Designing an Industrial Automation Lab for K-12 Outreach

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Abstract

As a result of a generous donation from the Caterpillar Foundation, the Department of Technology at Illinois State University recently completed the installation of a state-of-the-art industrial automation lab called the Caterpillar Integrated Manufacturing Laboratory (CAT-IML). Although the design of the lab focused primarily on undergraduate education, deliberate steps were taken to ensure the lab could also be used to deliver K-12 outreach activities. The purpose of this paper is three fold. First the paper will describe the development of the CAT-IML, including specific K-12 outreach considerations. Second, the CAT-IML itself will be described with emphasis placed on the safety features that were added in part to accommodate K-12 students. Finally, the K-12 outreach activities conducted in the lab to date will be described including assessment.

Key Words

K-12 Outreach

Designing an Industrial Automation Lab for K-12 Outreach

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Introduction

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Design of the Caterpillar Integrated Manufacturing Laboratory

The CAT-IML is the result of a generous 1.2 million dollar donation from the Caterpillar Foundation specifically targeted to support the manufacturing program at Illinois State University. The commitment to make the donation was announced by Caterpillar in March, 2002, with funds made available in 2005 and 2006 (two installments). The Caterpillar Foundation's only oversight of how their donation was to be used was the approval of a one paragraph conceptual "vision" of a state-of-the-art automation lab. The overall goals for the lab were to: a) Provide students hands-on experiences to develop basic technical skills in automaton; b) Provide students hands-on experiences to help them better understand management principles; c) Provide current and future technology educators with experiences that help them better understand manufacturing; and d) Attract new students into the program.

To help learn the automation landscape, faculty members visited several Midwestern universities to see automation lab facilities and speak with colleagues regarding the strengths and weakness of their labs. Faculty members also attended many trade shows and met with many vendors to become better educated in the world of automation. Finally, many manufacturing companies in Illinois invited the faculty to tour their facilities and shared their opinions regarding the future of automation and their future employment needs. These efforts took a great amount of time to complete, but in the end proved to be extremely valuable.

Armed with both prior experience working with automation and fresh insights obtained from the interaction described above, faculty members developed a conceptual framework for the automation lab. The initial design efforts focused on several key factors including the need for flexibility to allow for lab reconfiguration and incorporation of future technology, the use of duplicate workstations for maximum student hands-on time, and the ability to use the lab in a wide range of educational settings (K-12 through graduate level). Conceptual drawings of the lab workstations were created and a potential room layout was developed. The conceptual plan did not specify equipment vendor or model information, but called for twelve identical workstations, each including an industrial quality robot, programmable logic controller (PLC), small conveyor, machine vision, radio frequency identification (RFID), various pneumatic devices and a variety of sensors. It was determined that the workstations would need to be custom designed for the lab, and it was decided that the faculty would design and build the lab rather than hire an outside systems integrator. The twelve workstations (later reduced to ten) would allow students to work in-pairs to complete identical activities at each workstation, an ideal situation for K-12 outreach activities and introductory level college courses. In order to facilitate more complex integration activities in advanced courses, two palletized conveyors were incorporated into the lab design, allowing work to be passed from one workstation to another.

The conceptual plans were presented to a standing manufacturing program industrial advisory board for review. The advisory board reacted favorably to the design concept and encouraged the faculty to continue adding details to the design. As details were added to the design, the advisory board was consulted many times, always yielding valuable insights and suggestions for consideration. At one point an ad-hoc advisory board comprised of automation technical experts from a variety of manufacturing industries helped identify specific hardware and software technologies that should be included into the lab. This ad-hoc group also identified what they considered to be key educational objectives for each technology component in the lab. The faculty made every attempt to keep the design process open to all, and consulted industry experts at every opportunity during the design process. Technology Education professionals and many K-12 teachers were also consulted during the design of the lab. Most of the people consulted seemed excited about the development of the lab and readily volunteered to look over designs and provide advice whenever needed. All told, the design process benefited greatly from the guidance of both academic and industry experts.

