AC 2012-5066: IMPACT OF AN UPDATED ROBOTICS LABORATORY IN AN INDUSTRIAL ENGINEERING PROGRAM

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Impact of an Updated Robotics Laboratory in an Industrial Engineering Program

Abstract

Robotics is the study of the design, manufacture and application of robots used in a variety of existing systems or systems to be created. The impact and benefits of robotics in education at all levels have been documented by many researchers and educators all across the country, as well as, the world. Several universities have developed robotics programs which provide unique opportunities for students to learn about robotic systems through coursework and conduct high-level research. When these courses are combined with hands-on laboratory modules, robotics provides a means for student to utilize their analytical skills learned in other Science, Technology, Engineering and Math (STEM) courses to solve real-world problems in the areas of transportation, scheduling, manufacturing, logistics, and many others.

With a Course, Curriculum and Lab Improvement (CCLI) grant project sponsored by the National Science Foundation from 2009 - 2011, an updated Industrial Robotics and Automated Manufacturing (IRAM) laboratory was developed. Utilizing this newly updated laboratory at Morgan State University (MSU), students are now able to use modern equipment within a set of courses specifically designed around the facility. These courses are in the areas of advanced material handling systems, robotics and automation, computer-aided manufacturing, and flexible manufacturing systems. The integration of these courses with a hands-on laboratory approach into the Industrial Engineering (IE) undergraduate curriculum allows the student population to get a new and innovative type of training and preparation for the engineering workforce, and to strengthen it through increased awareness in learning how to use robotic-related software to model systems. In addition, students can determine solutions for various manufacturing and service scenarios and engage in realistic applications of manufacturing systems through the new lab modules.

Overall, the CCLI project has had a significant and broad impact as the engineering students have participated in these courses and the results show that the students have gained much from them. Due to the interest in taking these new elective courses and successfully completing the courses which utilize the IRAM lab, the number of under-represented students (women and minorities) who graduate with this new background has increased in the IE department at MSU. In addition, the readiness of these engineering students entering into graduate research programs and the engineering workforce has also increased.

Introduction

Robotics is a technology that is concerned with the design, operation, and application of industrial and/or mobile robots. The official definition as provided by the Robotics Industries Association[1] states that a robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks. In addition, these mechanical devices are commonly used and operated automatically to perform routine work for human beings. These robotic work cycles can be performed with a consistency and repeatability that cannot be obtained by humans[2].

With the use of robotics, it is possible to minimize the time it takes to complete repetitive tasks (e.g., assembly operations, machine loading and unloading, lifting, spot welding, spray painting, etc.) which could also translate into cost savings for a given industry. In addition, tasks which are not suitable for humans (e.g., deep sea excavation, space exploration, or bomb diffusion, hazardous waste removal) could be executed and simplified using various robots. Even today robots are used with assisting humans with common everyday tasks such as performing general office work, doing the laundry, or retrieving a newspaper. However, none of these robotic actions are possible without the use of a computer to execute and control the actions and tasks.

Since robots are controlled by computers, they can be integrated and connected to other computer systems to perform computer-integrated manufacturing (CIM) activities. Therefore, CIM is the pervasive use of computer systems to design the products, plan the production, control the operations, and perform the various information processing functions needed in a manufacturing firm[2]. These environments are generally automated, complex systems with components such as conveyors, computer-numerically controlled (CNC) machine workstations, automated guided vehicles (AGVs), and robots. Industrial automation can be classified into three classes: (1) fixed automation, (2) programmable automation, and (3) flexible automation. With fixed automation, specially designed equipment is utilized to produce a single product only. Programmable automation uses equipment to make batches of products at a time. Once a single batch is finished, the equipment can be reprogrammed to make another batch of products. On the other hand, flexible automation allows for the manufacture of different parts to be made at the same time within the same manufacturing system.

Combining robotics and automation technologies together allows for an efficient, automatically operated system to be achieved which can be formed to accomplish an infinite number of tasks and operations, especially those concerned with the manufacture and assembly of parts or products. A proper fully-equipped system will allow for the automated production of various parts/products in a flexible manufacturing system (FMS) environment using non-traditional methods (e.g., CNC milling, CNC turning, CNC drilling, automatic part storage and retrieval, etc.).

