Outcomes and Case Studies of Undergraduate Student Participation in Research

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The National Science Foundation has noted that research experiences are one of the most effective avenues for attracting and retaining students in science and engineering [1]. Other studies also suggest that undergraduate research may hold some of the answers to increasing student learning, retention, graduation rates and entrance into graduate programs [2-8].

Recent studies by Deloitte and The Manufacturing Institute note that the U.S. faces a need for nearly 3.5 million manufacturing jobs over the next decade due to baby boomer retirement. Two million of these jobs are likely to go unfilled, largely because young people do not view the industry as a career destination [9].

In addition, a recent national survey showed a decline in the number of undergraduate students moving on to graduate school after graduation [10]. The Council of Graduate Schools has noted that the U.S. must continue to develop highly skilled human talent through graduate school to maintain its leadership role in global innovation and discovery [11].

In addition to NSF, other federal agencies such as NASA [12], Department of Energy [13], Department of Homeland Security [14], and Department of Defense [15] also recognize the needs for qualified technical engineers. They all offer summer research/internship programs for undergraduate students.

This paper extends previous work [16-17] about an NSF-funded REU site focusing on mechatronics, robotics, and automated system design. Here we present survey results, lessons learned, and project highlights from three years (2014-2016) of hosting the program. We also compare REU students' experiences with automated system design and building projects with the experience of students who completed similar work for semester projects during fall 2016.

Student Background

Summer Research Program. The NSF Research Experiences for Undergraduates (REU) site for Mechatronics, Robotics, and Automated System Design targets motivated students who have a desire to participate in research and interest in careers in STEM fields. Special effort is made to recruit students who 1) have limited opportunities to participate in research on their home campuses, including two-year college students; or 2) belong to groups that are traditionally underrepresented in engineering and science, including women, underrepresented minorities, and persons with disabilities. Most participants are from Mechanical, Electrical, or Computer Science departments.

Semester Research Project. The author teaches a semester course on Manufacturing Automation and Robotics. The course has an optional team semester project that involves the application of techniques/methodologies discussed in classes and labs, such as use of sensors, relays, robot, PLC, and interfacing techniques. An example of an appropriate topic would be automating a manufacturing process (e.g., egg packaging). Students must identify a product and a process; examples of past student projects are made available for review. The project begins after the

first week of class. Project deliverables include a working system, a written report, and an oral presentation.

Case Studies

Summer Research Program.

The REU site is as intensive 10-week program; each student has a research mentor and joins a research group. Program activities include: (1) welcome party, (2) research seminar, (3) research milestone presentations, (4) GRE course, (5) lab tours, and (6) final presentation and poster session. Participants identify their research topics and tools needed to work on the project by the end of the first week. Graduate research assistants provide tutorials as needed on how to use tools such as LabView or Arduino.

This REU program has been offered since 2014. A few new strategies were implemented in 2016 with the intent of improving program effectiveness in areas such as gaining research skills, generating outputs such as publications, and overall participant satisfaction. These strategies include (1) asking students about their research projects during the first week of the program to ensure they were interested in their assigned project; (2) at various program milestones, checking students' understanding and progress by asking them about their projects (e.g., What is the motivation of your project? What is the research question? How do you plan to solve it? Can you make significant contributions to publish the work? Do you have enough support?); and (3) during weekly research seminars, we invited PhD students to talk about why they decided to go to graduate school, how they picked their topic, and what their future work plans were (e.g., industry, national labs, or university).

Semester Research Project.

The semester project is available for students with background in Mechanical and Manufacturing engineering technology. Students work as a group of two or three. Students work on the project as the lecture and labs progress throughout the semester. The project allows them to integrate what they learn in the course and apply it to real-life problem solving. Course topics include programmable logic controller (PLC); sensor technology; industry robots; I/O interfacing; and machine vision. Students are responsible for coming up with a process they want to automate, Project milestones include 1) develop concept paper; 2) build physical model; 3) perform wiring and interfacing; 4) write control program; 5) demonstrate model. Project deliverables include a working system and a written report. The report should include (a) introduction, (b) problem to be solved – process to be automated (c) construction of physical model - description of major components – CAD drawings, parts and sensors, (d) sequence of operations, (e) I/O ports assignments, (f) overall system schematic, (g) ladder logic programming – explanation of logic (h) conclusion and future directions and (i) appendix – bill of materials. Instructors and teaching assistant monitor project progress and provide support as needed. Students work in a secured area with tools available and are able to access the room between classes during the week and over the weekend by request.

