

# A Four-year Automation and Integration Concentration for Manufacturing Engineering

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**Abstract**—This paper outlines plans to develop an Automation and Integration concentration for a Manufacturing Engineering program in response to a growing interest in manufacturing automation in the Pacific Northwest (PNW) region and among our regional industrial partners. The concentration will build off of an introduction to engineering and design course sequence, which will introduce students to microcontrollers, and continue with five concentration-specific courses in areas including automatic controls, industrial robotics, automated inspection and data analysis, and automated system integration. While the bulk of the courses will occur during the junior and senior years, the intent of the program is to achieve more depth than most programs by including courses in all four years of the curriculum.

**Keywords**—*Manufacturing, Automation, Integration*

## I. INTRODUCTION

This Innovative Practice Work in Progress paper outlines a proposed four-year concentration in Automation and Integration (A&I) for Manufacturing Engineering (MFGE) students that we are trying to implement for an ABET EAC accredited MFGE program in the Engineering & Design (ENGD) Department at Western Washington University (WWU). Traditionally, automation is not introduced until students are at the end of their junior year or are seniors, so by the time it is introduced, there is little time to get into advanced topics like automated inspection, automated quality control, and automation system integration. We are finding that many of our local industrial partners are increasing their reliance on automated production, inspection, and data collection and analysis, so there is demand for students who have broader and deeper experiences with automation. While the bulk of this concentration will take place during the junior and senior years, our plan is to begin to introduce automation topics during the first and second years so that topics that do not require advanced math like pneumatic circuit design, PLCs, industrial robot programming, and pre-integrated robot-guiding vision systems can be introduced earlier.

To set the foundation, the members of the faculty are also working to introduce microcontroller programming as part of a revamped introduction to engineering and design sequence, which will serve as the entry point for the A&I concentration. The main goal of this new sequence is to improve diversity, equity, and inclusion in our programs by helping students to develop skills, knowledge, and/or experience that if lacking might undermine their ability to advance into an engineering

major. The first course in the two-course sequence is to address deficiencies in students' skills and/or experiences, such as a spatial visualization unit for students with poor spatial visualization skills, and the second is designed to provide a rich introduction to engineering design through open-ended projects, including a microcontroller project that will serve as the first step in the A&I concentration.

The first course that is fully in the A&I concentration will be an Introduction to Manufacturing Automation course at the end of sophomore year. This course will focus on the technology, design, and integration required for automated part extraction and inspection for an injection molding process. The next courses in the sequence will be modifications of two existing courses, Introduction to Automation & Control and Industrial Robotics. These courses will be able to go into more depth than they do now, because some of the introductory material will move to the new course before them. Finally, the sequence will end with an Automated Inspection and Data Analysis course and an Automated Systems Integration course, or possibly a capstone sequence that has the same focus. This paper will outline the motivation for the A&I concentration, briefly explain each of the course in the A&I concentration and its learning goals, and give an overview of the implementation plan.

## II. BACKGROUND

### A. MFGE Program Overview

The MFGE program is one of three ABET accredited engineering programs in the ENG D Department at WWU, with the other two being Electrical Engineering (EE) and Plastics and Composites Engineering (PCE). All three programs recently transitioned from ABET ETAC accredited engineering technology programs to ABET EAC accredited engineering programs, with ABET EAC accreditation granted in fall 2015. All three programs are undergraduate only, and two characteristics that all three programs brought with them through the transition from engineering technology are an application focus and strong ties to industry. As part of the transition, the MFGE program worked with the SME Four Pillars and its industrial partners, through its Industrial Advisory Committee (IAC) to make sure that the program was appropriate for the region [1,2]. Because WWU is located in the PNW region of the country, the dominant industry is aerospace. Traditionally the aerospace industry has not had much reliance upon automation, so while the two courses related to automation were amended from engineering

technology to engineering courses, the proportion of automation in the overall program was not increased during the transition.

Recently, however, more and more of our industrial partners, including those in the aerospace industry, have begun to introduce automation or to expand their use of it. The result is that the demand for manufacturing engineers with knowledge of and experience with manufacturing automation and the integration of automation systems has increased significantly in the last few years. Given that increased demand and interest, we believe that an A&I concentration in manufacturing is needed in the region, and that graduates of it will have more opportunities than those with traditional manufacturing engineering or mechanical engineering degrees. There is also a general lack of such programs throughout the country, so graduates of an A&I concentration will likely have many opportunities outside of the region as well.