In 2009, Dr. Richard Pitts, Jr., Associate Professor of Industrial Engineering at Morgan State University (MSU), received a CCLI grant to improve the quality of education and training to which its undergraduate industrial engineering students have access. MSU is minority-serving institution (MSI) located in Baltimore, MD. In fall 2011, MSU’s enrollment surpassed 8,000 undergraduate and graduate students in various academic disciplines which is the largest enrollment in the history of the university[3]. Additionally, the university is home to the majority of African American engineering graduates in the state. CCLI grant funds were used to improve MSU student access to modern industrial engineering equipment and technology, and to help students develop and enhance the skills needed for success in the field of industrial engineering. Funds were used to purchase up-to-date equipment for the MSU IRAM Laboratory located in the School of Engineering. Prior equipment had been purchased in 1991 and was not compatible with Windows-based control software and did not allow students to use modern manufacturing methods to manufacture parts and products within a single facility. Thus, there was a necessity for the new equipment to enable the students to have increased access to areas of robotics and automation.

Literature Review

Recently, there has been increased attention paid to STEM education at all levels. Policymakers, educators, and researchers have emphasized the importance of improving the STEM education pipeline, and recent government reports have called for an increase in investment in STEM education[4]. New government programs such as the National Robotics Initiative also highlight the need for improvements in STEM education and the extent to which such improvements are tied to the nation's economic competitiveness in an increasingly technological, global economy[5].

At MSU, Robotics and Automation is taught in a course to provide an impetus for allowing students to learn the basic concepts of the organization and operation of microcomputer-based manipulators (i.e., robots)[6]. Various assignments and lab projects which consider topics such as control systems planning, design and implementation planning, trajectory planning, and programming are key elements for the Industrial Engineering (IE) students in the course. While utilizing the Industrial Robotics and Automated Manufacturing (IRAM) Laboratory, the students get a chance to experience the actual integration and utilization of mid-sized industrial robots and automated equipment that is used to manufacture customized parts. Overall, the newly updated and improved IRAM laboratory enhances student learning at the university and helps to improve STEM education within the curriculum in the IE department, as well as, help to meet the National Robotics Initiative previously mentioned.

Other researchers at various universities are using robotics education in undergraduate curriculums as well. Touretzky discusses how various computer science (CS) departments around the country utilize robots to help teach and promote computer programming[7]. At Carnegie Mellon University, Touretzky and his team developed a robot programming language called Tekkotsu which provides a unified framework that undergraduates can master in two-thirds of a semester and then move on to working on an interesting final project. He believes that robotics is the leading candidate for the next dramatic change in the CS curriculum, provided that the understanding of robot programming will broaden in the coming years.

Mataric briefly surveyed his experiences of using robotics as an educational tool at the University of Southern California[8]. He considers robotics a growing field that has the potential to significantly impact the nature of engineering and science education at all levels, from K-12 to graduate school. He concluded that his undergraduate Introduction to Robotics course (including a regular lecture and a lab) provide true inspiration for students, while serving as a good retention and showcase tool for the university.

At Santa Clara University's Robotic Systems Laboratory, interdisciplinary teams of undergraduate students build and deploy a wide range of robotic systems, ranging from underwater vehicles to spacecraft[9]. Over a five year period, Kitts and Quinn have conducted a robotic development and operations program which has given over 150 students exposure to various computer science and engineering topics such as software engineering, algorithm development, human-computer interface design, and artificial intelligence. The authors believe that the program provides exciting and compelling educational opportunities for students, offers real-world applications that naturally motivate the need for specific computing technologies, and serves a broader research and development program that utilizes the functional robotic systems to support externally-funded science and technology demonstration missions.

Duke *et al.* offer their "Introduction to Mobile Robot Programming" robotics course to undergraduates at early stages of their coursework at Carnegie Mellon University in Qatar Campus[10]. The authors state that this course is designed to leverage robotics as a platform to teach analytical skills, and to give students early exposure to teamwork and large-scale projects. It culminates in students building all the major components to solve a non-trivial task on real hardware. Duke and his team of researchers conclude that the course has been well received by the students, most of whom find interactions with robots and competition with their peers to be good motivators to explore and invent.

There are numerous other examples in the literature such as Manseur[11] and Anderson & Baltes[12] who have implemented and developed undergraduate robotics courses to change the curriculum at their respective universities. However, it is even rarer to find in the literature examples where entire manufacturing systems (with robots and other automated machines) are used in academia to transform an engineering curriculum. This research shows that such projects can make an impact for an entire engineering department, and improve the student interests in this STEM area.