As work on the technical design proceeded, an architectural firm was hired to convert two existing lab spaces into the new CAT-IML. From its initial conception it was recognized that the lab must have visual appeal in order to help accomplish the goal of attracting new students into the program. As part of the architectural design team, an interior designer worked with the faculty to develop a variety of color schemes and renderings of the space. It was stressed at every meeting that the lab needed to look high-tech and must appeal to K-12 students and parents.

The construction phase of the project took place during the summer of 2005. Funds were also available to build one of the ten workstations. This "prototype" workstation allowed faculty and students to work with the hardware and software to confirm that the configuration would accomplish the educational objectives. Students were also able to provide feedback regarding the ergonomic design of the workstation. In the end, only minor modifications were made to the size of the prototype workstation before the remaining nine workstations were built and installed during the summer of 2006. Figures 1 and 2 show a workstation and highlight the principle hardware components. Figure 3 shows the fully-equipped CAT-IML.

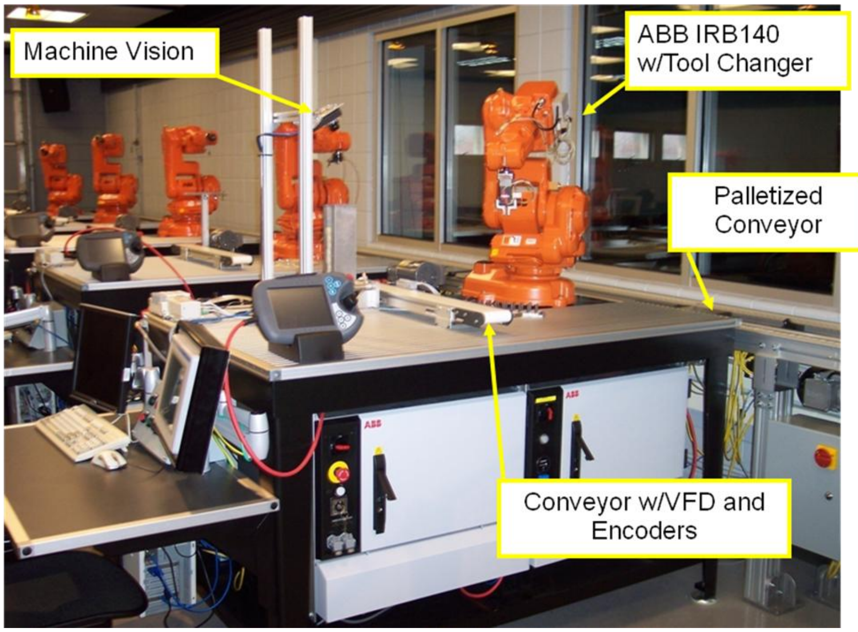

Figure 1 – Front of Workstation

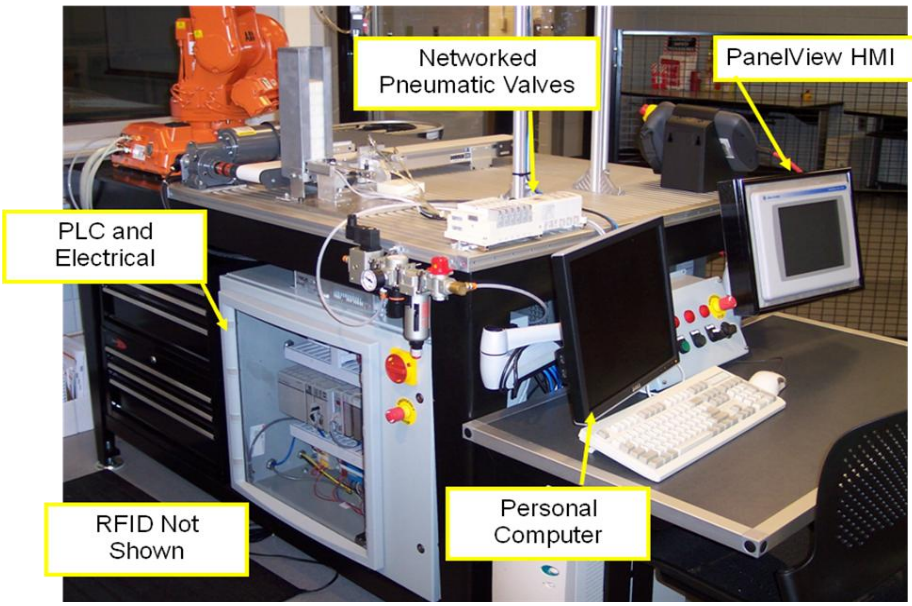

Figure 2 – Back of Workstation

Figure 3 – CAT-IML

CAT-IML Safety

In a virtually unanimous voice, the many industry professionals who gave input to the design of the CAT-IML stressed the importance of safety. Of primary concern was the risk associated with the use of industry-quality robots, which are clearly the most dangerous equipment items in the lab. While safeguarding any college lab is recognized as being important, Universities are not obligated to meet many of the safety standards for which industrial manufacturers are held accountable. While designing the CAT-IML, the decision was made to follow industrial safety guidelines to every extent possible for several reasons. First, regardless of the legal requirements, the faculty at ISU wanted to take every possible action to provide students and faculty/staff with a safe learning and working environment. Second, by utilizing many of the safety measures commonly seen in the workplace, university students can experience and learn about various safety protocols first hand before entering the workplace. Finally, a robust safety system would be critically important when working with K-12 students during outreach activities. Of grave concern was how to keep young students safe while affording them the opportunity to participate in hands-on learning activities in the CAT-IML.