Evaluation and Comparisons

Two comparisons are addressed in this section. First, we compare survey results by 2014-2015 participants with 2016 participants in terms of program goals and measurements. Second, we compare the summer and semester research project experiences.

Comparison of REU 2014-2015 with REU 2016.

Below are results from the 2014 to 2016 program surveys. A survey link was sent to participants roughly two months after the summer program ended. Completion of the surveys was anonymous and voluntary. For the 2014 batch, eight of the ten participants responded. For the 2015 batch, seven of the nine participants responded. For the 2016 batch, ten of the ten participants responded. The total number of responses was 25. Below are summaries of responses for six question sets.

The first question set was "How much did you gain in the following areas as a result of your REU experience?"

- Figuring out the next step in a research project
- Problem-solving in general
- Understanding the connections among scientific disciplines
- Understanding the relevance of research to my coursework

Participants rated their gain on a five-point scale (no gain, a little gain, moderate gain, good gain, great gain). In all four areas rated for this question, a higher percentage of the 2016 participants reported good or great gains than the 2014-15 participants.

- On the 2014-2015 surveys, about 67% of respondents reported good or great gains in figuring out the next step in a research project; in 2016, this figure was 70%.
- On the 2014-15 surveys, 60% of respondents reported good or great gains in problem-solving in general; in 2016, this figure was 80%.
- On the 2014-15 surveys, 60% reported good or great gains in understanding the connections among scientific disciplines; in 2016, this figure was 70%.
- On the 2014-15 surveys, 67% reported good or great gains in understanding the relevance of research to my coursework; in 2016, this figure was 70%.

Figure 1 compares the 2014-15 and 2016 responses in terms of means. Overall, the means of the responses of the 2016 participants are higher than the means for the 2014-2015 participants, possibly due to the influence of the strategies implemented in 2016.

How much did you gain in the following areas as a result of your REU experience?

Answer Options	No gain		A little gain		Moderate gain		Good gain		Great gain		N/A		Response Count		Average	
	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15
Figuring out the next step in a research project.	0	1	0	2	3	1	5	6	2	4	0	1	10	15	3.90	3.47
Problem-solving in general.	0	1	1	2	1	2	5	6	3	3	0	1	10	15	4.00	3.33
Understanding the connections among scientific disciplines.	0	1	0	2	3	3	4	5	3	4	0	0	10	15	4.00	3.60
Understanding the relevance of research to my coursework.	0	1	1	2	2	2	2	7	5	3	0	0	10	15	4.10	3.60

Figure 1. Comparison of the Participants' Ranking on Gains in Research Method

The second question set was “How much did you gain in the following areas as a result of your REU experience?”

- Writing scientific reports or papers
- Explaining my project to people outside the field
- Preparing a scientific poster
- Understanding journal articles
- Managing my time

In four of these five areas, a greater percentage of the 2016 participants reported good or great gains than the 2014-15 participants.

- On the 2014-2015 surveys, 47% of respondents reported good or great gains in writing scientific reports or papers; in 2016, this figure was 70%.
- On the 2014-15 surveys, 67% of respondents reported good or great gains in explaining their project to people outside the field; in 2016, this figure was 80%.
- On the 2014-15 surveys, 47% reported good or great gains in understanding journal articles; in 2016, this figure was 70%.
- On the 2014-15 surveys, 53% reported good or great gains in managing time; in 2016, this figure was 760%.
- There was a slight decrease in the reported gain for preparing a scientific poster; in 2014-15, 87% reported good or great gains in preparing a scientific poster; in 2016, this figure was 70%.

Figure 2 compares the 2014-15 and 2016 responses in terms of means. Overall, the means of the responses of the 2016 participants are higher than the means for the 2014-2015 participants, possibly due to the influence of the strategies implemented in 2016. The mean reported gain for preparing a scientific poster went down; this may have been because of changes in the presenter for this topic or perhaps because more of the 2016 participants already knew how to prepare a poster.