Project Goals

Today, industry-driven companies are not only requiring new engineering hires to have the traditional math and science background of typical engineering students, but they are also requesting that their engineers can do problem solving and perform analysis, as well as have the ability manage and lead others. Further research suggests the need for restructuring of the undergraduate engineering curriculum in order to better prepare students for engineering practice[13]. In addition to this, Eskandari *et al*. states that future IE graduates should have courses and learning experiences that develop their knowledge base, skill set, and work experiences in the area of non-traditional industries[14]. This leads to the fact that industrial engineers will have more opportunities which stretch further than the traditional manufacturing areas that it was originally founded upon.

Thus, courses which suggest and/or promote and address these types of learning opportunities will become necessary in the undergraduate curriculum. The recently renovated IRAM laboratory and the courses associated with this lab have delivered these types of learning objectives by exposing undergraduate students to various robotic and computer-controlled applications. The combination of the robotics and automation in a single facility branches allows students to use non-traditional technologies (i.e., CNC milling, CNC turning, etc.) for the development of multiple parts and products with different processes. In addition, the upgrading of the IRAM laboratory provided students with ongoing, hands-on access to technology to develop the knowledge and decision-making skills required for these fields.

The specific goals of the program are inter-related and included the following:

- Improving the IRAM laboratory with modern equipment allowing for the creation and dissemination of educational materials;
- Promoting enhanced learning for students by providing exposure to the integration, programming and utilization of manufacturing resources;
- Assessing educational impact with mini-module laboratory projects for problem solving;
- Engaging and retaining under-represented students in the area of IE to promote a diverse workforce and encourage research education at this Minority Serving Institution (MSI).

The purchase of the new equipment allowed the IE department to establish a flexible manufacturing cell (FMC). This is a small FMS with a computer-controlled configuration of semi-dependent workstations and material-handling systems designed to efficiently manufacture low to medium volumes of various job types. The new equipment also allowed MSU to re-introduce courses which had been sparsely taught due to the lack of appropriate technology (IEGR 468 and IEGR 470) and to provide new courses in automation and robotics for MSU students (IEGR 478 and IEGR 488). Table 1 provides an overview of the courses supported by CCLI grant funds. Review of the course goals reveals a consistent focus on developing the problem-solving, knowledge acquisition, and decision-making skills required for the various stages of product and part development within a manufacturing environment.

Evaluation Framework and Methodology

The CCLI IRAM laboratory grant evaluation documents the extent to which the project achieved each of its goals. The primary evaluation methods were (1) reviews of existing documents and (2) a spring 2011 survey administered to enrollees in all four courses. Reviewed documents include the following:

- Enrollment and grade records for all courses
- Syllabi for all courses
- Descriptions of IRAM laboratory assignments
- Research abstracts and agendas from research conferences

The survey was administered over a three-week period in June 2011. The external evaluator e-mailed the surveys to all 23 students in the CCLI-supported courses (7 students enrolled in more than one course, but each student received only one survey). Next, the external evaluator conducted two follow-up administrations for non-respondents to help boost response rates. Students returned a total of 18 surveys, yielding a 78% response rate. Survey responses were numerically coded and entered into PASW Statistics 18. Analytic methods included frequencies of survey responses.

Table 1. IRAM Course Offerings Fall 2009 through Spring 2011

Course Number and Name	Course Status	Course Goals
IEGR 468 – Advanced Material Handling Systems (MHS)	Offered Fall 2009	• Use math and engineering skills to evaluate and solve MHS problems • Find solutions when solving cost-related MHS problems • Apply computer programming skills in the development of MHS applications
IEGR 470 – Industrial Robotics and Automation	Offered Spring 2010	• Develop ability to determine which robots and other automated equipment are best for specific industrial applications • Program industrial robots for solving engineering-related problems efficiently • Develop knowledge to design basic robotic control systems • Develop ability to determine which sensors and other devices are necessary for specific systems which use robots and other automated equipment
IEGR 478 – Computer-Aided Manufacturing	Offered Fall 2010	• Acquire knowledge and develop ability to determine which machines or other automated equipment are best for specific industrial or manufacturing applications • Program CNC machines for solving engineering-related problems efficiently • Acquire knowledge to design basic NC programs and computer-aided manufactured parts • Develop ability to determine how to use various manufacturing-related areas with CAD/CAM systems and other manufacturing environments
IEGR 488 – Flexible Manufacturing Systems	Offered Spring 2011	• Develop ability to determine which machines or other automated equipment are best for specific industrial or manufacturing applications in a flexible manufacturing system (FMS) and computer-integrated manufacturing environment (CIM) • Program robots, CNC machines, and other automated equipment for solving-engineering related problems • Develop ability to design basic robot programs, NC programs, computer-aided manufactured parts, and FMS/CIM related layouts • Develop ability to determine how to use various manufacturing-related areas such as group technology (GT), computer-aided process planning (CAPP), etc. within FMS and other manufacturing environments.