As was the case throughout the design process, the faculty relied heavily on industry experts to help design a safety system for the CAT-IML. In this case, a robot safety consultant well versed in ANSI/RIA R15.06-1999 "American National Standard for Industrial Robots and Robot Systems – Safety Requirements" was hired to help design a safety system for the lab. The ANSI/RIA R15.06 standard, a voluntary set of guidelines created to improve the safety of personnel using industrial robot systems, describes two robot safeguarding methodologies [2, 3]. Safeguards can either be installed in a prescriptive manner following the specifications contained in the R15.06 standard, or a comprehensive risk assessment (also outlined in the standard) can be conducted, after which appropriate safeguarding is installed[1]. Unfortunately, most of the prescriptive safeguarding methods contained in the standard were impractical to implement in the CAT-IML due to space constraints and the fact that many educational activities would be impossible to conduct if students were prevented from interacting with the equipment. The comprehensive risk assessment method was therefore used to develop a safety plan for the lab.

The risk assessment involved four distinct steps[1]. First, potential hazards were identified. This step involved identifying all potential "user groups" (lab technicians and instructors, college students, K-12 students, attendees at demonstrations, custodial staff and building workers, etc.), the tasks each user group would perform in and around the lab, and the hazards associated with each task. Second, each hazard identified was placed into a "risk reduction category" by assessing the severity (potential level of injury), probability of user exposure to the hazard (likely or not likely), and avoidance potential (easy or difficult to avoid the hazard). Once categorized, at least one appropriate risk reduction method was selected for each hazard. Those risks categorized as being severe were reduced using control reliable safeguarding devices such as interlocked barrier guards and safety mats, while risks categorized as non-severe were reduced through various awareness means, formal procedures and training.

