Session 2642

Manufacturing Systems Integration: What is it and how do we teach it?

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Introduction

In today's increasingly fast-paced manufacturing environment, engineers are called upon to design and develop manufacturing systems that can respond quickly and efficiently to constantly changing demands. The increased use of automation and continuing trend toward shorter life cycles and more customized products creates a heavy demand for sophisticated skills in information technologies, engineering management, quality engineering and many other areas. These skills need to be provided to our students, and need to be provided in a way that allows them to be viewed as part of their engineering skills, rather than as a separate set of "management tools" that can be "picked up later" or "learned on the job."

Manufacturing Systems Integration

The phrase "Systems Integration" can be used to describe many different things. In manufacturing, the phrase is often used to describe the combination of highly sophisticated pieces of automated equipment into untended manufacturing systems. This use is very restrictive though, and fails to truly encompass the demands of modern manufacturing. To be effective at integrating manufacturing systems together, an engineer must have the ability to incorporate the perspectives of several different traditional "fields." These fields include not only Manufacturing Engineering, but also Industrial Engineering, Mechanical Engineering, Electrical Engineering, Computer Science, and Engineering Management. Since engineers doing manufacturing systems integration are expected to be able to interface well with their counterparts in the "traditional" engineering disciplines, they need to know the vocabulary, models, basic theories and assumptions that these "counterparts" will be using. To provide these abilities to our students, courses need to be developed that can expose students to these issues while reinforcing their relevance in manufacturing.

Challenges

Most courses in manufacturing engineering programs are too focused on enabling technologies and provide only cursory coverage of management and business issues. Most courses in business programs are too focused on financial aspects and information management and provide only limited exposure to the technological limitations and constraints of manufacturing hardware. This is not unexpected, the instructors in these programs are often teaching to students from a single major, and the need to "speak to your audience's level" forces them to focus on the area where their students have had strong preparation.

The textbooks available for a course in manufacturing systems integration are quite limited for similar reasons. It is quite possible to find an outstanding text on computer control of automated manufacturing systems, but the text will normally be very limited in its coverage of management issues like worker empowerment or benchmarking (if it addresses them at all). It is also possible to find an excellent text on quality engineering and design of manufacturing systems, but the text normally does not discuss communication standards or data transfer protocols. Publishers target texts for well-defined audiences. The task of integrating a manufacturing system doesn't fit very neatly under the headings that they use.

To further complicate the issue, it should be noted that lecturing on the subject of manufacturing systems integration is not sufficient. To truly understand the difficulties and uncertainties that can arise in a systems integration effort, students really need to be involved in a project that exposes them to the unpredictable and unforeseeable nature of the task.

A Solution

In the Industrial and Manufacturing Engineering Department of the University of Wisconsin-Milwaukee, a course has been developed to address these needs. The course is entitled (not surprisingly) Manufacturing Systems Integration and is a senior-level undergraduate/first-year graduate level course. It is an elective course and is offered every third semester at present. This is a laboratory-oriented course in which the students work as a team to design and develop working automated manufacturing cells involving machining and/or assembly tasks.

Students are required to design and build the appropriate fixtures, robot grippers, electronic systems, etc. and write the complete protocol and software for the machining/assembly operation. In the early weeks of the course, the laboratory work involves primarily "demonstration" experiments to acquaint students with the larger hardware available in the laboratory. This equipment includes robots, machine tools and programmable controllers, as well as the appropriate programming and control software needed to utilize them.

Although the laboratory project is a major focus of the course (comprising 50% of the semester grade), it is not the only one. The structure of this course is somewhat unique, in that the lecture topics covered in two distinct areas are interwoven, and the semester project efforts are conducted throughout the majority of the semester. The lecture topic areas can be broadly defined as falling into two areas, Integrated Manufacturing Issues and Programmable Logic Controller Topics.

Course Introduction/Project Team Organization (1 class)
Fundamentals of Systems Integration (1 class)
Project Team Training Concepts and the Nominal Group Technique (1 class)
Computer Integrated Manufacturing: Limitations and Shortcomings (1 class)
Planning and Organizing for Integrated Manufacturing (1 class)
Strategic and Corporate Level Issues Related to Integrated Manufacturing (1 class)
Information System Design for Integrated Manufacturing (1 class)
Benchmarking (1 class)
Manufacturing System Redesign (1 class)
Managing Implementation of Integrated Manufacturing (2 classes)
Cost and Performance Measurement in Integrated Systems (2 classes)
Communication Networks and Standards (2 classes)
Modeling of Integrated Manufacturing Systems (1 class)
Cost Justification of Integrated Manufacturing (1 class)
Case Studies in Integrated Manufacturing (3 classes)

Figure 1. Integrated Manufacturing Issues

The Integrated Manufacturing Issues (Figure 1) are presented and discussed through the use of a collection of readings focused on systems integration. Students are required to read 2-3 papers prior to each class and write summaries describing and discussing the papers. The topics are then discussed in class as a group, and the instructor facilitates exploration and explanation of the subject matter. This is normally conducted during the first fifty minutes of class. (The class is normally taught in two weekly seventy-five minute sessions.) The summaries are graded for correct grammar, spelling and punctuation, and also for content and understanding. The "summaries" are not limited to presenting a brief version of the paper. Instead, the students are further required to discuss their opinions about the paper and what the authors have to say. This format encourages analysis of the papers prior to class (not just reading them) and dramatically improves the quality of the in-class discussions on the subjects.