### *B. Automation & Integration Concentration Impetus*

As was outlined by the author as part of the transition of the Industrial Robotics course from engineering technology to engineering, dedicated manufacturing robotics courses are rare [3]. Not surprisingly then, manufacturing automation sequences are even rarer. There are, however, some interesting courses and very well-appointed automation laboratories out there, though almost exclusively at the senior level, and Oregon Institute of Technology offers a dual major in Automation, Robotics, and Control Engineering, though the courses in those topics are all senior level courses as well [4-6].

The main impetus for the A&I concentration comes from our industrial partners rather than the literature. The MFGE Industrial Advisory Committee (IAC) meets twice each year. The concept of an automation concentration in the MFGE program was first brought to the IAC as a discussion item at the fall 2016 meeting. The concept was enthusiastically received by the IAC, and the IAC input led to the inclusion of the integration portion of what has become the A&I concentration that this paper is outlining. Each subsequent MFGE IAC meeting has included an update on the progress of the development of the A&I concentration, and the fall 2017 meeting included a review of the proposed content for the Introduction to Manufacturing Automation course. The MFGE IAC has continued to enthusiastically support the A&I concentration development, and has provided good input regarding content and learning outcomes for the specific classes. Additional industrial input has been provided by companies that have sponsored MFGE senior projects but are not represented on the MFGE IAC. Based on feedback from the MFGE IAC and other industrial partners, we believe that the main portions of the A&I concentration are well-aligned with broad industrial needs in the PNW.

While the content of the A&I concentration is designed to address regional industrial needs, the main reason to take the approach we are trying to implement rather than the traditional approach of doing all of the automation in senior year is that students learn more effectively when new knowledge builds off of existing knowledge so that concepts are reinforced over time [7]. This means that we should be able to achieve better learning and more depth by introducing automation applications to lower-division students and building upon that through the upper-division

courses. Moreover, many simple applications can be completed with technical tools that have good user interfaces and are easy to use, so the advances in technology have made this more feasible as well. Thus, our plan for an A&I concentration that begins with the introduction to engineering design sequence. The intent is also to use project-based learning (PBL) as the primary pedagogical approach in the A&I concentration courses. Some of the courses will use a handful of smaller projects while others will have a quarter-long project, but all of the courses will use PBL to tie concepts together.

## III. CONCENTRATION OVERVIEW

This section gives a brief overview of the current plan for implementing the A&I concentration. While the A&I concentration initiative began as the author's project, full implementation of it will be a team effort, so realization of some aspects of it will be different than what is outlined below, especially for the last two courses in the sequence. What is outlined below is the current thinking on each of the courses. It should also be noted that WWU is on the quarter system, so the five courses that are specific to the A&I concentration are the rough equivalent of three semester courses, although the quarter system does give us the opportunity to spread the courses over a longer portion of the MFGE degree program.

### *A. Introduction to Engineering and Design Sequence*

As was mentioned in the introduction, the revamping of the introduction to engineering design (ItED) sequence is a separate, parallel project, but it will provide the foundation for the A&I concentration by making sure that students coming into the MFGE program as majors have a microcontroller project experience. The intent of revamping the ItED sequence is to improve diversity, equity, and inclusion in our programs by helping students to develop skills, knowledge, and/or experience that if lacking might undermine their ability to advance into an engineering major, so some of the portions of it will be custom to students' needs, but other parts will be common for all students.

One of the parts that will be common for all students is an open-ended, microcontroller-based design project. As with many other departments, we have had good success with such a project in our EE program, and we believe that automation is becoming prevalent enough that students in the other majors should be introduced to it early as well [8]. Currently MFGE students do not complete a microcontroller project until they take the Introduction to Automation & Control course at the end of their junior year, and we have found that, at least so far, the majority of them have never seen or used a microcontroller before. By giving all students an open-ended design project experience as part of the introductory design sequence, we expect that students will be both better prepared to and more excited about learning how to use industrial automation components when they are introduced in the A&I concentration courses.

### *B. Introduction to Manufacturing Automation*

The first course that is truly part of the A&I concentration is the Introduction to Manufacturing Automation course. This

course is intended to introduce students to parts of industrial automation that do not require advanced mathematics or an understanding of control theory. The current plan is that this course will be offered the last quarter of sophomore year after students have been accepted into the MFGE major. This course is also envisioned as an elective course for students majoring in PCE, so the theme for the course is the automated unloading and inspection of parts from an injection molding process. This theme ties all of the course components together in a final project, it is directly relevant to PCE majors, and can be implemented in the laboratory. The six topic areas of the course are: 1) pneumatics for automation, 2) basic sensors (at least microswitches and optical sensors), 3) robotic programming (though not robotic modeling), 4) 3-2-1 locating principles for basic gripper and fixture design, 5) machine vision for inspection (pattern matching) and planar robotic guidance, and 6) programmable logic controllers (PLCs). The reason that injection molding has been selected as the unifying theme for the course is that automated injection molding unloading process that include part inspection make use of all of these tools. Moreover, several of our industrial partners have implemented these types of automation systems for their injection molding processes.

