An Effective Learning Approach for Industrial Robot Programming

Dr. Guanghsu A. Chang, Western Carolina University

Dr. Guanghsu A. Chang is currently an associate professor of the Engineering and Technology Department at Western Carolina University. He has spent the last 21 years in teaching industrial and manufacturing engineering programs. His research interests involve the study of robotic applications, manufacturing automation, Design for Assembly (DFA), and Case-Based Reasoning (CBR) applications. He was a vice president of Southern Minnesota APICS (2009-2012). He holds both MSIE, and Ph.D. degrees from the University of Texas at Arlington.

Dr. Wesley L. Stone, Western Carolina University

Dr. Wes Stone is an associate professor in the Department of Engineering and Technology at Western Carolina University in Cullowhee, NC. He earned his bachelor's degree from the University of Texas at Austin, master's degree from Penn State, and Ph.D. from Georgia Tech, all in Mechanical Engineering. His research interests include manufacturing processes and quality techniques. He also serves as the Engineering Technology program director at WCU.

An Effective Learning Approach for Industrial Robot Programming

Abstract

Programming an industrial robot by using a teach pendent is a tedious and time-consuming task that requires a considerable amount of work-related skills, robotics knowledge and experience. Robot applications design also requires a tremendous amount of programming skills and input/output controls to make them useful. Obviously, a good robot programmer is a key factor of successful robot applications. In order to teach manufacturing engineering technology (MET) students to program industrial robots, we propose an effective learning approach for industrial robot programming in our curriculum. Research indicates that the use of off-line programming (OLP) method for learning industrial robot programming has a positive impact on reducing the robotics lab programming time (Ex. only two robots are available for 20 students), reducing the downtime of equipment when programming new work pieces/variants, and accelerating programming complex paths. This paper describes the development of off-line programming method to help students learn industrial robot programming. The off-line programming method is based on examples from industry and illustrates several good robot program designs. Overall, The OLP method provides not only our students an excellent learning environment but also a powerful teaching tool for MET instructors. Our results indicate that the students have the following competence to: 1) study multiple scenarios of a robotic workcell before any decision is committed, 2) determine the cycle time for a sequence of manufacturing operations, 3) Use libraries of pre-defined high-level commands for certain types of robotic applications, 4) minimize production interruption and help meet flexible automation goals, and 5) ensure that a robotic system will do the functions that an end-user needs it to do. We also recognize that the students who understand both robotics hardware and offline programming (OLP) software in combination is a challenge for many other colleges and universities. Not many students are proficient at both, but our students are.

1. Introduction

Today's industries use various types of industrial robots to manufacture parts and products [1]. Many college students misunderstand what an industrial robot is. They confuse the terms automation, remote-controlled, and numerical-controlled. Obviously, the most generally accepted definition for the industrial robot in the United States has been published by the Robotics Industries Association (RIA) as follows [2]: An industrial robot can be defined as

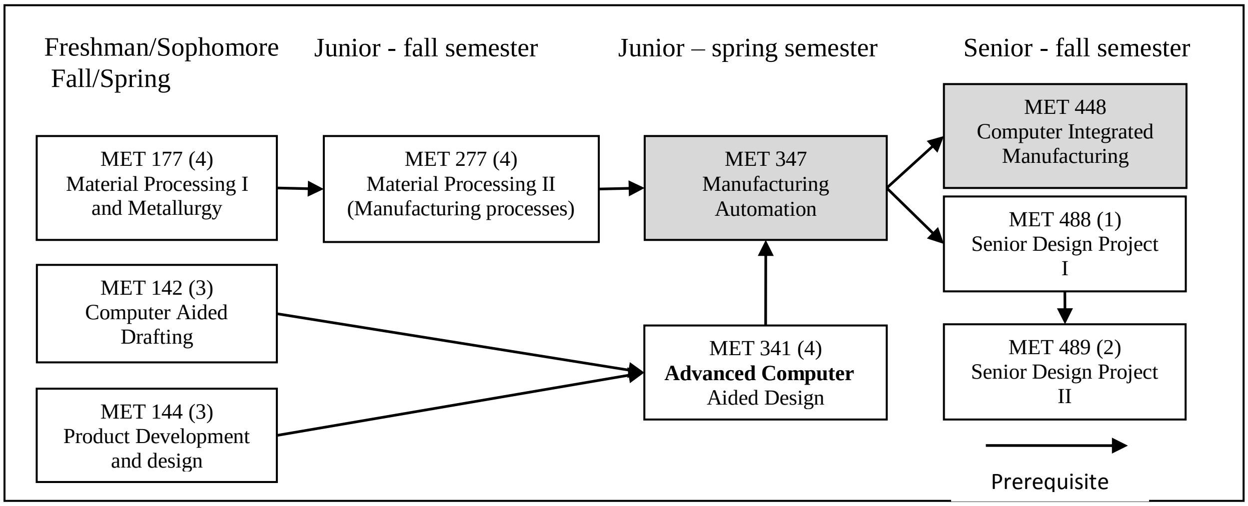
> *"A programmable, multifunction manipulator designed to move materials, parts, tools or special devices through programmed motion for the performance of variety of tasks"*.

