Agile Manufacturing Curriculum Development for Undergraduate Engineers

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Abstract
This paper describes some early efforts to incorporate agile manufacturing concepts into the undergraduate curriculum for industrial and manufacturing engineering. Our premise is that the best way to prepare students for the world of agile manufacturing is to use agility as an educational model, not merely a set of technologies and concepts to be taught in appropriate courses. With the recent articulation of agile manufacturing concepts, many companies are realizing the need to reengineer their businesses in order to remain competitive. Educators need to create and implement methodologies for introducing agile manufacturing into undergraduate education.

In the summer of 1991, the Iacocca Institute at Lehigh University organized a team of 15 industrial leaders to assess the ability of U.S.-based manufacturers to compete into the next century. The leadership team, organized at the request of Congress and supported by the Department of Defense, ManTech Office, represented 13 industrial firms and was joined by more than 150 executives from 77 other companies. Together they produced the "21st Century Manufacturing Enterprise Strategy," in which the challenges of agile manufacturing are detailed. The report concluded with recommendations for turning the vision of agile manufacturing into reality. Among those responsible for this transformation are government, industry, and academe.

The reader is first introduced to the background and concepts underlying agile manufacturing. The authors then draw an educational parallel to the agile enterprise. Following this is a discussion of the benefits to be gained from building on the functional core of the engineering process and balancing lateral and vertical thinking. This section includes several anecdotes from some leaders and innovators in the educational arena. The paper then describes several programs being created and tested by the authors in an effort to reengineer the undergraduate industrial and manufacturing engineering curriculum.

Introduction
With the recent articulation of agile manufacturing concepts, many companies are realizing the need to reengineer their businesses in order to remain competitive. In curricula where it is appropriate, educators need to create and implement methodologies for introducing agile manufacturing into undergraduate education. However, with the real or perceived fullness of most four-year programs, the mere addition of new material would likely be ineffective in causing meaningful improvements. Consequently, new approaches to engineering education should be developed and tested to enable the infusion of agile manufacturing philosophies, tools, and techniques.

Background on Agile Manufacturing
In the summer of 1991, the Iacocca Institute at Lehigh University organized a team of 15 industrial leaders to assess the ability of U.S.-based manufacturers to compete into the next century. The leadership team, organized at the request of Congress and supported by the Department of Defense, ManTech Office, represented 13 industrial firms and was joined by more than 150 executives from 77 other companies. Together they produced the "21st Century Manufacturing Enterprise Strategy," in which the challenges of agile manufacturing are detailed.

According to the report, the world is currently witnessing the end of an industrial era characterized by mass production. Agile manufacturing enterprises will dominate the industrial world of the next century. As next-
generation competitors, agile organizations will be able to leverage the skills and decision-making abilities of both management and labor.

Agile enterprises foster an environment where intellectual power is the key to competition. Regarding knowledge as a key asset, agile organizations view worker training and education as conditions of survival. The envisioned organizations transform the intellectual skills of talented employees into new and constantly evolving products, processes, and services. By doing so, they will be able to meet the market-driven requirements for high quality, speed, and customer satisfaction.

The report concluded with recommendations for turning the vision of agile manufacturing into reality. Among those responsible for this transformation are government, industry, and academe. It emphasized that the academic community must institute continuous review and reform in engineering and science education, and in business and management education, in support of agile manufacturing. The report also stressed the need for academe to partner with industry and government in order to most effectively strengthen undergraduate curricula leading to careers in manufacturing. This paper focuses on several possible approaches to meet the challenges that face academe in this transition to agility, specifically in undergraduate engineering education.

An Educational Parallel to Agile Manufacturing

Initially, we looked for central themes of the agile enterprise and determined appropriate educational parallels. These findings were used in the development of specific educational initiatives.

Agile manufacturing organizations are characterized by the following:

- Flexibility
- Knowledgeable workforce
- Participative management structures
- Empowered individuals and teams
- Both lateral and vertical thinking
- Cooperation both within and among firms
- Experienced employees

There are several ways to introduce agile manufacturing into the undergraduate curricula. One option would be to teach agile manufacturing concepts in the appropriate courses. However, this approach is less than ideal since agile manufacturing cuts across a broad spectrum of undergraduate courses. It would be much more effective to infuse agile manufacturing into the entire learning process.

