provide a wealth of educational components, but both also have limitations, causing a perceived curriculum gap in mechatronics course sequence design. Program faculty have developed a unique way to fill this gap, retrofitting older robotics platforms with newer technologies. In this project, several 30+ year-old robots were disassembled, reverse engineered, and then updated with modern components. With the retrofit completed, implementation of these "retrofit robots" into the curriculum began. In a year-long lab-based course sequence, students start learning concepts on robotics toys, then shift to these retrofitted robots for more advanced concepts, and then complete the sequence on industrial robotics systems. Pre-survey and post-survey assessments of student learning, as well as anecdotal evidence, were collected during our preliminary first year of implementation (N=22 students). Although the results of our formative and summative student assessment are not statistically significant, the corresponding analysis of the data infers that we have a plausible solution to the problem and can make evidence-based changes to our curriculum for future offerings of this course sequence.

Background

The Engineering Technologies, Safety, and Construction (ETSC) department at Central Washington University offers three bachelor's degree paths for undergraduate students: Electronics Engineering Technology (EET), Industrial Engineering Technology (IET), and Mechanical Engineering Technology (MET). These specialized programs provide students with a combination of engineering theory and application-based instruction to prepare graduates for careers in industry [1]. The department also offers a variety of minors from which students may choose to enhance their academic careers. After years of discussions with department faculty and industry advisory boards, coupled with research showing growing popularity of robotics curriculum across academia [2] [3], the decision was made to add a Robotics and Automation Minor (RAM) to the department offerings. The goal of the RAM is to provide a broad education in the fundamentals of mechatronics engineering where students also learn best practices for automation applications. Students often enter their collegiate career with some robotics experience from their primary and secondary school education, and thus have an interest in continuing that education at the collegiate level. Feedback from industry advisory boards also showed that there was industry interest in graduates with robotics skillsets, but more so on the industrial automation side. The RAM became a successful way to attract students interested in continuing their robotics education while also preparing them with the automation skill sets for which industry is looking. The development of the RAM included the creation of new courses as well as revisioning of existing courses, to create proper curriculum sequencing. This led to the formation of a year-long sequence of courses specific to robotics and automation education:

<u>RAM Course Sequence – offered every other year</u>
Fall quarter: ETSC 277 - Introduction to Robotics and Automation
Winter quarter: EET 377 - Advanced Robotics and Automation
Spring quarter: EET 477 – Industrial Robotics and Automation

As program faculty began researching existing robotics platforms and software to implement in these courses, it became immediately apparent that a wide gap exists between what we define as "robotics toys" and "industrial robotics." The realization of this educational chasm sparked an entire new set of pedagogical challenges and research. This paper chronicles our journey from concept to initial implementation.

Pedagogical Approach

Curriculum development for the RAM course sequence began with an overall plan of increasing pedagogical complexity throughout the course sequence. The idea started with a progression from simple robotics fundamentals in the introduction course (ETSC 277), to more complex topics in the advanced course (EET 377), which would culminate in industry-specific complexity in the final course (EET 477). In order to match the lab equipment with the increasing pedagogical complexity, we realized that different robotics and automation platforms would be needed for proper implementation. Also, efforts were made to keep this progression as smooth as possible by minimizing content division between platforms though utilizing a single programming language that worked across all devices. Figure 1 shows the initial plan for RAM course sequence, along with the robotics platforms to be utilized in each course.