As new parts or new products are needed, industrial robots can be reprogrammed to build the parts or products required. This flexibility saves money because the equipment does not have to be discarded or rebuilt. In addition, it takes much less time to reprogram the same industrial robots than to install new ones. In the last twenty years, the advances in robot hardware and software design have made it possible for bringing industrial robots into the classroom, especially for Manufacturing Engineering Technology (MET) students [4]. The introduction of industrial robots into MET program at Minnesota State University, Mankato (MnSU) not only has the opportunity to enhance students' hands-on practices and real world experiences, but also motives them for pursuing advances research and education in robotic vision, simulation and off-line programming. Actually, robot hands-on experience plays a key role in engineering education. It is an effective tool for student learning, as well as for encouraging participation in class learning and in research outside the classroom. In general, industrial robot programming subject can be integrated with the MET curriculum in three different ways: (1) for manufacturing automation class that is specifically designed to teach students how to program different industrial robots; (2) for Computer Integrated Manufacturing (CIM) class that is designed to teach students how to integrate industrial robots into a production system; (3) for advanced level programming classes or other specific topics such as robotic simulation, and OLP, where robotic projects can be used to facilitate real world experience for the students and motivate their interests in the various topics. Offline programming is the technique of generating a robot program with using a real robot machine. This OLP method presents many advantages over the on-line method (Physically use a robot teach pendent to generate a robot program): (1) robot programs are generated without interruptions of robot operation, (2) removal of the students from the potentially dangerous environment, (3) there is a greater possibility for optimization of system layout and the planning of robot motions. We teach our MET students offline programming software to emulate the robot motions, generate program instructions, and determine whether each movement can be successfully executed by repeatedly checking.

2. Background

Robotics courses are commonly found in many Manufacturing Engineering Technology programs in the USA. They include coverage of robot programming and often utilize robot motion simulation software such as WORKSPACE 4.0. Many Manufacturing Engineering Technology curricula include both Computer Aided Design and Computer aided Manufacturing (CAD/CAM) and Robotics courses. These courses may focus on different robotic workcell designs and manufacturing process analysis, which often involve a lot of design and manufacturing issues and theoretical concepts. At MnSU many design and manufacturing projects attempt to provide the students opportunities to practice their CAD/CAM knowledge and promote creativity and innovation. In the last two years, almost 40 students in our program were involved robotic workcell design projects. In general, all of the students are given foundational manufacturing and design concepts, principles, and methodologies of the engineering disciplines during their first two years. MET students have to finish their study of Material Processing I (MET 177), Computer Aided Drafting (MET 142), and product development and design (MET 144) courses before they are accepted by the program (see Figure 1).

Figure 1 - MnSU MET program of study (Partial view)



In order to verify that the students meet the program outcomes, a robotic workcell design project has been utilized to help them practice their robot programming knowledge and continuously improve the student learning environment. The supporting evidence in table-1 shows the relationship between ABET criterion 2 outcomes a-k and the robot programming learning outcomes. As we continue to use and improve this model, we expect that the robot programming learning outcomes will eventually meet ABET criterion 2 perfectly. Additionally, we will utilize more surveys to assess the effectiveness of the model.

Table 1 - Student project learning outcomes, program outcomes and ABET criterion 2 mapping

Student project Learning Outcomes	ABET Criterion 2 Outcomes a-k	*MET Program Outcomes	Learning Outcomes	ABET Criterion 2 Outcomes a-k	*MET Program Outcomes
Analytical Ability	a,c,f	1,2,4	Oral Communication	e,g	6
Teamwork	e,f	6,7	Written Communication	e,g	6
Project Management	b,e	6,7	Visual Communication	e,g	6
Math Skills	b	3	Creative Problem Solving	d	1,2
System Thinking	d,e	4	Ethics and Professionalism	a,i	8
Self-Learning	h	5	Technology Skills	a,f	1,2
Respect for diversity	j	8	Continuous improvement	k	4

Note: ABET Criterion 2 Program Outcomes – Students will have:
a. an appropriate mastery of the knowledge, techniques, skills and modern tools of their disciplines;
b. an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering and technology;
c. an ability to conduct, analyze and interpret experiments and apply experimental results to improve processes;
d. an ability to apply creativity in the design of systems, components or appropriate to program objectives;
e. an ability to function effectively on teams;
f. an ability to identify, analyze, and solve technical problems;
g. an ability to communicate effectively;
h. a recognition of the need for, and an ability to engage in lifelong learning;
i. an ability to understand professional, ethical and social responsibility;
j. a respect for diversity and knowledge of contemporary professional, societal and global issues; and
k. a commitment to quality, timeliness, and continuous improvement.
***MET program outcomes:** http://cset.mnsu.edu/met/about/outcomes.html

Although robotics topics can be possibly integrated into MET 347 and MET 448 courses, there are still many challenging issues we need to face and solve. In the world market for industrial robots, there are so many hardware and software platforms available for developing robot programming. What is the appropriate choice? These are the factors that need to consider when selecting the right platform. There are many tradeoffs when selecting the appropriate programming platform for learning purposes. Robotic Simulation enables a fast learning cycle (programming, debugging, and testing) by assuming that robot work in an ideal environment.