How much did you gain in the following areas as a result of your REU experience?																
Answer Options	No gain		A little gain		Moderate gain		Good gain		Great gain		N/A		Response Count		Average	
	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15
Writing scientific reports or papers.	1	1	0	1	2	6	3	3	4	4	0	0	10	15	3.90	3.53
Explaining my project to people outside the field.	0	1	1	0	1	4	6	4	2	6	0	0	10	15	3.90	3.93
Preparing a scientific poster.	0	1	2	0	1	1	2	4	5	9	0	0	10	15	4.00	4.33
Understanding journal articles.	0	1	1	1	2	6	4	3	3	4	0	0	10	15	3.90	3.53
Managing my time.	1	2	0	1	3	4	5	4	1	4	0	0	10	15	3.50	3.47

Figure 2. Comparison of the Participants’ Ranking on Gains in Research Method

The third question set was “During your REU experience, how much did you:”

- Engage in real-world engineering research
- Feel responsible for the project
- Feel a part of a research group

In all three areas, a greater percentage of the 2016 participants reported good or great gains than the 2014-15 participants.

- On the 2014-2015 surveys, 60% of respondents reported that they engaged in real-world engineering research a fair amount or a great deal; in 2016, this figure was 70%.
- On the 2014-15 surveys, 73% of respondents reported feeling responsible for the project a fair amount or a great deal; in 2016, this figure was 90%.
- On the 2014-15 surveys, 47% reported that they felt they were a part of a research group a fair amount or a great deal; in 2016, this figure was 40%.

Figure 3 compares the 2014-15 and 2016 responses in terms of means. The mean rating for feeling part of a research group was the same (3.00). The short length of the program (10 weeks) and being from different universities may make it difficult for participants to have a sense of belonging. However, there was improvement in 2016 on the other two indicators ("Engage in real-world engineering research" and "Feel responsible for the project").

During your REU experience, how much did you:																	
Answer Options	None		A little		Some		A fair amount		A great deal		N/A		Response Count		Average	
	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15
Engage in real-world engineering research.	0	1	1	2	2	3	4	7	3	2	0	0	10	15	3.90	3.47
Feel responsible for the project.	0	2	0	1	1	1	3	1	6	10	0	0	10	15	4.50	4.07
Feel a part of a research group.	1	2	5	2	0	3	1	5	3	2	0	1	10	15	3.00	3.00

Figure 3. Comparison of the Participants' Ranking on Gains in Research Method

The fourth question set asked participants to "Please rate the following:"

- My working relationship with my research mentor
- My working relationship with research group members
- The amount of time I spent doing meaningful research
- The research experience overall

Participants rated the items as poor, fair, good, or excellent. In 2016, ratings improved for all four items.

- On the 2014-2015 surveys, 53% of respondents rated their working relationship with their research mentor as good or excellent; in 2016, this figure was 90%.
- On the 2014-2015 surveys, 53% of respondents rated their working relationship with research group members as good or excellent; in 2016, this figure was 90%.
- On the 2014-2015 surveys, 33% of respondents rated the amount of time they spent doing meaningful research as good or excellent; in 2016, this figure was 60%.
- On the 2014-2015 surveys, 60% of respondents rated the overall research experience as good or excellent; in 2016, this figure was 70%.

Figure 4 compares the 2014-15 and 2016 responses in terms of means. Overall, the means of the responses of the 2016 participants are higher than the means for the 2014-2015 participants, particularly in participants' ratings of their relationships with their research mentor and research group members.

Answer Options	N/A		Poor		Fair		Good		Excellent		Response Count		Average	
	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15
My working relationship with my research mentor	0	1	1	2	0	4	6	3	3	5	10	15	4.10	3.60
My working relationship with research group members	0	3	0	1	1	3	4	5	5	3	10	15	4.40	3.27
The amount of time I spent doing meaningful research	0	1	0	2	4	7	6	2	0	3	10	15	3.60	3.27
The research experience overall	0	1	0	0	3	5	5	6	2	3	10	15	3.90	3.67

Figure 4. Comparison of the Participants' Ratings of Various Aspects of the Program

The fifth question set asked participants "Rate how much you agree with the following statements"

- My research experience has prepared me for graduate school
- My research experience has prepared me for a job

Participants rated their level of agreement with these statements as strongly disagree, disagree, agree, or strongly agree. In 2016, ratings improved in both areas.

- On the 2014-2015 surveys, 67% of respondents agreed or strongly agreed that their research experience prepared them for graduate school; in 2016, this figure was 100%.
- On the 2014-2015 surveys, 67% of respondents agreed or strongly agreed that their research experience prepared them for a job; in 2016, this figure was 70%.

Figure 5 compares the 2014-15 and 2016 responses in terms of means. The means of the responses of the 2016 participants are higher than the means for the 2014-2015 participants, particularly in participants' agreement that their research experience prepared them for graduate school.