Course Enrollment

A total of 30 students completed at least one of the four IRAM courses; seven students enrolled in more than one course. Figure 1 displays final enrollment counts by course.

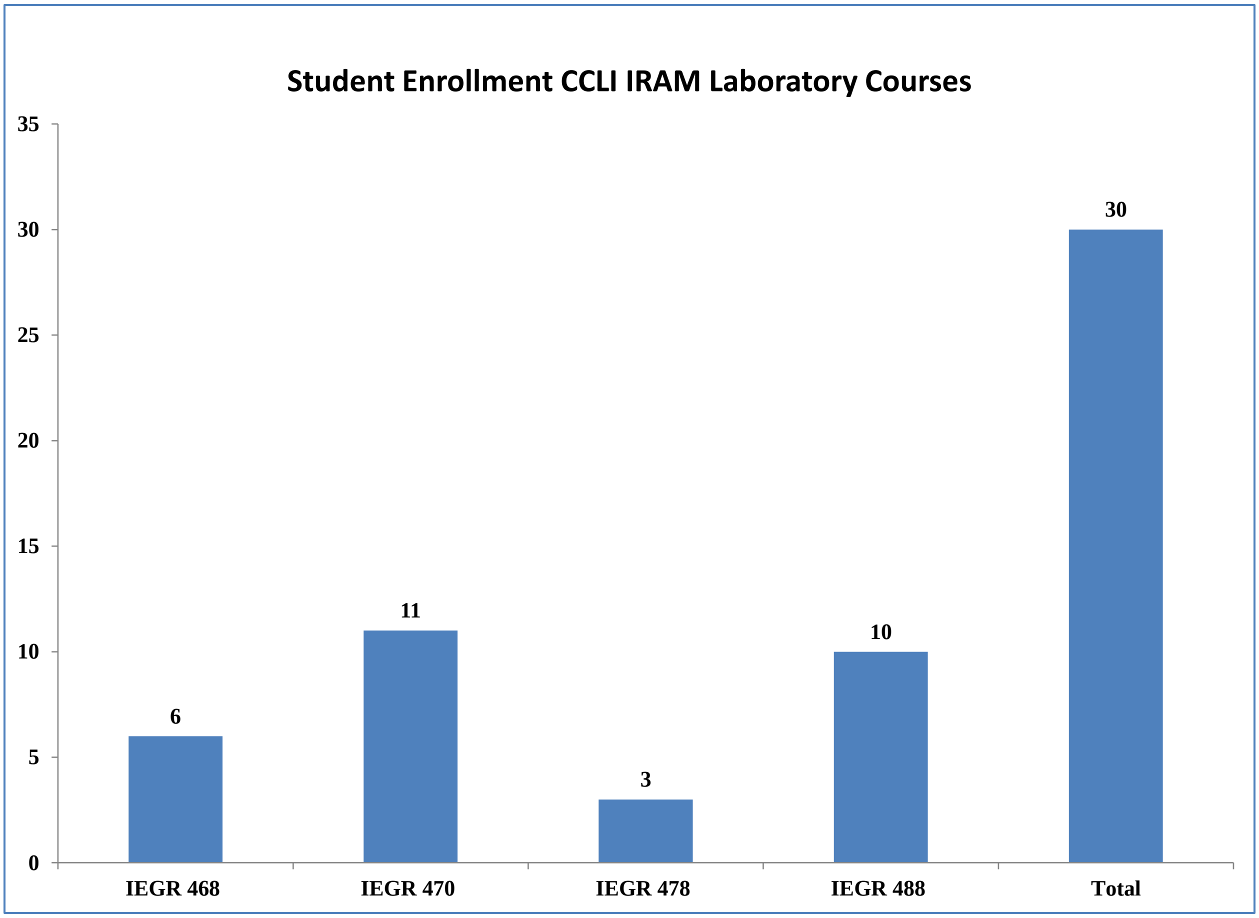

Figure 1. Student enrollment for CCLI IRAM lab courses

Outcomes by Goal

Goal 1 - Improving the IRAM laboratory with modern equipment allowing for the creation and dissemination of educational materials.