Unlike JIT and flexible manufacturing systems, agile manufacturing is a way of improving the entire business entity, not merely the factory floor. Similarly, an agile approach to education would impact the curriculum as a whole, not just a few specific courses.

Therefore, an educational parallel would include the following:

- More cooperative, team-oriented work
- More exposure to hard manufacturing
- Integrated case studies
- More applications to complement theory
- More hands-on experience
- Industrial tours
- Intensive design exercises
- Real problem solving instead of unsatisfying number crunching
- Increased emphasis on communication skills, both written and oral

This set of educational objectives and goals will help us create, structure, test, evaluate, and implement new programs and initiatives in the undergraduate engineering program.

Building on the Functional Core of the Engineering Process

Under many existing systems, the first two years of undergraduate engineering education includes the foundation courses in math and science. These courses are treated independently, sometimes with little integration and applications that students need in order to obtain a complete understanding of the subject matter. In addition, these math and science courses are designed for the development of scientists, not engineers. The Engineers Council for Professional Development has defined engineering as "the profession in which a knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to use, economically, the materials and forces of nature for the benefit of mankind." The key to this definition is the word "applied," for which there is commonly a need for further emphasis in engineering curricula.

By providing students with an understanding of the functional core of the engineering process early in their education, we will not only produce
better graduates but will also stimulate interest in undergraduate engineering. The first two years are critical in the undergraduate education, and too often we turn students off to engineering during this period.

Dr. Joseph Bordag of the University of Pennsylvania has effectively articulated this point: "We say to our engineering freshmen, 'You have studied physics, chemistry, mathematics, humanities, and social sciences in high school and gained admission to our college. Now go away and study the same subjects for two more years; then we'll let you study engineering.'"

Introducing early on what engineering is all about will make freshmen and sophomores more enthusiastic about engineering. We can then teach the basics on more of an as-needed basis. This can be described as a just-in-time approach to teaching. It is more effective than stockpiling information and expecting students to retain this knowledge for later applications. Reducing "information inventories" will increase the agility of the curriculum and the educational efficiency of the undergraduate engineering program.

Lateral vs. Vertical Learning

Working effectively in an agile organization requires an understanding of the company as a whole. With the trend toward flatter enterprises, engineers are assuming more of an entrepreneurial role in the corporate organization. It is becoming increasingly evident that we can improve the way we prepare our engineers for these new global challenges. It is no longer sufficient to simply master one's own task without being familiar with all aspects of the operation. Such tunnel vision hampers communications within the company, an integral part of agile competition. Engineers must also be able to think across a wide variety of disciplines (lateral thinking). Therefore, it seems logical that engineers should be educated in such a holistic manner.

In some ways, this lateral approach to engineering education already exists. At Lehigh, for instance, engineers are required to fulfill a distribution requirement, which includes select engineering courses outside a student's major. In addition, a general studies program requires engineering students to take a minimum of 25 credit hours of courses in the humanities or social sciences. Nevertheless, an important element is lacking—integration.

Engineering education programs should shift from specialization in course content to a more comprehensive view, focusing on the development of human resources and the broader educational experience. The individual parts should be connected and integrated. The majority of engineering courses are treated separately and act as filters. Adopting a unified approach is appropriate in preparing students for life-long learning.

Accomplishing this goal will be a formidable task, but it must be done. The steadfast nature of the university institution makes it practically impossible to reform the system overnight. The challenge will be to effectively create and implement an agile educational paradigm in an environment that has traditionally been anything but agile. Many educational philosophers have proposed some radical departures from the traditional system of undergraduate education. We should be careful not to fool ourselves into believing that these changes can occur instantaneously. Nevertheless, we should structure smaller short-run changes to consistently steer us toward a long-run goal.

Example Approaches to Creating an Agile Educational Model

In order to introduce these agile elements into undergraduate engineering programs, the authors have begun testing the following delivery mechanisms:

- Increased emphasis on learning through case studies
- Leadership development through student-run companies, short courses and seminars, and communication skills development
- Stressing and promoting valuable real-world experiences for undergraduates

Case Studies

Case studies are an effective education tool. Real-life problem solving is often more rewarding than traditional number-crunching exercises. Students are often too concerned over whether their answer matches that in the back of the textbook. Such a "right-or-wrong" view of engineering is unhealthy, not to mention inaccurate. Case studies can portray engineering problems in a more realistic manner.