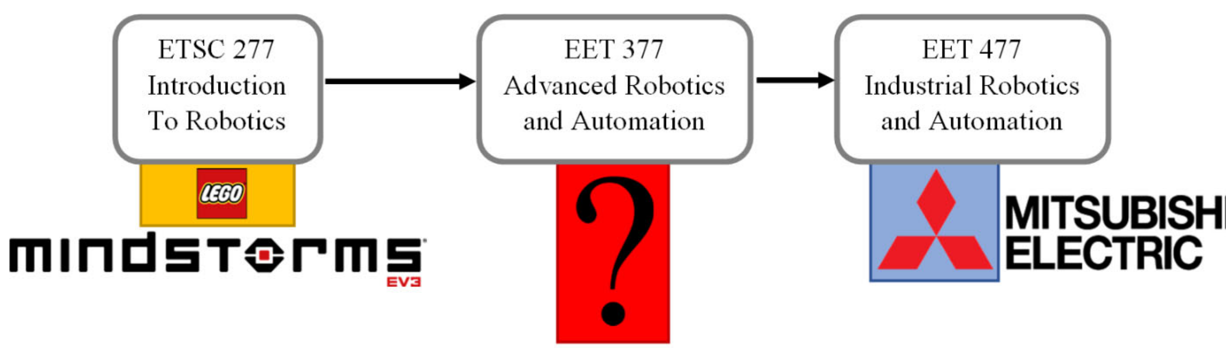

Figure 1: RAM Course Sequence Planning with educational gap

As research continued, it was quickly realized that a multitude of options for beginning-level robotics such as Lego Mindstorms and VEX, as well as options for industrial robotics from solutions providers like Fanuc and Mitsubishi exist. Options to fill in the middle were exceedingly difficult to find. The intro 277 course could easily adopt the Lego Mindstorms platform, and the industrial 477 course could adopt the Mitsubishi platform (already purchased at the time), but this gap left 377 without a clear solution.

We determined that readily available robotics systems essentially fall into two categories: robotics toys, and industrial robots. The "robotics toys" provide a fantastic solution for entry-level learning [4] [5], hence the adoption for the 277 course. Similarly, the "industrial robots" are also a great solution for program graduates who will work with robotics systems in the industrial automation fields. However, they are also somewhat limited in the educational environment. These "black-box" robots are purposefully designed for automation facilities where exposure to internal components would be limiting within some factory conditions and possibly dangerous [1]. In an educational setting however, having the ability to visualize and analyze the motors, gears, linkages, and electrical components, under safety-guided rigor can be a handy pedagogical tool [1]. Software packages for these industrial robots are also a "black-box" type of environment. Access to top-level programming can occur but accessing subroutines and root-level coding is not possible.

A discovery of several robots from the 1980s, that were slated for disposal, was made on campus. These robots were previously deemed unusable due to their archaic technology. Upon analysis, we recognized that they included the accessibility options that we were looking for. Therefore, we began to investigate the possibility of reverse engineering and updating these systems with current technology thus filling our curriculum gap. Budget concerns were also a deciding factor. A massive undertaking of reverse engineering circuits, along with developing new communication protocols and software programming began. The result of the project was named "Retrofit Atlas Robots (RARs)" and access to all levels of hardware and software on this platform became the main focus of the design. We then set forth developing matching curriculum to implement them for use in the 377 course. One benefit that was designed into the project was that all three platforms could be ran using LabVIEW software. This consistency in software communication brings cohesion to the learning process but still allows for native languages to be implemented in the curriculum. Figure 2 shows the before and after pictures of the original Atlas Robot systems and the newer RARs.