Grant funds were used to purchase the following equipment for the IRAM laboratory:

- Motoman HP3 Performer industrial robot mounted on a linear slidebase
- eXpertMILL 0600 CNC milling machine center
- proLight 3000 CNC turning center
- Scorbot ER-4u industrial robot (upgraded from ER-4 model)

As discussed above, the equipment allowed for the creation of a fully-equipped FMC.

Goal 2 - Promoting enhanced learning for students by providing exposure to the integration, programming and utilization of manufacturing resources.

Survey responses indicated that enrollment in IRAM courses increased student knowledge of engineering concepts targeted by the grant (Figure 2). Approximately three-quarters of respondents (14 of 18) said they had little or no knowledge of robotics, automation, and manufacturing systems before enrolling in the courses, and 72% (13 of 18) said that they had little or no hands-on experiences with robotics or automation systems prior to enrolling in the courses. In fact, the only pre-requisite courses in which the students had previously taken in preparation for enrolling in these new IRAM courses were Introduction to Programming for IE (IEGR 304), Solid Modeling and Design (IEGR 317), Engineering Economy (IEGR 350), and Manufacturing Processes (IEGR 363). These pre-requisite courses introduced concepts such as C++ programming, computer-aided design, economic principles of engineering, and the application of process and product development as it relates to traditional and non-traditional manufacturing technologies. However, after completing the IRAM courses, students reported that they had learned a broad range of industrial robotics and automation engineering concepts and applications. Nearly 90% of students (16 of 18) reported that they had learned ‘some’ or ‘a lot’ about robot programming, automation design, and control systems. Approximately 83 percent (15 of 18) reported that they had learned ‘some’ or ‘a lot’ about material handling systems, manufacturing automation, and process planning. Approximately three-quarters of students reported that they had learned ‘some’ or ‘a lot’ about quality control assurance (14 of 18, 77.8%) and manufacturing design or computer hardware and software (13 of 18, 72.2%). Students were least likely to report that they had learned ‘some’ or ‘a lot’ about industrial logic networks or computer programming (50%, 9 of 18 students).

Students saw the value of the courses they took. One student said, “I learned a lot from the course and would highly recommend it. For it to be the first time that the instructor taught the class, it ran smoothly.” Similarly, other students reported “It was a good course, and the robots were pretty fun. The simulation of a part being cut and watching it in real time was awesome.” Another student said, “The concept of this course was very interesting and can be applied to plenty of real-life applications.”

Final course grade data indicate that all students enrolled in the IRAM courses earned passing grades. Final average grades were in the B range, approximately 79.5%. Three students earned A’s in IEGR 488; two students earned A’s in IEGR 470; and one student earned an A in IEGR 468. Figure 3 displays the distribution of final grades for each course.

Goal 3 - Assessing educational impact with mini-module laboratory projects for problem solving.

The review of course syllabi, final course grades, and example laboratory assignments reveal a consistent focus on hands-on, laboratory experiences. Students received separate laboratory or mini-project grades which were factored into overall grades. Laboratory grades comprised 40% of IEGR 478 and IEGR 488 overall course grades and were the largest single grade component. Examples of laboratory assignments include using CNC programming skills to design parts to be milled on the eXpertMILL 0600 CNC milling machine. At the end of the course students manufactured parts and also displayed them for other IE students. Students also designed and created parts using the proLight 3000 CNC turning center and also displayed these parts for other IE students. Students also programmed the Scorbot ER-4u robot to solve the Tower of Hanoi game (the 3-ring version) while simultaneously given the task of designing a non-permanent fixture for the game's platform.