Case studies are rarely used in undergraduate engineering education. Even when professors integrate case studies into their courses, it is usually in a limited manner. Students are only allowed to look at the story through a small window, since the professor is merely concerned with the case material that is
relevant to the course.

Employing comprehensive case studies as early as the freshman or sophomore year would accomplish several of our aforementioned goals. Cases can be introduced in appropriate courses as supplements to the typically highly structured textbook problems. Many cases are multidisciplinary, so professors can often use one case in several courses. In this manner, the cases can be seen as a glue that pulls together topics taught in various courses, allowing students to better see the "big picture" of engineering. They provide a vital link in undergraduate engineering education by portraying the reduction-to-practice aspect of real engineering. The authors are introducing case-study learning into a sophomore-level industrial engineering course. This course, which teaches students the fundamentals of computer graphics and computer-aided design, is being framed in case studies on agile organizations.

Case studies can also be used to educate students on a more as-needed basis. By strategically using the cases to frame the curriculum, concepts can be taught with a specific goal in mind. It seems logical that engineering students should learn in such a goal-oriented fashion, since this is what engineers so often do in the real world. Rarely do engineers collect a bunch of facts and go in search of an application.3

Leadership Development
In addition to competency in the traditional engineering, mathematics, and science disciplines, engineers in an agile organization require further leadership qualities to make them capable professionals. For an organization to become agile, the product design process must be transformed from a compartmentalized approach to a multidisciplinary team approach, allowing for more rapid product realization through concurrent engineering. With the team approach and the inverting of the organizational pyramid, engineers will be required to rely more and more on communication skills and managerial techniques.8

Communication Skills for Leaders. Most professionals agree that strong writing and speaking skills are more of the exception than the rule among engineering graduates. Yet, as organizations become more agile, these skills will become increasingly essential to engineers. Freshman English requirements for engineering students may not prepare engineers for the type of communication skills required for success in their professional careers. Too often, engineering students take no writing-intensive course that is relevant to their discipline. Speaking and writing should be an integral part of the engineering curriculum, from the freshman through senior year.

One approach to enhancing the communication skills of engineers is to require engineering students to take an undergraduate technical writing course. However, with a curriculum described by many as "crowded" or "jammed," there is often no excess capacity in the undergraduate years for the inclusion of such a course. Furthermore, the benefits of a single course emphasizing technical writing, if not integrated with other engineering courses, would be limited. Speaking and writing skills are best improved through continuous practice. It, therefore, seems quite logical that communication should be a fundamental part of many engineering courses. Unfortunately, this is not the case. Senior project courses are often highly communication-oriented. However, for many students, this is their first opportunity to enhance their communication skills in such an intensive manner. In their senior project course, students should be integrating all the speaking and writing skills that they developed throughout their undergraduate years.

Engineering faculty need to recognize the communication-skill requirements of their students and develop a systematic method of introducing speaking and writing elements into their courses. At least one course each year should stress oral communication through project presentations and group discussions. In addition, at least one course each year should be writing-intensive. In appropriate undergraduate courses, professors should consider requiring that their students keep engineering journals. In this manner, engineering students would inevitably enhance their oral and written communication skills through continuous practice and experience.

Engineers with well-developed communication skills will be essential to agile companies wanting to strive for or maintain a competitive edge in a global economy. Engineers will use these skills in discussions, negotiations, exchanges of information, and communications with the global community of engineers, scientists, and managers. These skills will help transform engineers from technical specialists into competent, well-rounded professionals.

Virtual Student-Run Companies. The authors have developed a program that incorporates "virtual" student company start-ups into the undergraduate engineering curriculum. In Lehigh's industrial engineering (IE) senior project course, a requirement for all IE majors,
students work on real-world projects in industry. Typical senior projects team two seniors to work at a local company. The projects allow them to use and practice in a realistic setting many of the IE tools and techniques they have learned as undergraduates.

Student interns at Lehigh’s Computer-Integrated Manufacturing (CIM) Laboratory work with companies and professors to find better ways to help students enhance their leadership skills. Many of the IE seniors have gained experience by working for two or more summers in industry, so the opportunity to gain entrepreneurial experience in the senior year seems like a natural progression. This new program also offers students the chance to learn about the responsibilities and concerns of the entire organizations, not just the industrial engineering department.