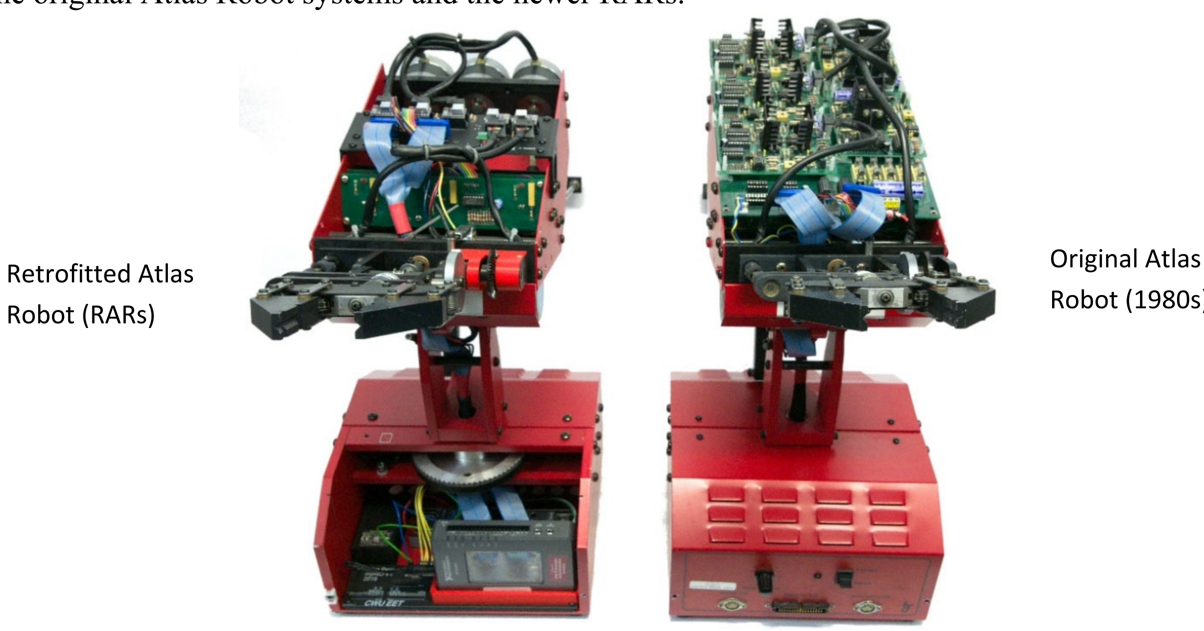

Figure 2: Atlas Robots: RARs and original

Once the retrofit was complete and the systems had new components, communication protocols, and programming software, the RARs were utilized in labs completed by students in both 277 and 377 for the first iteration. We wanted to get as much use as possible in the first year of implementation to obtain both qualitative and quantitative data for improvement and further adaptations in future course offerings. In 277, the students were given a pre-survey at the beginning of the course, and then completed several labs using the Lego Mindstorms platform. The RARs were utilized for some labs towards the end of the term, and then a post-survey was given in the last week of the term. In 377, the pre-survey was again administered during the first week of the course. Many of the students in this course had also been enrolled in the previous 277 course. There were a handful that had not been previously enrolled, so they were brand new to the RARs platform. We felt it was necessary to get their pre-survey input as well. The entire lab sequence for 377 was implemented with the RARs platform and the post-survey was administered during the last week of the course. Figure 3 shows the implemented plan with the RARs filling the 377 gap that previously existed.

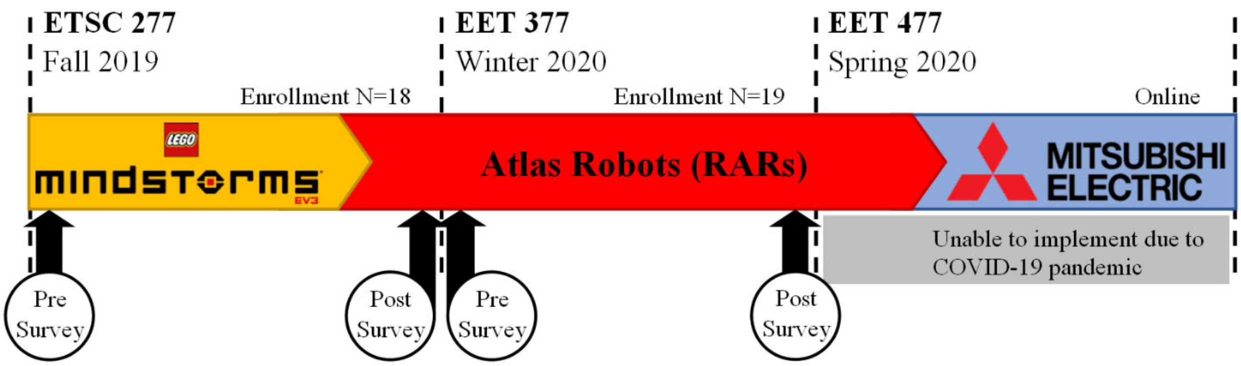

Figure 3: First implementation of course sequence with educational gap filled

The pre and post survey questions that were administered are included in Appendix A.