3. Methods

Research has shown that project-based learning is an extremely effective learning activity. Many university professors today accept this learning environment to help students make the transition from passive learning to active learning learners in their classrooms [8]. In order to find better ways of involving the students in this learning process, we introduced Offline Programming (OLP) Project into our MET 347 Manufacturing Automation course. With the successful OLP design project (see Table 2), the students learn more materials, retain the information longer, and enjoy the class activities more. The OLP design project allows the students to learn many OLP concepts, principles, and guidelines in the classroom with the help of the instructor and other classmates, rather than on their own. The OLP design project consists of project-based learning activities to encourage students to do more than simply listen to a lecture. They are able to evaluate and redesign their own robotic workcells to prove their ideas and what they have learned from MET 347 course. After learning, processing, and applying information from OLP (WORKSPACE 4.0) software, the students are ready to share their ideas with team members (3-4 students/per team). By dividing students into different roles and working cooperatively, the whole class will be able to work together to design their own robotic workcells.

Table 2 – learning modules and lessons of Industrial Robot Programming

Module	Lesson	Learning Outcomes
Fundamentals of Robotics	1.What is an Industrial Robot? 2.Characteristics of an Industrial Robot 3.Manipulator Configurations (number of Axes) 4.Robot Coordinates 5.Repeatability, Precision, and Accuracy 6.Industrial Applications of Robotics 7.Advantages and Disadvantages of Robots	1.Define an Industrial Robot 2.Identify robot configurations 3.Describe the operating principles of an Industrial Robot 4. Recognize Robot degrees of freedom 5.Identify six factors which should be considered when selecting an Industrial Robot 6.Differentiate between robot links and joints
Components of an Industrial Robot	1.General components of an Industrial Robot 2.Types of Actuator Drive 3.Tool Orientation 4.Work-Envelop Geometries 5.Sensor Areas for Robots 6.Motion Control Methods	1.List the main components of an industrial robot 2.Identify four types of actuators 3.Name two types of robot arms 4.Name the two most popular types of drive systems used in Industrial Robots 5.Define point-to-point control 6.Describe three characteristics of a continuous path robot 7.Differentiate between servo and non-serve control systems
Manipulators and End-of-Tooling	1.Characteristics of End-of-Arm Tooling 2.Calculating Gripper Payload and Gripper Force 3.Manipulator Power Supplies 4.End Effectors and Grippers Design	1.Determine tool length using a tool center point (TCP) 2.Name the most common type of manipulator 3.List six end effectors used in Industrial Robotics 4.Name the three types of revolute joints
Robot Programming	1.Robot Programming Methods 2.Online and Offline Programming 3.Programming Languages 4.Types of Programming 5.Voice Recognition	1.Name the two major categories of robot programming 2.Differentiate between manual and automatic programming 3.Identify five different types of motion instructions 4.Describe the most popular type of robot programming language 5.Explain how program touch-up is used when programming
Robot Applications	1.Integrating Industrial Robots into the Manufacturing Process 2.Industrial Applications of Robotics 3.Justifying the Cost of Robots 4.Robot Safety and Maintenance	1.Describe the most Common Application for Industrial Robots 2.List eight Applications for Industrial Robots 3.Identify the three most common functions performed by inspection robots 4.Differentiate between robot handling and assembly 5.Define the term Palletizing

Offline Programming	1.Evolution of Robotic Simulation Technology and Off-line Programming 2.Robotics Workcell Design 3.Robot Calibration	1.Analyze Collision Situation 2.Create and Generate Automatic Path Generation 3.Evaluate and Visualize Manufacturing Process 4.Optimize Cycle time 5.Design appropriate Robotic Workcells for different manufacturing processes

Bloom's cognitive domain vs. OLP learning Objects

In 1956, Benjamin Bloom created taxonomy of cognitive development levels [10]: (1) B1-Knowledge, (2) B2 - Comprehension, (3) B3 - Application, (4) B4 - Analysis, (5) B5 - Synthesis, and (6) B6 - Evaluation. These six levels of cognitive development help us describe and classify observable learning outcomes, knowledge, skills, behaviors and abilities. By creating OLP learning objects using measurable verbs (see Table 3), we indicate explicitly what the students must do and complete in order to demonstrate student learning outcomes and thinking skills.