The resulting CAT-IML safety system has several "layers" of risk reduction, many of which are controlled by a safety PLC and safety control panel. The safety control panel has a keyed-switch which allows authorized personnel to activate one of four safety modes for the lab. Safety mode 1 allows all controllers to be turned on but will not allow any equipment to move (robots, conveyors, pneumatic devices, etc.). The lab is always placed in this safety mode when an instructor is not present. Safety mode 2 disables all robot motion but allows conveyors and pneumatic devices to operate. This mode is used when teaching classes that do not require robot movement. Safety mode 3 allows all devices in the lab to function. When this safety mode is selected, the safety PLC enforces specific workstation safety rules based on the robot's current mode of operation (teach or automatic) which is selected via a keyed-switch on each robot controller. Each of the ten workstation's safety rules work independently of each other utilizing interlocked awareness barriers and safety mats located at each workstation. Safety mode 4 enforces all the safety rules of mode 3, and also monitors an additional interlocked safety barrier gate that prevents entry into the equipment-area of the lab. Safety mode 4 is designed to be used during open houses when large numbers of visitors are present with minimal lab supervision, or when very young and/or unpredictable children are watching the robots work in automatic mode.

K-12 Outreach in the CAT-IML

During the first year of operation, a variety of K-12 outreach activities were conducted in the CAT-IML. The sessions conducted have been treated as "pilot" sessions with a variety of activities being used in order to gain experience working with K-12 students in the lab. Groups of students ranging from pre-K through 12th grade have participated in the activities to date. The purpose of this section is to describe the outreach activities that have been conducted to-date and to briefly assess the results of the activities.

For large groups (more than 20 students) and groups comprised of young children, hands-on activities with the robots have not been feasible to conduct. Therefore, some of the outreach activities conducted to-date has included primarily system demonstrations and short movies, with minimal visitor hands-on time. System demonstrations, for example, were held during and after the grand opening of the CAT-IML in April-May 2007. During these sessions, five of the robot workstations worked in concert to automatically assemble a personalized box of chocolate candy. Visitors to the lab used a computer touch-screen to design their unique box of candy by selecting from the six available types of candy and by typing their name (see figure 4). Visitors then watched as the automated assembly line created their product and placed a personalized label containing their name on the finished box. The grand opening demonstration was open to the public and was well attended by all age groups (children through senior citizen). During a four week period after the grand opening, approximately 120 children aged pre-K through 5th grade attended demonstrations of the candy assembly line.

Figure 4. A Pre-K Student Using a Touch Screen to Select Candy

Outreach activities for older students (ages 12-18) were designed to maximize hands-on time with the robots. To help establish the context in which robots are used, these sessions generally started with a brief movie showing industrial robots being used in a variety of traditional (welding, assembly, etc.) and non-traditional (mail sorting, cow milking, etc.) applications. The movies were followed by a discussion about robot safety and a sequence of hands-on activities that allowed students to jog and program the robots. Of critical importance during these activities is the ability to use a “virtual” robot controller running on a personal computer to project the robot teach-pendant screens for all to see. Using the virtual controller, the instructor is able to lead the students through complicated procedures they would otherwise have great difficulty completing.

Hands-on activities start out by allowing the students to jog the robot in various modes (see figure 5). During this phase of the session, the students are shown what buttons to push and then they are asked to observe what effect the action has on the robot’s movement. By observing the robot movements in different jogging modes, concepts such as interpolation, tool center point (TCP) and axes are introduced through discovery. Linear jogging also offers the opportunity to relate robot operation to the Cartesian coordinate system previously used by the students in various mathematics courses.

Figure 5 – A Middle School Student Jogging a Robot

Once jogging has been practiced by all participants, the students are walked through the steps to create and run a simple three to four line program using the teach mode. Students are then shown how to create a program to simulate welding around the perimeter of a cardboard box (cardboard is used because it is easy for novice programmers to bump the robot tool into the work-piece). Once written, the students are asked to observe various things while the program is running. For example, with various amounts of prompting, the students observe that the default "move-joint" interpolation mode does not move the welding tool in the straight line needed to weld along the perimeter of the box. The students are then shown how to use "move-linear" to solve this problem. The students also notice that the robot does not make the square corners they want (by default the robots use a "fly-by" point mode). The students are shown how to change the fly-by point to a stop-point. In each instance, the students are prompted to observe what the robot is doing and make judgments about whether the robot is completing the programmed task as they intended. If it is not working properly, they are shown how to fix the problem.