Results

The results from the pre and post surveys begin to show a positive trend in student success. Some of these initial student data provide feedback for future improvement and implementation. Figure 3 shows the quantitative results from the surveys in ETSC 277 and EET 377 (N=22 students). Unfortunately, the EET 477 course was moved online due to the COVID-19 pandemic and, as a result, we did not utilize RARs nor Mitsubishi robotics. We will utilize these platforms again in this course as soon as we move back into the classroom for in-person instruction.

AY 2019-2020 Data		Perceived Level of Robotics Competency			
Course	Survey	None	Some	Good	Expert
ETSC 277	Pre	0%	59%	41%	0%
	Post	12%	47%	41%	0%
EET 377	Pre	6%	81%	19%	0%
	Post	0%	64%	31%	0%
EET 477	Pre	No data due to COVID-19 pandemic			
	Post				

Figure 3: Pre and Post Survey Quantitative Results (N=22 students)

An immediate appearance of the Dunning-Kruger effect [6] is recognized in the analysis of pre-vs-post data in ETSC 277. Students showed an overconfidence of robotics knowledge in the pre-survey with 100% of the students believing they already had at least some or good competency around robotics topics [7]. Although post-survey results for the ETSC 277 course shows a drop in confidence, as students performed our inquiry-based engineering lesson, we view this as a recalibration of their personal reality as they were ultimately able to make positive learning gains toward our robotics lesson. This was reflected in learning assessments throughout the quarter. In fact, student frustration with inquiry-based lab curricula is well documented in science education, where lab students valued more authentic scientific exposure. In general, experiencing the complexity and frustrations faced by practicing scientists is challenging and may explain the widespread reported student resistance toward our inquiry curricula. These engineering educators interpreted the ETSC 277 student data results as a reduction in self-perceived competency in robotics and that their authentic engineering experience placed them in a cognitive conflict with a higher potential for maintaining a growth mindset [8].

The EET 377 data shows a positive gain in the competencies between the pre and post surveys. A positive gain in student self-perception from “Some” to “Good” shows increasing confidence levels, with no students feeling as though they were experts yet. As improvements are made for the next iteration, further changes to the survey questions could address student's perception on self-assessment [9]. Our ideal vision for students’ self-assessments is to see a trend of high percentages in the “Some” category for 277, a majority in the “Good” category for 377, and then 477 registering as “Expert”. Although our initial quantitative data does not support this vision, our post-surveys show anecdotal evidence that our curriculum could produce this trend in the future.

Further analysis of the pre and post survey quantitative data showed the following:

<u>ETSC 277</u>

- 89% of students recognized the benefits of the hands-on approach and believed that it created a better understanding of the course material
- 94% of students agreed that it would be beneficial to access the internal components of the hardware and software

<u>EET 377</u>

- 95% of students in the pre-survey assumed that learning course concepts on an open-access system would be better than a “black-box” style of robotics platform.

- 100% of students agreed that the Atlas systems provided a good foundation of robotics hardware and software. It helped them improve their troubleshooting skills, as well as helping with understanding the textbook, mathematics, and physical aspects of the robots.

Qualitative data was also gathered in each survey where students were asked to describe their strengths and weaknesses as they progressed through the courses. An analysis of the qualitative feedback showed the following:

<u>ETSC 277</u>

- A large majority of students agreed that the Lego robotics platform provided a solid rudimentary introduction to robotics topics. Others stated difficulties relating them to industrial robotics. Examples include:
  - Student A: "I got a good groundwork of how robots work in the industrial world; however, I don't believe I am knowledgeable enough to work in industrial robotics as of yet."
  - Student B: "I feel there is so much to learn left. I feel that I know enough to play with Atlas Robotics hardware and figure it out."
- Several students commented on the complexity of programming in LabVIEW as well as difficulty with mathematical models. Examples include:
  - Student C: "I think that I am strong in understanding the concepts with robotics and automation, but I don't have enough programming knowledge to be able to recreate the programs without help."
  - Student D: "My weakness would include specificity of the associations relative to robotics, mastery of programming platforms, and how it all comes together in the industrial world."

