Designing and Implementing a European Production Engineering Education

Mihai Nicolescu[1], Ove Bayard[1], Magnus Areskoug[2]

Abstract
Modern production engineers must be able to perform a wide variety of tasks with steadily increasing complexity. In this context, it is especially important to endow production engineers with cross-disciplinary knowledge since this is vital to changing technology and international competition. Production engineering (PE) curricula must therefore keep pace with the changes demanded by future trends in advanced manufacturing. A homogenous production engineering curricula that specifies the most important areas in this field is a suitable platform to start from. The paper presents the some results from the EPRODE project being conducted by a number of European academic institutions and industrial organizations into manufacturing education issues. The aim of the project is to anticipate the needs for education of European and national manufacturing organizations of the future and to provide a unified framework for a common body of knowledge development that meet these needs.

Introduction
Manufacturing is a process which transforms information into a product. The information includes design data, quantities required, and delivery dates. The transformation involves developing tools and processes, obtaining material, processing material, assembly, testing, and delivery. The factory of the future will be an integrated system with a common engineering and manufacturing data base. Data processing will be used extensively to receive design information without having to reconfigure for manufacturing, estimate and order material, control inventory, program machines, monitor yields, and program test equipment. Automation will be extensive, encompassing material handling, numerically controlled machines, and closed-loop process control. Robots will function as welders, painters, assemblers, and inspectors [8].

As manufacturing industry embraces and remodels innovative technologies and strategies aimed to increase its efficiency, the education system in production engineering must also keep pace with these changes in the way the new generation engineers received their education and training. This will reflect the manner production engineers will manage the new automated manufacturing systems. Europe competitiveness will depend on increasing the productivity of manufacturing systems and the ability of production engineers to implement and operate advanced technologies, achieving product quality and lowering production costs.

The emergence and proliferation of the so-called 'knowledge-intensive industry' within the industrial sector demanded manufacturing employees to learn continuously and re-skill themselves. A knowledge-intensive organization is an organization where the majority of employees are highly educated and the production does not consists of goods and services but complex non-standardized problem-solving [1]. The rapid growth of industrial production that has occurred in recent years has been primarily concentrated in the knowledge-intensive branches of the economy. These now account for no less than 50 per cent of the total value added of the industrial sector. In 1970 the comparable figure was 30 per cent. This rapid expansion in the knowledge-intensive industries has brought about a substantially more rapid growth of industrial productivity than during the 1970s and 1980s (Figure 1).

[1] Kungliga Tekniska Högskolan, Stockholm, Sweden
[2] Teknikföretagen, Sweden

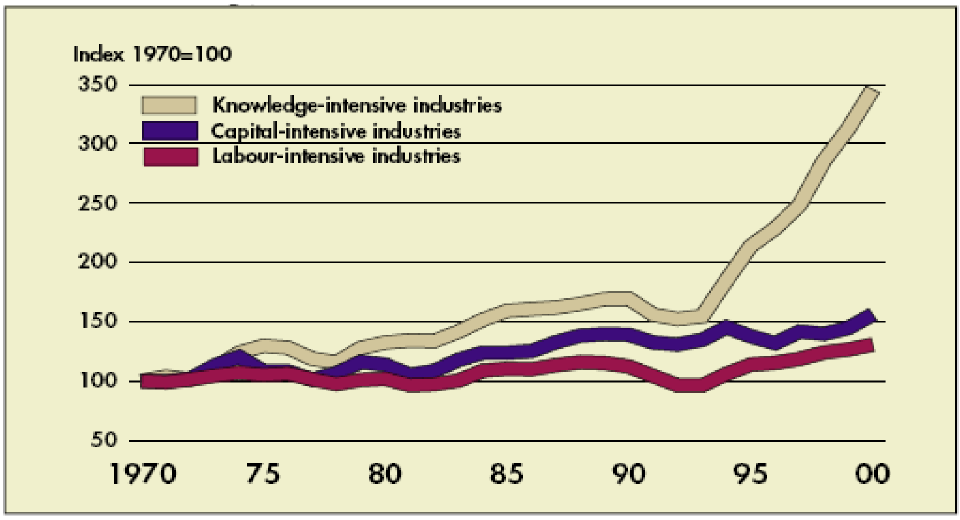

Figure 1: Changes in industrial sector
"Facts about Swedish economy" Confederation of Swedish Enterprise 2001