Table 3 - Bloom's Taxonomy of Cognitive Development vs. OLP Learning Objects

Levels of Learning	Bloom's Taxonomy Verbs	OLP Learning Objects	Thinking skills
B1: Knowledge - to recall or remember facts without necessarily understanding them	Define, list, name (label), count, order, assign, record, recognize ...	Object 1: **Define** an Industrial Robot Object 2: **Recognize** Robot degrees of freedom Object 3: **List** the main components of an industrial robot Object 4: **Name** two types of robot arms Object 5: **Name** the two major categories of robot programming Object 6: **Define** point-to-point control	Lower Order Thinking Skills
B2: Comprehension - to understand and interpret learned information	Identify, indicate, classify, discuss, locate, explain, review ...	Object 1: **Identify** robot configurations Object 2: **Identify** six factors which should be considered when selecting an Industrial Robot Object 3: **Identify** four types of actuators Object 4: **Identify** five different types of motion instructions Object 5: **Identify** the three most common functions performed by inspection robots Object 6: **Explain** how program touch-up is used when programming	
B3: Application - to put ideas and concepts to work in solving problems	Determine, apply, construct, operate, select, practice, sketch, use, solve ...	Object 1: **Determine** tool length using a tool center point (TCP) Object 2: **Describe** three characteristics of a continuous path robot	
B4: Analysis - to break information into its components to see interrelationships and ideas	Analyze, calculate, categorize, test, examine, inspect, question, differentiate contrast ...	Object 1: **Analyze** Collision situation Object 2: **Differentiate** between servo and non-serve control systems Object 3: **Differentiate** between manual and automatic programming Object 4: **Differentiate** between robot handling and assembly	Higher Order Thinking Skills
B5: Synthesis - to use creativity to compose and design something original	Create, design, develop, collect, formulate, propose, setup, compose ...	Object 1: **Create** and Generate Automatic Path Generation Object 2: **Design** appropriate Robotic Workcells for different manufacturing processes	
B6: Evaluation - to judge the value of information based on established criteria	Evaluate, appraise, assess, judge, justify, value, select, ...	Object 1: **Evaluate** and Visualize Manufacturing Process Object 2: **Optimize** Cycle time	

The above table of OLP learning objects contained six different levels of cognitive domains. In OLP learning process, critical thinking involves logical thinking and reasoning including skills such as creating, analyzing, designing, and comparison. Creative thinking involves creating and generating something new. It also involves the skills of brainstorming, modification, attribute listing, and originality. The purpose of creative thinking is to stimulate curiosity among students and promote operation and process simplification. Bloom's Taxonomy provides a useful structure in which to categorize OLP learning objects when assessing student learning outcomes. Asking students to think at higher levels is an excellent way to stimulate student's thought processes. In OLP learning process, the purpose of writing Bloom's questions is to apply Bloom's theory of developing higher levels of thought processes to OLP classroom. Asking high level questions of your shared inquiry groups is one way of making personal connections to literature, creating a bridge to your imagination, and developing your self-understanding.

4. Results - Student Projects

In the past two years, a number of student projects have been selected to help MET students understand the importance of OLP when the intention is to improve robotics course learning. In general, student design teams are given a small assembly product (25 ± 5 parts) that has not been designed using the principles and then asked to develop a robotic workcell solution that simplify the manufacturing process and also meet the product specification. Obviously, the robotic workcell design projects add the ability for students to not only complete a design cycle, but also to examine product improvement opportunities. Along with giving MET students the opportunity for a complete design experience, these student projects also give them the opportunity to practice their communication skills and to enhance their design learning experience. Below are some of student projects that demonstrate what they have learned from this project (see Figure 2, 3, 4, and 5).

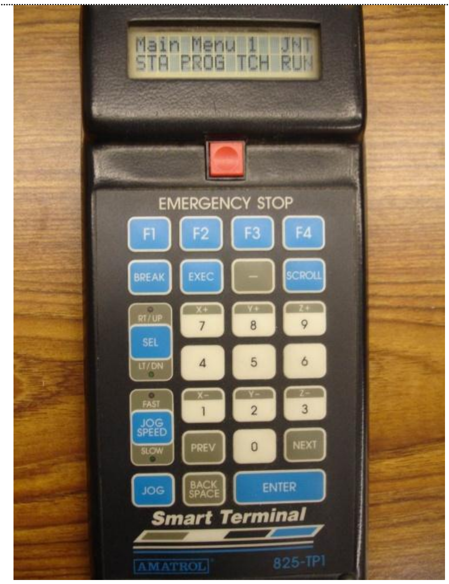
Traditional robot programming methods

Traditionally, most of MET students at Mnsu created their robot programs by using a hand-held


MET Students use Seiko teach pendant to program RT3000 robot

Teach Mover II teach pendant

Robot positions can be taught via Denso teach pendant



Amatrol teach pendant for programming Jupiter Robot

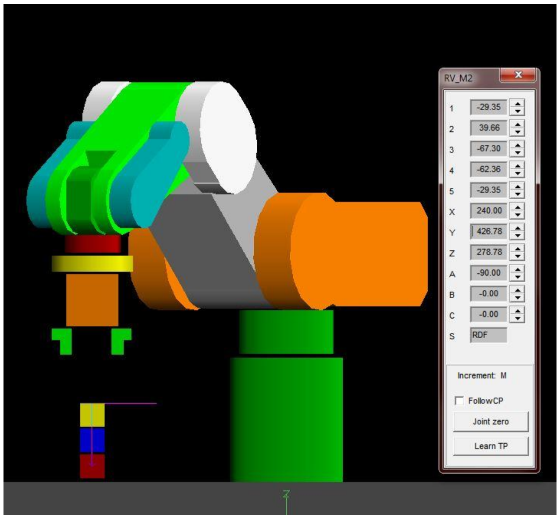
Figure 2 – Traditional robot programming methods

teach pendant attached to the robot controller. The teach pendants are microprocessor-controlled devices that facilitate a wide variety of robot operation and programming functions (see figure 2). Because there is no effective way to learn a teach pendant, the logistics for learning robot operating and programming procedures to students has long been problematic. Minnesota State University has very few industrial robots available for students, making it very difficult to provide students with robot programming learning experiences.