Rate how much you agree with the following statements.												
Answer Options	Strongly disagree		Disagree		Agree		Strongly agree		Response Count		Average	
	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15	16	14-15
My research experience has prepared me for graduate	0	1	0	4	7	7	3	3	10	15	3.30	2.80
My research experience has prepared me for a job.	0	1	3	4	7	8	0	2	10	15	2.70	2.73

Figure 5. Comparison of the Participants' Ranking on Gains in Research Method

The sixth question set asked "How satisfied were you with the following aspects of the research program?"

- Research group meetings
- Financial support
- Lab tours
- Workshops on preparing for graduate school
- Poster sessions

Participants rated their level of satisfaction as very dissatisfied, somewhat dissatisfied, somewhat satisfied, or very satisfied. In 2016, ratings improved in all areas.

- On the 2014-2015 surveys, 60% of respondents were somewhat satisfied or very satisfied with research group meetings; in 2016, this figure was 90%.
- On the 2014-2015 surveys, 87% of respondents were somewhat satisfied or very satisfied with their financial support; in 2016, this figure was 100%.

- On the 2014-2015 surveys, 87% of respondents were somewhat satisfied or very satisfied with the lab tours; in 2016, this figure was 90%.
- On the 2014-2015 surveys, 60% of respondents were somewhat satisfied or very satisfied with the workshops on preparing for graduate school; in 2016, this figure was 90%.
- On the 2014-2015 surveys, 87% of respondents were somewhat satisfied or very satisfied with the poster sessions; in 2016, this figure was 100%.

Figure 6 compares the 2014-15 and 2016 responses in terms of means. The means of the responses of the 2016 participants are higher than the means for the 2014-2015 participants, particularly in participants' satisfaction with the poster sessions.

How satisfied were you with the following aspects of the research program?														
Answer Options	Very dissatisfied		Somewhat dissatisfied		Somewhat satisfied		Very satisfied		N/A	Response Count		Average	
	16	14-15	16	14-15	16	14-15	16	14-15	14-15	16	14-15	16	14-15
Research group meetings.	1	1	0	5	5	4	4	5	0	10	15	3.20	2.87
Financial support.	0	1	0	1	0	1	10	12	0	10	15	4.00	3.60
Lab tours.	0	1	0	0	3	9	6	4	1	10	15	3.30	2.93
Workshops on preparing for graduate school.	0	1	1	3	4	5	5	4	0	10	15	3.40	2.53
Poster sessions.	0	1	0	0	2	8	8	5	0	10	15	3.80	3.00

Figure 6. Comparison of the Participants' Ranking on Gains in Research Method

Comparison of semester research project with summer research project

To better understand what makes a project successful, it can be helpful to roughly compare students' REU project experiences with the experiences of students working on a semester research project for a class. A semester project was incorporated into the author's Automation and Robotics classes in spring 2016. Students formed six teams with two members per team. Afterwards, 12 students completed an opinion survey rating various aspects of their experience using a semester research project as part of the course requirements on a 7 point Likert scale (1=strongly disagree; 7=strongly agree). The mean responses to the survey questions are shown in Figure 7 below.