The intent of this class is to use the project of unloading and inspecting parts from an injection molding process as a quarter-long project to both put the automation steps in context and to motivate students to learn the various parts. The plan is to use the quarter-long project and a combination of in-class and laboratory exercises to motivate students and introduce to the six areas outlined above, with sensors coupled with pneumatic circuits and 3-2-1 locating principles coupled with robotics through finger and fixture design, and then to bring the areas all together with the final project. The depth will be modest, and students will not do much analysis of the various system parts, but they will learn how to use fundamental automation tools, and they will get a simple yet highly relevant integration experience. We are hoping to introduce this course, at least as an elective course, during the 2019-20 academic year.

### *C. Introduction to Automation & Control*

Introduction to Automation & Control is the first of the two courses in the A&I sequence that already exists. The course currently introduces students to control theory, PLCs, microcontrollers, and DC servomotor control. The course culminates in a motor control project that includes the use of an optical encoder. The pre-requisites for the class are an introduction to analog & digital electronics and differential equations. Students currently take the course at the end of their junior year.

In the planned A&I concentration, the Introduction to Automation and Control class would be largely unchanged. The one major shift is that PLCs will now be part of the Introduction to Manufacturing Automation course, which will become one of the pre-requisites for this course, so that will free up two weeks of class time for new topics. The current proposal is to introduce students to multi-motor control and transducers, with the major and unifying project being a 4-axis robotic arm that the students design and build. It is also likely that students will take the course earlier during their junior year, although the final details on that have not been settled. This course will remain the pre-requisite for the Industrial Robotics course.

### *D. Industrial Robotics*

Industrial Robotics is the second of the two courses in the A&I sequence that already exists. The course currently introduces students to robotic applications, including the design of fixtures and fingers to support robotic applications, robotic modeling, including robotic kinematics and inverse kinematics, and machine vision systems for both inspection and robot guidance. The course has been designed so that students get significant laboratory time and are able to gain experience with multiple robot configurations, however the introduction to machine vision is brief and there is limited time in the course for simulation of robotic systems.

Because a number of the fundamental topics needed for robotic applications will be introduced in the Introduction to Manufacturing Automation course, it is anticipated that the Industrial Robotics course will be amended to include more CAD-based modeling and simulation of robotic systems. The ENGD Department recently acquired 3DEXPERIENCE (3DX), including the DELMIA robotic modeling apps, so the plan is to use the time freed up by topics moving to the earlier course to do more with these simulation tools. Since students will also have experience with the fundamentals of automation, the projects and labs will be able to be more sophisticated and include more on system integration. The goal will be to continue to use quarter-long, industry-sponsored projects as the main course projects, and to have the students complete a design, simulate, and implement process for a robotic cell with one robot for the project.

### *E. Automated Inspection and Data Analysis*

Automated Inspection and Data Analysis course is currently the least well defined of the courses in the A&I concentration, but it is clear from the information we have received from our industrial partners that such a course is important for the sequence. Manufacturing companies in our region are trying to do more with machine vision to increase flexibility, reduce the need for fixed tooling, decrease changeover time (e.g. from one model or size to another), and reduce cycle time. In addition, these manufacturers are trying to do more with automated, vision-based inspection. Finally, the same companies are collecting more data than ever before from their processing machines (e.g. injection molding) and working to find efficient ways to use that data for process improvement.

Given the growing application of machine vision, inspection, and automated data collection and analysis by our industrial partners, these three areas will be the major parts of this course, but what is not clear is what the balance will be between the three areas. Students in the MFGE program take calculus-based Engineering Statistics, Quality Assurance, and Data Analysis and Design of Experiments courses, so they are well prepared for automated data collection and analysis to be a significant part of the course, and much will depend upon how many machine vision topics can be added to the Industrial Robotics course once the introductory topics have been moved to the Introduction to Manufacturing Automation course. Given the uncertainty involved with this course at this time, it is not clear whether it will have a quarter-long project like many of the other courses or rely on smaller, shorter projects to motivate and focus student learning. It is also likely to be the last course implemented for the A&I concentration.

## *F. Automated Systems Integration*

Automated Systems Integration course is intended to serve as a capstone experience for the A&I concentration, though it is unlikely that it will replace the current senior project sequence, because it will probably be done with larger teams and in one quarter rather than across the entire academic year. The goal of this course will be to allow a team of students to select – within certain bounds – and integrate automation tools to solve a specific manufacturing problem or task, with the expectation being that the project will drive the majority of the course content and that there will be limited structured lab exercises to allow the students to focus on the main project. To support this course, and likely some senior project work as well, we are investing in a flexible automation testbed system with multiple robots.