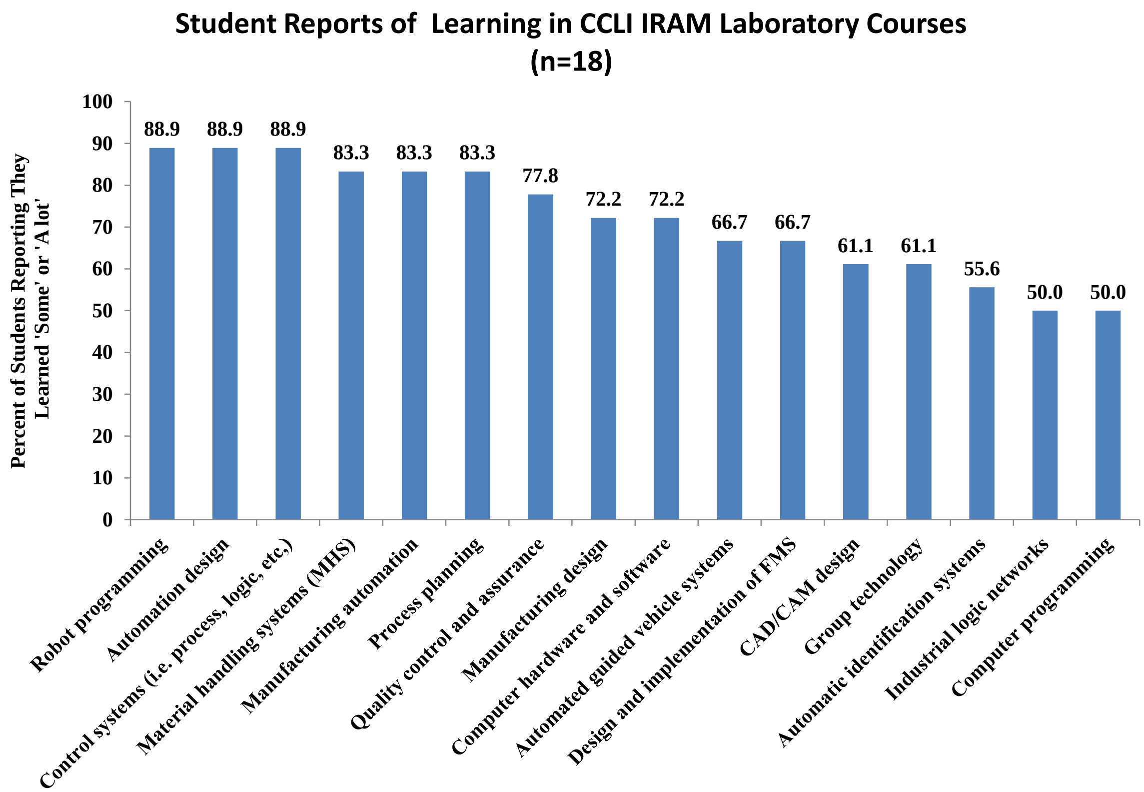

Figure 2. Student reports of learning from CCLI courses

Goal 4 - Engaging and retaining under-represented students in the area of IE to promote a diverse workforce and encourage research education at this Minority Serving Institution (MSI).

Students enrolled in the IRAM courses have presented their research at both local and regional research symposia. Presentation topics indicate that not only are students actively engaging in research activities, but they are also attempting to use their work to increase the interest of elementary, middle, and high school students in the engineering field. One student presented his research on robotic sensor and motion functionalities using the Robotino; The instructor discussed the goals of the CCLI IRAM project; and two students discussed their work on using robotics outreach to increase youth interest in the engineering fields at the 2nd Annual Advancing Robotics Technology for Societal Impact (ARTSI) Student Research Conference in Hampton, VA in March 2010. Later in June 2010, the instructor also presented his preliminary findings from year 1 of this project at the 2010 ASEE conference in Louisville, KY. Students also presented their work at the MSU Research Symposium in October 2010.