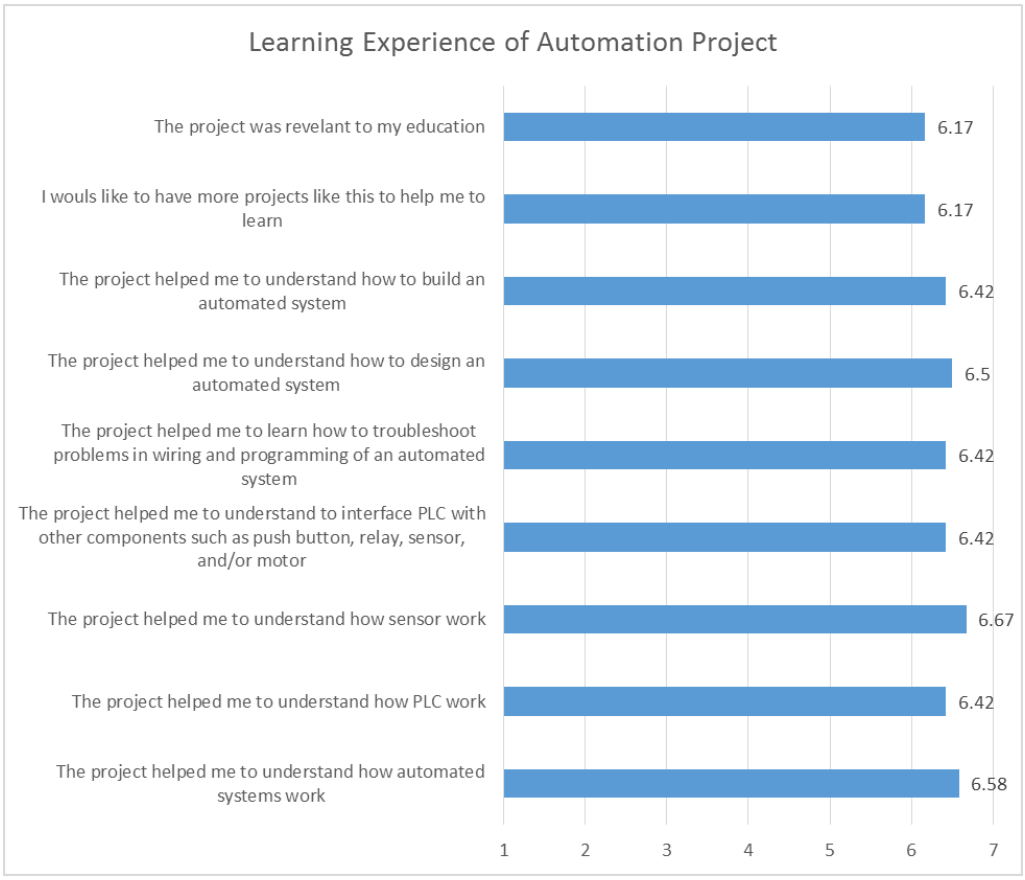

Figure 7. Mean responses to opinion survey questions related to semester project.

Student ratings were very positive for all items. The average rating was 6.2 on a 7-point scale. In general, students felt that the semester research project helped them to learn more about Manufacturing Automation and Robotics and that the hands-on experience helped them to visualize the process. They felt that the semester research project was useful and wanted to have more projects like it available.

Table 1. Comparison of semester and summer research projects.

	Semester research project	Summer research project
Audience	On-campus students	Students from other institutions
Duration	15 weeks	10 weeks
Program Format	Lecture, then working on the associated project element	Given a project to work on
Project Continuation	Likely since students are on campus	Not likely
Background related to the project	More likely	Less likely
Project topic	Self-selected	Given or negotiated; the motivation can be minimal
Satisfaction	Very high	High in 2016, medium in 2014-2015

Both types of projects can be successful, but it is somewhat more challenging to ensure a successful summer research project experience.

Student Comments

Below are student comments about the various research projects.

Summer Research Project.

Below are comments from the 2016 batch of participants about their experience.

In response to the question, "How did your research experience influence your thinking about future career and graduate school plans? Please explain."

- I had aspirations prior, but the REU program gave me a better idea on how to finance it.
- It showed me that a research oriented career can be exciting and meaningful.
- It has further solidified my commitment to attend graduate school.
- My plan for graduate school did not actually change after this experience. I still intend to get a master's degree. However, I do have a much better understanding now of what I might expect in graduate school.
- This research experience has increased my interest in applying for graduate school. I really enjoyed my research topic and was similarly fascinated with those of the others REU students. Being able to solve problems hands on is so much more exciting than the typical entry level engineering job. I plan on attending grad school at some point, if not directly after graduation.
- Research is largely independent work. I don't think I would want to permanently do research
- My summer experience showed me the importance of choosing a good mentor to work with. I plan to apply to graduate schools, but also look for jobs as a backup plan if I don't get an assistantship or grant for going to grad school.
- My research experience allowed me to gain insight into the research process and made me feel more comfortable with the idea of engaging in a long-term research project. I feel overall more prepared for graduate school and as though I have a greater understanding of what it entails.
- It helped me learn more about the graduate school experience and explore interests in mechanical engineering, and whether I wanted to continue my studies.

In response to the question, "Did you make other gains from doing research that we didn't mention? If so, please briefly describe these."

- I attend a smaller university so it gave me an idea on what large research institutions are like to attend.
- I learned a lot of knowledge outside of my specialization in school.
- Journal articles were already mentioned above, but I think this experience made me better understand how to write an effective literature review. Up until this past summer, I would mostly just cite websites when I needed to put background information in a paper. I now know how to find more credible sources of information.

- It's increased my interest to learn practical skills outside of my major: Arduino programming, electronics, and basic coding. I'm highly interested in pursuing a career in robotics and automation, and this experience exposed me to technical skills required by this field outside of mechanical engineering.
- I learned Arduino from scratch and a lot about motors.