The goal of the flexible automation testbed is to have a set of equipment such as a couple of robots, a controller, conveyors, a vision system or systems, and smaller sensors and actuators that can be reconfigured to solve real, ideally industry-sponsored, automation problems. The MFGE program shifted its priorities to hire an automation specialist into an open faculty position to lead this effort and has dedicated a small, but highly visible space for the testbed. We anticipate that the 2018-19 academic year will be used for purchasing and installation of the component parts, along with any utility modifications that are necessary, and that the testbed will be used as part of the first iteration of this class during the 2019-20 academic year.

## IV. IMPLEMENTATION OF THE A&I CONCENTRATION

The previous section outlined the courses that will make up the A&I concentration as they are planned to be as of right now. The reality of implementation virtually guarantees that there will be some changes made even as the concentration is implemented, but hopefully they will be reasonably small variations. This section provides a very brief overview of what we have done so far to implement the A&I concentration, what remains to be done, the planned order of the remaining steps, and how we plan to assess the sequence once it is fully implemented.

### *A. Steps Taken*

Beyond the obvious step of developing an overall plan for the A&I concentration, four steps have been started to implement parts of it. First, the Introduction to Manufacturing Automation course has been thoroughly planned to the point that it could have been offered in the 2018-19 academic year. Due to circumstances beyond the scope of this paper, its offering will be delayed for a year, but it is essentially ready to go. Second, as mentioned earlier, the MFGE program refocused an open faculty position and was able to hire a manufacturing automation specialist. This person will take the lead on the third item, which is the implementation of the aforementioned flexible automation testbed. Necessary changes to the physical plant will be made over the summer of 2018 and purchasing and implementation of the components will begin in the fall. Finally, although it is only peripherally related to the A&I concentration, we have hired a Director of Pre-Engineering Program Development to take the lead on the changes to the ItED sequence. This person will have a broader set of responsibilities than just that sequence, but the top priority for next year is expanding and improving the ItED

sequence, so the part most critical to the A&I concentration will begin in the 2019-20 academic year if all goes as planned.

### *B. Remaining Steps*

Once the steps outlined above are fully underway, we will be able to put the remaining steps into place. The introduction in 2019-20 of the Introduction to Manufacturing Automation course will allow the two existing courses, Introduction to Automation & Control and Industrial Robotics, to be revamped to take advantage of what is introduced in the first course. We also anticipate that the Automated Systems Integration course will be introduced, probably as an elective, during the 2019-20 academic year, and that planning for the final course in the sequence will begin development during that year as well. The MFGE program is also impacted, so as part of the implementation of the A&I concentration we hope to expand capacity in the MFGE major. To that end, a strategic plan for growth in the MFGE program and a set of budget requests to support it is under development as well. We anticipate being able to hire one more manufacturing automation specialist onto the faculty before implementation of this concentration is complete, which we hope will be during the 2020-21 academic year.

### *C. Assessment Approach*

Once the courses outlined above are being offered annually and the A&I concentration is fully underway, we plan to assess and evaluate each course based on the course project or projects, and to use the final course in the sequence, Automated Systems Integration, to assess ABET EAC student learning outcomes (SLOs) 1, 2, and 5 for students in the A&I concentration, for the newly adopted ABET EAC SLOs will be in place by the time the A&I concentration is fully implemented. The MFGE program conducts course reviews on a three-year cycle, so each course in the A&I sequence will be reviewed as to how well it met course learning outcomes after its first offering and then again three years after that, unless there is call or cause to review the course again earlier. The MFGE program also assesses and evaluates SLOs on a three-year cycle, and the major project in the last course will be how student performance is assessed.

## CONCLUSION

This work has outlined our plans to implement an Automation and Integration concentration in an ABET EAC accredited Manufacturing Engineering program in the XYZ Department at Public Comprehensive University. The development of this concentration is driven by increased use of automation in manufacturing in the PNW region and among our industrial partners, and therefore an increase in both demand for and opportunities for graduates who have relevant experience with the development and implementation of automated manufacturing systems. What makes the concentration different than existing programs is that students will get introduced to more accessible automation concepts in lower division courses so that they can go into more depth in upper division courses. The ENG D Department at WWU has begun to invest in and develop specific parts of the A&I concentration and expects to have the first courses in the concentration offered as elective courses during the 2019-20 academic year, with the remainder of the concentration to follow shortly thereafter.

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