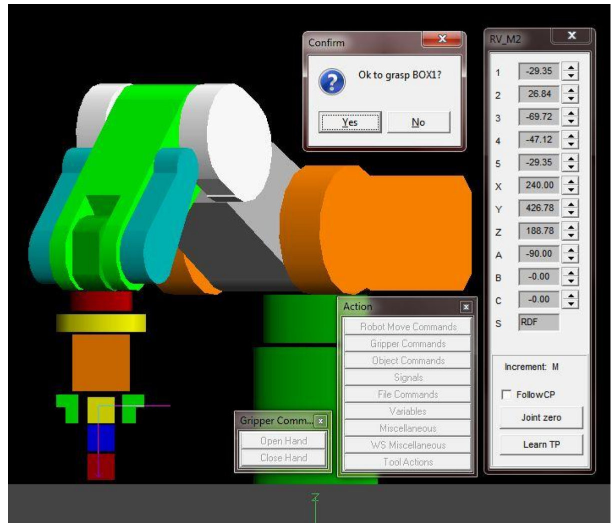
Off-line programming projects

The average students spent 8-10 hours on the design of their robotic workcells, and applied what they have learned from OLP lectures in the classroom. The OLP implementation in the product development and design course provided many benefits. The students were able to incorporate design experience and manufacturing experience early in the design cycle. Teamwork was promoted and communication increased between product design, and manufacturing. A better understanding of the design's impact on manufacturing cost was gained. In addition, students now have a much better sense of product development and design process.

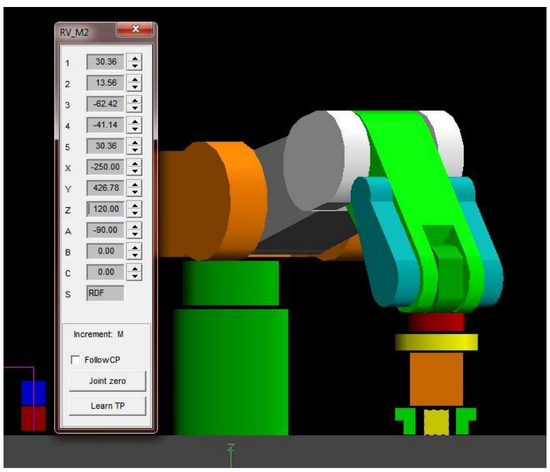
After students created their solution for their products (see Figure 2, 3, and 4) in MET 277 course, each team developed a redesigned case and modeled it in Pro/ENGINEER. These new designs were then built on the robotic assembly workcell and students were able to test how well their new designs worked. Most teams needed at least two different redesign solutions to demonstrate how much they have learned from this project. Figure 8 shows an example of one of the students redesign workcell. This particular redesign increased original design efficiency by 60%.



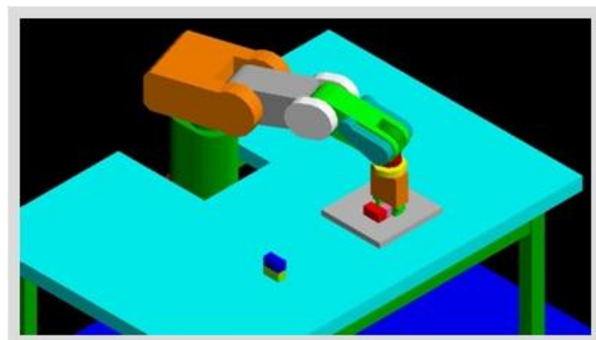
Lab 3-Pick-and-Place Lab (Using teach pendent to move RV-M2)



Using Action Command to Close RV-M2 Gripper

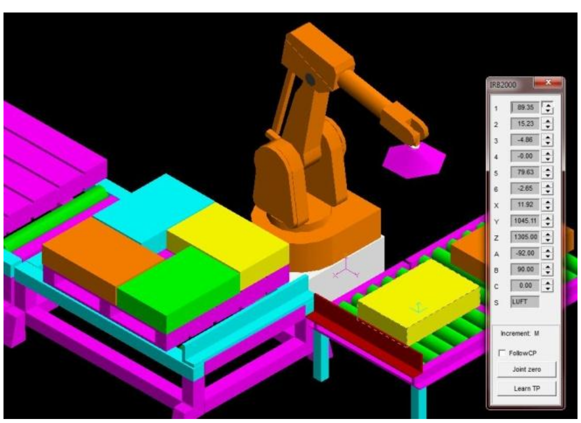


Place down the top block on the other side of table

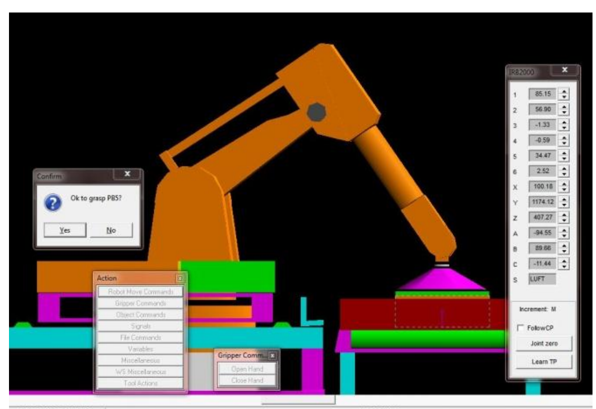


Using Simulation Option to record a video for Lab 3 demonstration (Ex. Creating an .AVI video file)