Student “owners” of the companies manage two to three consulting assignments. Each assignment is typically carried out by a team of two industrial engineering students. The owner is first responsible for recruiting the company’s workers and marketing the company’s skills to local companies. By printing brochures and pamphlets, as well as giving marketing presentations, the owner must sell the company’s services to obtain work assignments.

Once the student teams have begun their projects, the owner oversees the daily operations of the company. The company staff and manager must work together to resolve any problems or difficulties that may arise during the semester. The student owner is required to address these issues as if he were a manager in a real agile organization. The autonomy and entrepreneurial experiences associated with these student companies are appropriate and valuable in preparing engineers to work in agile organizations.

Additional Leadership Development. Through short courses and seminars, similar to those sponsored by industry, engineering students can learn valuable ways to develop and enhance their leadership traits. Covering such subjects as negotiating effectively, developing and selling a presenting to management, forming a strategic plan, and managing projects, these leadership-development seminars will help round out the undergraduate educational experience for engineers. These programs can give engineering graduates and the companies that employ them an important edge in the corporate world of agility.

Real-World Experience

Educating engineers for the agile manufacturing arena should include an emphasis on real-world experience. Engineering students most successfully retain knowledge and understanding when they see and do things, not when they listen to how things are done. Case studies are one way of introducing a more hands-on element to the classroom. However, additional improvements can be made.

There should be an increased emphasis on summer internship opportunities for undergraduate engineers. In today’s economy, newly graduated engineers are in many cases competing for jobs with engineers that have been out in the field for several years. With a finite number of job opportunities, engineering students need to realize the value that companies place on real work experience. In-plant problem solving not only allows students to practice some of what they have already learned, but it often instills in students a desire to continue learning more.

Courses should also be structured in such a way as to allow students to gain experience through practical application. The engineering curriculum should include extensive hands-on use of enabling technologies for agile manufacturing. Industrial tours should be an indispensable part of the engineering curriculum. In many cases, an engineering student rarely, if ever, sets foot in a factory before graduation. Engineering organizations such as the Society of Manufacturing Engineers arrange occasional plant tours open to any students who sign up. Those who attend are typically a small percentage of the student body.

Professors need to seize this opportunity and publicize such activities. In certain courses, it may be constructive to require student participation in a given number of relevant industrial tours. Some may argue that students learn little from touring an industrial facility. In many cases, this may well be true. However, industrial tours stimulate interest in otherwise bland engineering subjects and add a real-world dimension to what is taught in the classroom. It is an element which many undergraduate engineering programs are lacking.

Conclusion

Our experience has indicated that the agile approach taken by industry can be both taught and used as a model in the curriculum development process. We need to implement programs in undergraduate engineering education based on continuous review and improvement.
Periodic review may no longer be the most effective method if we want to parallel the rate of change in the global arena. Given the recent articulation of the agile manufacturing vision, we are presented with a golden opportunity. Since academe will play a vital role in the transition to agile manufacturing, universities need to act on this vision by enhancing and improving undergraduate engineering curricula.

In light of the increasing complexity and depth of technical knowledge, undergraduate engineering education needs to become more basic and foundational. Being limited to four years, it is simply impossible to provide students with a highly specific in-depth technical education. The university’s role in undergraduate engineering education is becoming one of preparing students for a career of life-long learning. We need to abolish the belief that one’s education ends upon completion of the four-year engineering program. The baccalaureate should represent the foundation and framework for the engineer’s future.

Agile competition will require engineers to be articulate, well-rounded professionals. The production of a product begins with the design process, when the functional need of customer demand must be satisfied. It continues through the manufacturing process to a final acceptable product. However, the process does not end until the product is shipped, and a diverse range of technologies is involved. The undergraduate curriculum should, therefore, promote an interdisciplinary approach and provide a broad view of manufacturing. Core courses in an agile manufacturing curriculum are designed to cover the range of subjects from the manager’s point of view to the engineer’s "feel" of the factory floor.

Traditional education views have been criticized for providing a "filter" process where students merely memorize equations for exams and have little or no understanding of the usefulness of applying the general concepts. Upon passing the tests and completing the course, students filter to the next level where the process repeats. An agile approach provides a foundation that will make students strive to advance their education, not just through their undergraduate years, but also for the rest of their lives. As organizational characteristics of traditional corporations move towards agile manufacturing environments, it is useful to examine the teaching philosophies associated with traditional engineering curricula and utilize agile principles in both the structure and content of undergraduate programs.

References