A strength of this activity is that it is very scalable. With a group of 20 students and one teaching assistant, the hands-on activity described above generally takes approximately 2 hours to complete. It has, for example, been reduced to 1 hour by covering just the jogging and simple program creation. The activity was also extended to 4 hours for one group by adding an introduction to digital I/O, program counters, and subroutines.

Outreach Assessment

System demonstrations with minimal hands-on activities proved to be very appropriate for young children (under approximately 12 years of age) and large groups. The children seemed to enjoy using the touch screen to choose their candy and it was obvious that the pre-K and kindergarten children really received a great sense of accomplishment when they typed their name. All the visitors liked leaving with a customized box of candy with their name on it, and many children were excited about the opportunity to tell their family about how the box was assembled. The elementary school teachers were thrilled with the experience and seemed excited about the prospect of coming back next year with another class.

The hands-on demonstrations designed for the 12-18 year old students were also well received. When contacted several months after visiting the CAT-IML, some of the instructors stated they thought the hands-on session in the robot lab increased their students' technological confidence. The instructors commented the activity helped their students believe "hey… I can do this". One instructor commented that the videos would be more effective after the hands-on session rather than before because the students could see the robots working in the movie and think "I know how to do that". Virtually all of the instructor comments about the activity were focused on building student confidence and opening students' eyes to new career and education possibilities. One group of 12-18 year old students spent two hours at the CAT-IML as part of a 4-H one-day "technology tour", after which the students were asked to complete a program assessment. The comments made by the students were extremely favorable and clearly indicate they had fun during the activity and that they are very interested in learning more about robotics and technology. Appendix A presents the results of the technology tour assessment that pertain to the robot session.

Conclusions

This paper described the development of a state-of-the-art automation lab that was purposefully designed to accommodate instruction in college courses as well as K-12 outreach activities. From its inception, one of the primary goals of the CAT-IML has been to attract new students into manufacturing disciplines. Throughout the design of the lab, considerable attention was focused on creating a lab that would generate interest and excitement in youngsters. Lab safety was deemed especially important because of the inherent risks associated with industrial robots, and the desire to give K-12 students meaningful, age-appropriate learning activities in the lab. During the first year of operation, approximately 200 students ranging from pre-K through high school have participated in a variety of learning activities in the lab. Feedback obtained from many of the students and their instructors clearly indicate that K-12 outreach activities such as those described in this paper can have a positive impact on student confidence while also helping to broaden students' understanding of education and career options.

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Dr. Kevin L. Devine, Ed.D, Assistant Professor in the Department of Technology at Illinois State University, was one of the lead designers of the CAT-IML described in this article. Dr. Devine currently teaches courses in robotics, machining and CNC programming, and solid modeling. Dr. Devine may be reached via email at kldevin@ilstu.edu.

Appendix A

4-H "technology tour" student assessment comments regarding the robot hands-on activity.

I'd like to learn more about:	Robotics (4) Non industrial robots Robotics and cows (note: the students were shown a video of a robot milking cows) Milking cows and robots Robotics and wind? (the students visited a wind farm earlier that same day) ISU tech & science edu. Robotics Lab
Because of attending the Technology Tour I will:	Look into a future in the area of Robotics Might be a Robotics Designing Consider robotics in the future Present technology Think about working in the robotics lab and attend next year if you do it Want to come back on another tour Try to bring my group with me Share this info with others Hopefully be coming back to see everything soon
Summing it up in 1 or 2 words, I'd say the Technology Tour was:	Great (3) Totally Sweet Exhilarating Very good Best thing all summer Fun, informative Entertaining, fun Interesting Awesome Cool