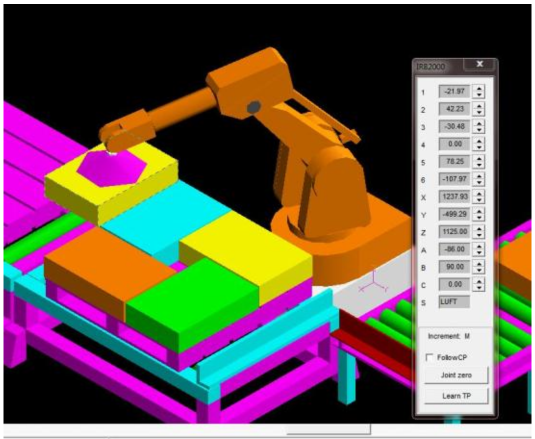
Figure 3 – Student Lab 3 - Sequence of views in WORKSPACE 4.0 offline programming software



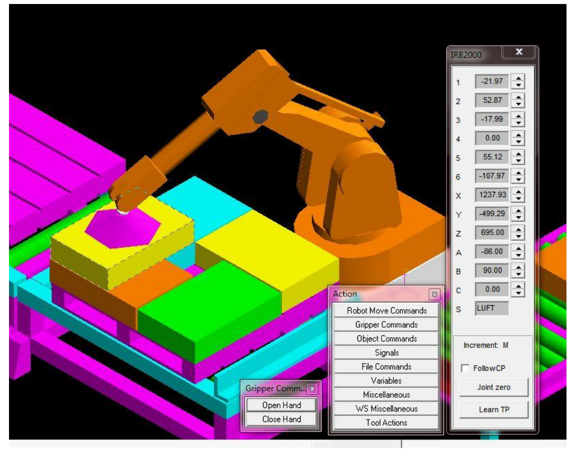
Robotic Workcell Design – Box Palletizing



System Equipment Layout (Ex. Conveyor, Pallets, and IRB 200 Robot …)

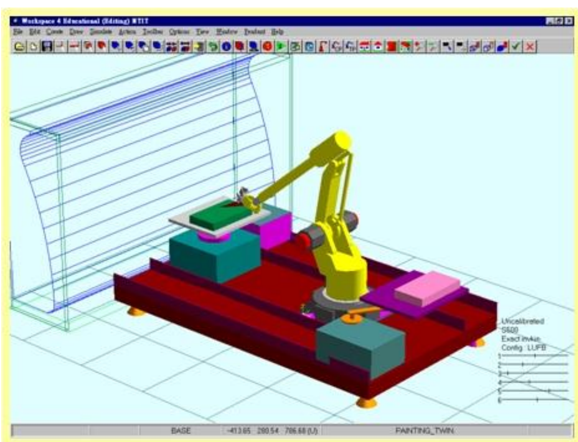


Creating Robot Motion path and Pallet pattern

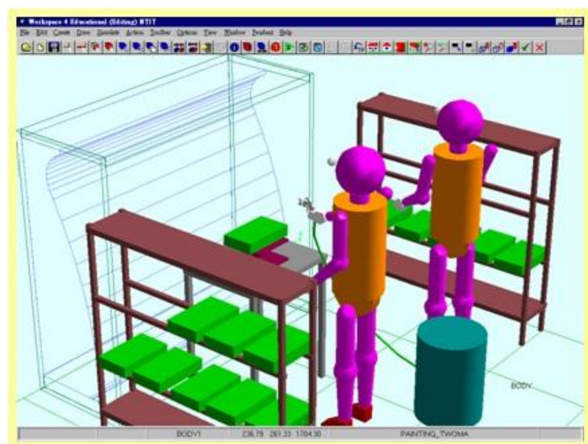


Using "Simulation Option" function to Record Palletizing Process

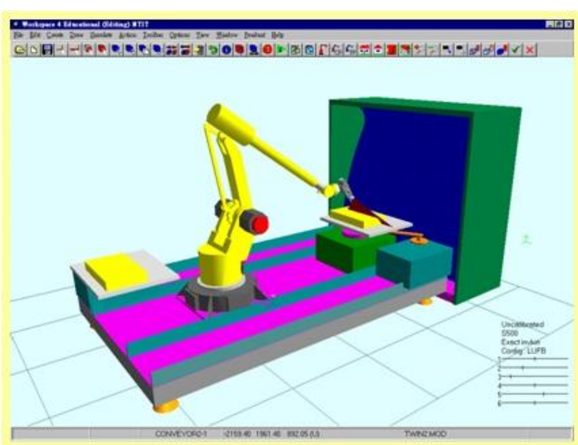
Figure 4 – Sample student projects (Robotic workcell Design for Box Palletizing)