<u>EET 377</u>

- Most students felt good about their individual skill sets and concepts (math, movements, and systems) while a few stated difficulties translating those concepts into industrial automation. Examples include:
  - Student E: "I have a general knowledge of the aspects of Industrial Automation, and an understanding of logistical math, but not as in depth as I deem necessary for having an expert level understanding."
  - Student F: "I understand how the industrial robot[s] operate, but [am] still having problem[s] grasping how it fully automate[s]."
- There was a diverse set of feedback regarding which aspects they felt most comfortable. Some students preferred the RARs along with programming, while others enjoyed the textbook assignments. Examples include:
  - Student G: "Coming out of the first robotics class I felt that I had a decent understanding of what industrial robotics was about, but after this class I know quite a bit more of the terminology and a lot more about specific robots that accomplish specialized tasks instead of just general robots like an arm-on-an assembly line."
  - Student H: "I believe I learned a vast amount of industrial robotics during this course to the point where if someone asked me what applications need which robots, I could tell them."

Question number two on each survey, pre and post for both courses, addressed the concept of "seeing behind the curtain" regarding the previously discussed black-box nature of robotics equipment. In total, out of 71 responses across all surveys, 68 stated an agreement with being able to access all levels of hardware and software as highly beneficial, and 3 either disagreed or stated that they were unsure.

Upon final analysis of the qualitative data, students were largely able to develop connections between the math and robotics movements/programming on the RARs that they couldn't make on the LEGO platform. Primarily, the feedback was positive, with only a few students stating they were still uncomfortable with migrating overall concepts to actions independent of which robotics platform on which they were working. This feedback will greatly assist in continuously improving the course curriculum. In general, the RARs were assessed as a positive addition to the robotics courses and students enjoyed being able to work on all levels of the hardware and software.

Potential improvements for the next cycle could include more quantitative assessment methodology (ex. pre/post quizzes, lab reports meta-analysis of online/in-person lab discussions, etc.) that provide data for evidence-based curriculum adjustments. The current assessment method primarily analyzes the students' perception of learning through surveys, which we found valuable as a tool for student-perception assessment. Plans for adding specificity to survey questions, lecture modifications, and lab assignment clarity are also being worked on. In an attempt to bolster the students' perception of programming as being "fun," lecture materials will be designed to shift from conceptual topics to actionable items. With these minor modifications, we believe we can deliver a strong robotics and automation curriculum with the RARs as the main platform utilized throughout.

Conclusion

Based on a holistic review of the quantitative and qualitative data gathered, there is evidence of success with this project, as well as areas for improvement in the next cycle. Students were able to gather skill sets that bolster their overall knowledge of robotics and automation topics. The "learn-by-doing" [10] aspects of the RARs have shown to be beneficial in the first assessment cycle. While we are pleased with the results of the research thus far, the effects of the COVID-19 pandemic caused some issues with the overall initial data collection. Program faculty are looking forward to collecting further data in future years when this course sequence is again offered. At this juncture, we can infer that we have a highly plausible solution for filling the educational gap in the robotics and automation curriculum.

References

[1] G. Lyman, J. Wilcox and R. Sanford, "Robotics Retrofit: Renovating Outdated Robotics Platforms to Meet Current Curriculum Requirements Driven by Industry Demand," in *ASEE PEER*, New Orleans, LA, 2019.

[2] M. Mikhail, "Enhancing College of Technology and Engineering Technology Programs with Industrial Robotics Concentration," in *ASEE 126th Annual Conference and Exposition*, Tampa, FL, 2019.

[3] A. Yousuf, M. A. Mustafa, A. G. De La Cruz, A. Villanueva and M. M. Hayder, "Robotics in Engineering Technology," in *ASEE 125th Annual Conference and Exposition*, Salt Lake City, UT, 2018.

[4] A. Behrens, L. Atorf, R. Schwann, J. Balle, T. Herlod and A. Telle, "First Steps into Practical Engineering for Freshman Students Using MATLAB and LEGO Mindstorms Robots," *Acta Polytechnica,* vol. 48, no. 3, pp. 44-49, 2008.

[5] S. Lorimer, J. Davis and O. Tronchin, "Using LEGO Mindstorms and MATLAB in Curriculum Design of Active Learning Activities for a First-year Engineering Computing Course," in *ASEE 126th Annual Conference and Exposition*, Tampa, FL, 2019.