The remaining twenty-five minutes of each class are spent in one of two ways. Either in a "team meeting" working on the semester project, or in a mini-lecture on a Programmable Logic Controller (PLC) Topic. The PLC topics are normally presented once per week, and there is a team meeting during class time once per week.

The team meeting is student-led and directed (with periodic guidance from the instructor) and serves as a known time that all class members can meet at the same time. UW-Milwaukee is an urban campus, many of our students work full time or commute, and outside-of-class meetings are difficult to arrange. Actual laboratory time is often coordinated by the student team leadership and normally occurs during evening hours. Some technician support is available during business hours, but it is limited.

The structure of the student team often changes and fluctuates during the semester as the project progresses and passes through various phases. It normally begins as a hierarchical structure (one leader, a few subordinate leaders) passes through a matrix phase (where people end up hopping between “groups” helping out where there specific skills are needed) and then ends up in a hierarchical structure again (as the project documentation has to be prepared and finalized). The students also evaluate each other on several specific performance factors, and they know this from the beginning of the class, so team participation is often higher than in typical project work. Nonetheless, despite the best efforts of the team leadership and peers, there are always some students who don’t “pull their own load.” There are also always some students who carry more than their “fair share” of the load. This is realistic though, and not unexpected. The student peer evaluations tend to reflect this well, and it is a component of the grading policy.

The PLC topics (Figure 2) are presented in this class in order to form the basis for the control structure that is normally used in the project. The students are exposed to PLC’s in earlier required classes, but the in-depth exposure in this class is meant to assure proficiency. The students complete a mini-project in the first part of the semester where they individually create and enter a ladder logic program, but then the group also uses PLCs as the controllers for each cell. The final project incorporates fairly sophisticated use of the PLCs including peer-to-peer communication, as well as hierarchical host/subordinate communication and handshaking.

Overview of PLC’s and Numbering Systems (1 class)
Fundamentals of PLC Programming (1 class)
Sensors, Input/Output Modules and Wiring (1 class)
Arithmetic Instructions and Advanced Programming (1 class)
Overview of Plant Floor Communication/Installation and Troubleshooting (1 class)

Figure 2. Programmable Logic Controller Topics

This combination of facilitated discussions, traditional lectures, extensive laboratory usage and self-directed team experience results in a very exciting and, at times, quite demanding environment for learning.

Disclaimers and Comments

The response to this class has been excellent. Students who take it routinely praise it and refer it to their friends. However, as with any course, there are some complaints. Students sometimes complain that there’s “...simply too much to do in the class.” This comes primarily from students while they are “in” the class or have just completed it. There is a lot of material to read, and the laboratory work is time consuming. Various steps have been taken as the course has developed to balance the load in the class, and make it clear how much is expected and when. By it’s nature, the laboratory portion of the course tends to be very time intensive toward the end of the project, and this is a bad time of the semester for large time commitments for most students. Having said this though, it is necessary to point out that alumni of our program who had taken the course are virtually universal in their praise of it. More importantly from the students’ perspective, the response from employers has been outstanding too!

It is also a time consuming course for the instructor. There is a lot of “behind-the-scenes” work and preparation necessary to make sure that things go according to plan. Unexpected crises develop and must be dealt with, and the resources required are hard to predict completely in advance. In addition, there is a fine balancing act that must be maintained between giving enough information/guidance to allow the students to plan, design, explore and create, and giving too much information/guidance which results in the students doing only what the instructor can think up. Part of the valuable learning in the course is intangible, like learning how to find specific technical information or how to interact with various personalities in the team. Students must be allowed to flounder around a little to find their own way, but can't be left alone too long or they will give up or pick a bad solution.

Conclusion

The Manufacturing Systems Integration course at UWM does a good job of achieving the goals that we set out for it. It provides students with exposure to a broad array of fields, and does so in a way that maintains the relevance to manufacturing, stresses the shortened development cycle of manufacturing systems, emphasizes team work skills and project management, and stresses concurrent engineering. It exposes them to management tools and techniques that they do not commonly see in engineering courses, and it allows them to pull together many of the "tools" and "models" that they've learned in other classes and use them to support a realistic project. Manufacturers are increasingly interested in hiring engineers who have knowledge beyond the traditional boundaries of their chosen disciplines. The need for training in this area is real and often unmet. The course described in this paper may be useful as a template for other colleges and universities, but is unlikely to remain fixed. The field is changing all of the time and new technologies and standards will undoubtably change the lists of topics that are included in the text. For further information or discussion please contact the author.

Biographical Information

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Dr. Borchelt received his B.S. in Electrical Engineering, as well as his M.S. and Ph.D. in Engineering Management from the University of Missouri-Rolla. He has been an assistant professor at UWM since 1991 and teaches and conducts research in a variety of manufacturing topics. He is the proud father of three wonderful children and is a second degree black belt in taekwondo.