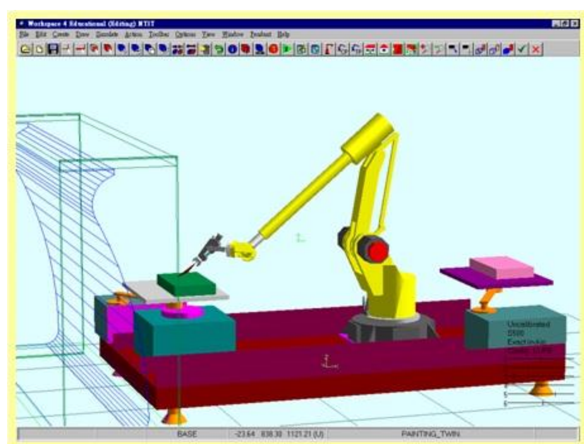
Robotic Workcell Design – Painting operation



Manual Spray Painting Layout- Simulation View



System Equipment Layout (Ex. Waterfall screen, two slide tracks, and GMC Robot …)



Using "Simulation Option" function to Record Spray Painting Process

Figure 5 – Sample student projects (Robotic workcell Design for bamboo box painting)

Using OLP simulation software to teach students in MET 347 course is a significant improvement to the class. Without the addition of OLP course project to the curriculum, students would not have been able to understand how to apply OLP concepts to robot programming phase and they would not have had access to real-world design experience. The OLP course project has the potential to positively affect student learning outcomes in the area of robotic workcell design. It allows students to simplify product structure and close the loop on design process that have traditionally been taught through lecture and homework. The additional learning and resulting student confidence is both noteworthy and exciting, and can be also easily accomplished through the choice of an appropriate OLP project.

Course Outcome Evaluation

Course outcome evaluation is a key factor for recognizing the benefits, identifying the deficiencies, and improving course contents. Through the evaluation, we should be able to assess students' attitudes towards using offline programming software in class, whether it is a source of motivation, or it does not improve their learning process. Typical evaluation process includes assessing students' labs, projects, and exams. In addition, we can also get feedback from students through the use of SurveyMonkey™ questionnaires. These outcomes can be compared with the outcomes in the previous classes to see the differences. There are a number of approaches to assessing student learning outcomes. Each assessment method has different advantages and disadvantages and yields only partial insight into student learning and teaching effectiveness. However, a combination of direct and indirect outcome measures can provide valuable information that can be used to address students' problems and enhance instructional organization and delivery. In order to measure OLP learning outcomes, we used the following methods to assess the outcomes and collect necessary data:

(1) Course-based tests and examinations - What knowledge and abilities have students acquired from our lectures and project activities (see Figure 5),
(2) In-class observation - Many student skills are demonstrated by performing product disassembly and assembly in the classroom (see Figure 5 and Table 3),
(3) Student survey - according to our university policy, we have to collect and conduct student surveys (at least two courses/per semester) at the end of each semester,
(4) Project presentation - Students present their results and findings to the class (peer evaluations 50% + instructor grading 50%),
(5) Project report - Normally prepared outside of class, students report include written assignment, designs, analysis worksheets, portfolios, or redesign drawings.

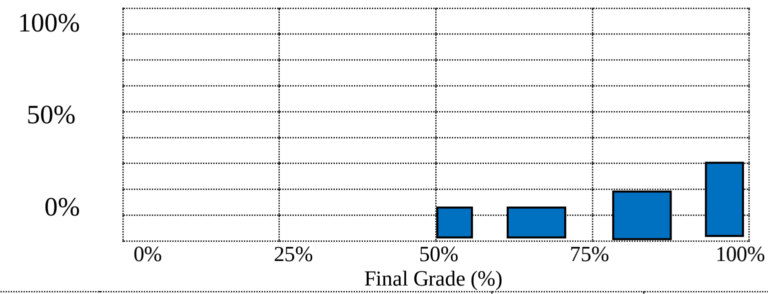
When employed carefully and thoughtfully, the OLP learning outcomes may highly contribute to judgments of teaching. Apparently, we will continuously use the above student outcome information to support and improve instructor teaching styles and/or student learning, not contribute to instructors' fear, stress and alienation.

Figure 5 - Exam I Robotic Offline Programming (part I) MET 347 Manufacturing Processes - spring 2011

Class Statistics: 10 multiple choice questions

Class average: 82.22%

Score distribution:



Question Statistics

Questions	Statistics	Avg. Grade/ attempts	Levels of DFA Learning
Question1: Define Robot		100% (18 attempts)	B1, B2
Question2: Robot configuration		100% (18 attempts)	B2, B3, B4
Question3: Recognize Robot degrees of freedom		83.33% (18 attempts)	B4, B2
Question4: Identify four types of actuators		88.89% (18 attempts)	B6, B1, B6
Question 5: What is Offline programming?		100% (18 attempts)	B2, B4
Question 6: Identify five different types of motion instruction		88.89% (18 attempts)	B2, B4
Question 7: Name the two major categories of robot programming		50% (18 attempts)	B3
Question 8: List the most common application for Industrial Robots		83.33% (18 attempts)	B4, B5
Question 9: Define the term Palletizing		61.11% (18 attempts)	B4, B5
Question 10: Determine tool length using a tool-center-point		66.67% (18 attempts)	B4

After the OLP curriculum was developed through the cooperative effects of two MET courses, a number of student assessment and feedback was collected in Manufacturing Automation classes at the end of semester 2009 and 2010. The population size was 30 students (22 undergraduate students and 8 graduate students) and the total number of responses was 28. Some of the results from these student assessments present as follows:

1. Most (90%) of the students had strong confidence in their ability to apply OLP knowledge and correctly solve a similar problem in the future.
2. Almost (85%) of the students were able to examine and analyze existing designs, identify assembly difficulties, and create alternative designs
3. 22 students ranked robotic workcell design project experience in the top two activities they liked overall
4. 23 students agreed that are more likely to remember the content delivered in these courses because of this new curriculum
5. When compared to a traditionally-taught course, 24 students preferred this approach over the traditional one.