[6] J. Kruger and D. Dunning, "Unskilled and Unaware of It: How Difficulties in recognizing One's Own Incompetence Lead to Inflated Self-Assessments," *Journal of Personality and Social Psychology,* vol. 77, no. 6, pp. 1121-1134, 1999.

[7] C. Sanchez and D. Dunning, "Overconfidence Among Beginners: Is a Little Learning a Dangerous Thing?," *Journal of Personality and Social Psychology,* vol. 114, no. 1, pp. 10-28, 2018.

[8] C. Gormally, P. Brickman, B. Hallar and N. Armstrong, "Effects of Inquiry-based Learning on Students' Science Literacy Skills and Confidence," *International Journal for the Scholarship of Teaching and Learning,* vol. 3, no. 2, 2009.

[9] C. R. Critcher and D. Dunning, "How Chronic Self-Views Influence (and Mislead) Self-Assessments of Task Performance: Self-Views Shape Bottum-Up Experiences With the Task," *Journal of Personality and Social Psychology,* vol. 97, no. 6, pp. 931-945, 2009.

[10] N. Cosme, M. Z. Hauschild, C. Molin, R. K. Rosenbaum and A. Laurent, "Learning-by-doing: experience from 20 years of teaching LCA to future engineers," *The International Journal of Life Cycle Assessment,* vol. 24, pp. 553-565, 2019.

Disclaimers

LEGO® is a trademark of the LEGO Group of companies which does not sponsor, authorize, or endorse this paper.
MITSUBISHI® is a trademark of the Mitsubishi International Corporation (MIC) which does not sponsor, authorize, or endorse this paper.

Appendix A

<u>ETSC 277 Pre-Survey</u>

1. Now that you've completed assembly and programming of LEGO Mindstorms hardware and software, what level of competency to you believe you have regarding industrial robotics and automation? (Circle one)

   No idea *Some understanding* *Good understanding* *Expert*

   Explain your rationale for selecting your choice in the space provided below.

   (Essay answer)

2. Do you believe it would be beneficial to "see behind the curtain" regarding software and hardware? Describe why. For example: would you have preferred to see what was going on in the background of the LEGO code? Also, would you have preferred to see component details inside the sensors and motors of the LEGO robotics kit?

   (Essay answer)

3. Describe your strengths and weaknesses with robotics and automation topics.

   (Essay answer)

<u>ETSC 277 Post-Survey</u>

1. Now that you've completed assembly and programming of CWU EET's Atlas Robotics hardware and software, what level of competency to you believe you have regarding industrial robotics and automation? (Circle one)

   No idea *Some understanding* *Good understanding* *Expert*

   Explain your rationale for selecting your choice in the space provided below.

   (Essay answer)

2. Do you believe it was beneficial to "see behind the curtain" regarding software and hardware? Describe "why" and/or "why not".

(Essay answer)

3. Describe your strengths and weaknesses with robotics and automation topics.

   (Essay answer)

<u>EET 377 Pre-Survey (Note: Not all students in course had taken ETSC 277)</u>

1. What level of competency to you believe you have regarding industrial robotics and automation? (Circle one)

   No idea *Some understanding* *Good understanding* *Expert*

   Explain your rationale for selecting your choice in the space provided below.

   (Essay answer)

2. Do you believe it would be beneficial to "see behind the curtain" regarding software and hardware? Describe "why" and/or "why not".

   (Essay answer)

3. Describe your strengths and weaknesses with robotics and automation topics.

   (Essay answer)

<u>EET 377 Post-Survey</u>

1. What level of competency to you believe you have regarding industrial robotics and automation? (Circle one)

   No idea *Some understanding* *Good understanding* *Expert*

   Explain your rationale for selecting your choice in the space provided below.

   (Essay answer)

2. Do you believe it was beneficial to "see behind the curtain" regarding software and hardware? Describe "why" and/or "why not".

   (Essay answer)

3. Describe your strengths and weaknesses with robotics and automation topics.

   (Essay answer)