In response to the question, "What was the most challenging part of the experience?"

- Expanding my knowledge and using the different programs to conduct research.
- Having to adapt to changing project goal.
- Figuring out what to do without in depth knowledge of a subject
- I went into this program very used to *highly* structured schedules, deadlines, etc., so it was challenging for me to get used to the "as long as you manage your time well and finish this part of the project by X date, it's up to you how you want to plan your work time between now and then" atmosphere of research.
- Setting research goals for myself and developing an approach to conduct the research
- Presenting research work clearly
- Applying class concepts when I hadn't yet taken the class
- Having a clear idea of all the aspects of the project that I needed to complete.
- The biggest challenge was managing my schedule to ensure that things were done as needed, and juggling the various parts of a project to make sure everything went according to plan. Dealing with failures when things did not meet deadlines or work as intended was also a big challenge.
- Finding a project (the program should organize this much better) and working independently to research and solve problems and learn new things.

Semester Research Project.

The survey for the semester research project had two open-ended questions. In students' responses to the question "The most helpful thing about this project has been:" a common theme was that the students felt that project helped them to have hands-on experience to integrate what they learned from the class and to solve real-life problem. Below are the samples of their responses:

- Learn applicable solutions to real world problems.
- The wiring portion of the project was very useful to know. at the beginning of the project it was difficult to understand how wiring works. now that all wiring is complete I am more confident in my skills
- The hands on work, coding it by ourselves, making our own design and TA input when we had questions.
- I found this project to be most helpful with learning wiring and how to apply it. This also became useful when studying for the exam.
- Doing actual hands on work to help understand the complexity of automated systems.
- Setting up the wiring diagram and getting it checked by our TA and our professor was very helpful to my understanding, as well as being able to troubleshoot problems with some assistance.

- Was wiring and programming the PLC. Everything we learned in class we were able to apply to our project.
- It helped bring all the different lessons of the class together for a better understanding. Actually getting to wire the PLC and all the components was better than any lesson I could have learned in class.
- The interaction between the mechanical aspect of the project with the control logix
- The most helpful aspect of this project was physically wiring all the components. Before completing this I struggled with grasping the concepts of wiring. After completing the wiring of the project I was more confident.
- It taught me crisis management.

In students' responses to the question "This tool could be improved by:" common themes were 1) difficulty in wiring needs more support; and 2) need a larger work space. Note that normally students have access to a web resource called Virtual PLC to help them learn about wiring. This site was down for most of spring 2016, but was back up later in the semester. Samples of their comments are below:

- I know it wasn't available this semester but I would have been good to have some sort of online assistant with learning the material. We wasted a lot of time due to not knowing there was an issue with our physical wiring. It looked good on paper but when implemented with the program, we had issues.
- Defining the guidelines better.
- Larger work spaces would certainly be beneficial, and covering the topic of relays and wiring at the same time as the project is being assigned would also be beneficial.
- We were able to complete our project because we asked so many questions about wiring early on, but it would have gone by a lot faster if the wiring lectures were paired with the project.
- Having access to [the Virtual PLC] website would have helped a lot with the wiring as well, since there is a tutorial on wiring available."
- Bigger work spaces for the wiring of the project. We were crowded in the lab.
- I think the class, should be working on the project and the lessons could be tough as stages of the project
- Having more time and resources

Lessons Learned, Conclusion and Future Directions

This paper extends previous work [16-17] about an NSF-funded REU site focusing on mechatronics, robotics, and automated system design. Survey results, lessons learned, and project highlights from three years (2014-2016) of hosting the program were presented. We also compare REU students' experiences with automated system design and building projects with the experience of students who did similar work as part of a semester project during fall 2016.

Some changes were made to the REU program in 2016. These included regularly asking students about their projects, confirming they completed and understood research steps, having participants work as a group to help one another, and inviting graduate students to talk about the graduate study experiences. The 2014-15 post-program survey data were compared with the

2016 data. Results suggest that the changes had an overall positive effect on students' experiences with the program.

In addition, REU students' experiences were compared with the experience of students completing semester research projects in the area of manufacturing automation. While both REU and semester project participants reported positive experiences, it seems that the students completing the semester projects were more satisfied. Possible reasons include greater ownership of the project, more time to work on their projects, and integration of the project with class lectures. If the summer research project could be modified to include some of these elements, perhaps the REU student experience could be improved even further.

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