The result of the evaluation also indicated improvement in robot programming skills and techniques among students. These findings suggest that students learn robot programming better from coursework that incorporates content knowledge and practical, real case examples

Conclusion

This study investigated a new model of teaching MET students robot programming knowledge and skills that they need for a successful future. We also examined our curricula to ensure our students are familiar with the trends in manufacturing technology. This robotic workcell design project challenged our MET students to practice robot programming skills. It also helped our students to better understand OLP principles and guidelines. In addition, it allows our students to strengthen their design and manufacturing technology skills, exercise their creativity, and practice their research capabilities. The student project is a motivational, fun, and enlightening project that provides students a hands-on opportunity while combining and practicing manufacturing, design, and project management skills. Finally, they demonstrated their fundamental knowledge and insight by redesigning their robotic workcells and then estimating cycle time and operational costs. They understood how this might be helpful to them in their design and manufacturing learning.

References

[1] K. Foit, J. wider, The project of a platform-independent, off-line programming system for industrial robots. The 7th International Scientific Conference on “Computer Integrated Manufacturing - Intelligent Manufacturing Systems CIM'2005” (COMMENT 2005), 62-65.

[2] K.C. Chan, G.C.I. Lin, T.C. Wang, CAD based off-line robot programming, Proc. Int. Conf. Computer Integrated Manufacturing, ICCIM, Singapore 1991, pp. 381–384.

[3] M. Kortus, T. Ward, M.H. Wu, An alternative approach to off-line programing, Ind. Robot, MCB University Press, 20 (4) 17–20, 1993.

[4] K. Foit, J. wider, D. Mastrowski, The project of an off-line, remote programming system for Mitsubishi Movemaster industrial robot, XIII International Scientific and Technical

Conference “Machine-Building and Techno sphere of the XXI”, 11-16 September 2006, Sevastopol, Ukraine. Paper Collection Vol. 4, 252-255.

[5] A. Kusiak, Programming, off-line languages, in: R.C. Dorf, S.Y. Nof (Eds.), International Encyclopedia of Robotics: Applications and Automation, vol. 2, Wiley, New York, 1988, pp.1235–1250.

[6] D.M..A. Lee, W.H. Elmaraghy, ROBOSIM, a CAD-based offline programming and analysis system for robotic manipulators, Comput.-Aided Eng. J. (1990) 141–148.

[7] B. Millen, Programming of welding robots, Weld. Met. Fabr. (1993) 174, 176, 178.

[8] J. Norrish, D. Gray, Computer simulationa nd off-line programming in integrated welding systems, Weld. Met. Fabr. (1992) 119–120, 122.

[9] R.K. Stobart, Collision detection for off-line programming of robots, in: A. Storr, J.F. McWaters (Eds.), Off-line Programming of Industrial Robots, Proc. IFIP WG 5.3:IFAC Working Conf. Off-line Programming of Industrial Robots, FRG, Stuttgart, Germany, 1986, pp. 107–117.

[10] Bloom, B., Englehart, M. Furst, E., Hill, W., & Krathwohl, D. (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain*. New York, Toronto: Longmans, Green.

[11] A. Storr, H. Schumacher, Programming methods for industrial robots, in: A. Storr, J.F. McWaters (Eds.), Off-line Programming of Industrial Robots, Proc. IFIP WG 5.3:IFAC Working Conf. Off-line Programming of Industrial Robots, FRG, Stuttgart, Germany, 1986, pp. 1–4.

[12] S.F. Chan, R. Kwan, Post-processing methodologies for offline robot programming within computer integrated manufacture, Journal of Materials Processing Technology, 139 (2003), 8-14.

[13] G. Yasuda, Distributed autonomous control of modular robot systems using parallel programming, Journal of Materials Processing Technology, 141 (2003), 357-364.

[14] G. G. Kost, R. Zdanowicz, Modeling of manufacturing systems and robot motions, Journal of Materials Processing Technology, 164-165 (2005), 1369-1378.

[15] Jrobot. A Java interface for Mitsubishi RV-M1 Robot.http://jrobot.sourceforge.net.

[16] Mitsubishi Movemaster RV-M1 User's Manual.

[17] Hakan Gurocak "e-Lab: Technology-assisted Delivery of a Laboratory Course at a Distance"

[18] Hugh Jack "A Virtual Manufacturing Laboratory"

[19] Kevin Devine "Integrating Robot Simulation and Off-line Programming into an Industrial Robotics Course" ASEE Annual conference

[20] Yang Cao "Learning Robotics through Developing a Virtual Robot Simulator in MATLAB"