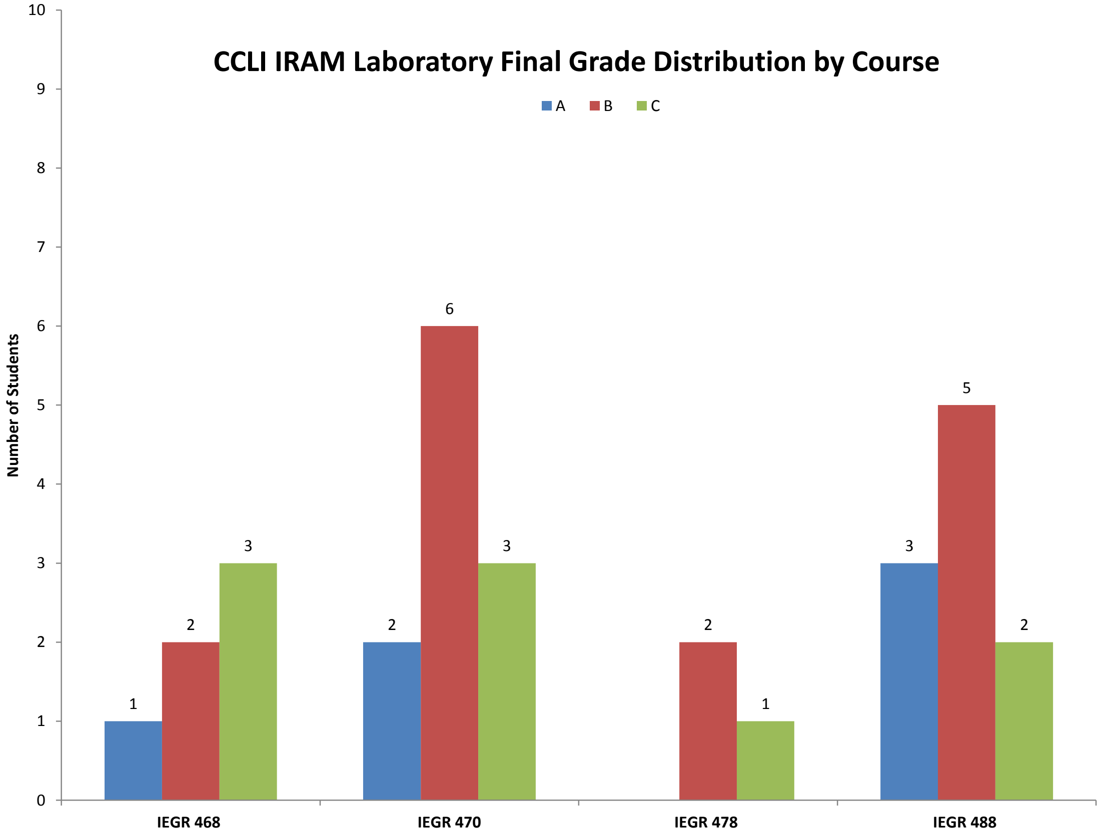

Figure 3. Grade distribution for CCLI courses

One student presented work on robot applications for K-12 outreach, and another student presented the Robotino research to MSU students. Course participants also presented their work at the February 2011 Morgan State University Innovation Day in Annapolis, MD, and one student presented his work on humanoid robots at the March 2011 3rd Annual ARTSI conference in Tallahassee, FL.

The four courses spurred nearly all students' continued interest in industrial engineering training and the desire to work and study in the field. Approximately 94% of students (17 of 18) indicated the courses had a positive impact on the likelihood that they would continue industrial engineering education and training, and an equal number of students reported that they were 'likely' or 'very likely' to continue working in the IE field over the next five years. Nearly all students (94%, 17 of 18 students) reported that participation in the IRAM course(s) had better prepared them to work in the IE field. Of the 10 students who provided suggestions on how to further improve the IRAM laboratory or the courses, all reported that the both the courses and laboratory could be improved by providing more access to and use of modern robotics and automation equipment. One student suggested including guest speakers who are currently working in the field as a part of the courses.

Early evidence also indicates that students are having some success continuing in the IE field. Approximately half of the 10 students who took the courses and who graduated in either 2010 or 2011 reported that they were currently working either part time or full time in the IE field. One student reported that he/she was currently pursuing graduate engineering education.

Conclusion

Available evidence suggests that the initial goals for the CCLI grant were met. Each of the courses were offered and made use of the new equipment. Student enrollment in some courses was low, but it is likely that enrollment will increase as other students learn about the potential of the IRAM laboratory. Students gave high ratings to the courses and most indicated that they had learned a lot about the IE field as a result of enrolling in the courses. Nearly 90% of students (16 of 18) reported that they had learned 'some' or 'a lot' about robot programming, automation design, and control systems. These reports indicate a significant increase in prior knowledge as approximately three-quarters of students reported little knowledge of or hands-on experience with robotics, automation, and manufacturing systems before enrolling in the courses. On average, students earned a 'B' as a final course grade. Survey data suggest that enrollment in these courses may have also encouraged students to continue working in the IE field. Approximately half of recent graduates reported that they are currently working in the IE field. Student suggestions of laboratory and course improvements indicate that the purchase of additional equipment and more time in the laboratory will further improve student interest and outcomes. The upgraded IRAM laboratory thus appears to be off to a positive start and may positively affect student learning of fundamental robotics and automation concepts and skills as well as facilitate continued student participation and involvement in the IE field.

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