The manufacturing activity in Europe represents today approximately 22% of the EU GNP. It is estimated that in total 75% of the EU GDP and 70% of employment in Europe is related to manufacturing. This means that each job in manufacturing is linked to two jobs in manufacturing related services. European manufacturing has great potential as part of a sustainable EU economy, but its success will depend upon continuous innovation in products and processes [3]. In spite of the importance of manufacturing engineering, relatively little change has occurred during the past several years in the status of manufacturing engineers.

Due to the variety of activities undertaken in manufacturing and the variety of products involved there is a significant ambiguity about the essence of production engineering (PE) in terms of education and training, the skills and ideas associated as well as the attributes of a manufacturing engineer. It is not directly apparent that a consistent discipline even exists, making it very difficult to describe an explicit curriculum that should be cultivated. The lack of a consistent body of knowledge about PE is the main obstacle in the development of a homogenous curriculum and educational program.

This paper presents some results from the EPRODE project being conducted by a number of academic institutions and industrial organizations from EUROPE into manufacturing education issues. The aim of the project is to anticipate the needs for education of European and national manufacturing organizations of the future and to provide a framework for a common body of knowledge development that meet these needs.

Production Engineering Education

Engineering educational goals are often general statements about the knowledge, abilities and skills, as well as attitudes, values, interests and motivations, that schools are expected to impart:

- To prepare graduates to contribute to engineering practice by learning from professional engineering assignments
- To prepare them for graduate study in engineering

- To provide a base for lifelong learning and professional development in support of evolving career objectives, which include being informed, effective, and responsible participants within the engineering profession and in society [6].

Engineering education has often tended to emphasize theory over practice. In addition, basic education has not always met the needs of industry, producing graduates with often inadequate skills. This has led to industries that are poor at turning innovation into successful products. This necessitates a change in priorities and closer ties between industry and educational institutions [5].

Performance as an production engineer requires the application of principles, methods, and techniques appropriate to the field of manufacturing technology, combined with practical knowledge of the construction, application, properties, operation, and limitations of manufacturing systems, processes, structures, machinery, devices or material, and, as required, related manual crafts, instrumental, mathematical, or graphic skills [2].

One of the main themes in the discussion about manufacturing education curricula is the balance between the engineering and non-engineering problems of manufacturing. There is a general agreement that a purely technical education is not enough for manufacturing engineers who have to direct much of the efforts to managerial problems in order to optimize the manufacturing systems.

Thus, the design of new understanding and of a new curriculum for manufacturing engineering education must be seen in the context of the engineering and managerial fields and manufacturing industry. The connections between industry and the university community must include both the engineering and non-engineering subjects, and these connections may play a role in which these two academic areas work together effectively to produce new systems understanding and methods for PE education.

Even if PE clearly and indisputably is important for our welfare, the status for production engineers in Europe and most of the Western hemisphere is very low. Since the importance is big, this fact is rather strange. Manufacturing has not been highly regarded as a career path for students because of its curious position in industry. The best students in engineering rarely choose to take manufacturing-related courses, even when they are available. An increased harmonisation of the PE education and training will also in the long range increase PE status in society.

European Programme in Production

In March 2000, the Lisbon European Council set the EU the ambitious strategic goal to become by 2010 "the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion" [4]. The sophistication of the goods and services provided and required by manufacturing industry, demands that Europe raises its level of technological attainment and increase the ambient level of technical and managerial understanding throughout its manufacturing sector. This requires sophisticated knowledge and skills from the manufacturing employees [7].

The main goal with EPRODE is to establish a unitary, transparent European educational system in Production Engineering based on modular and flexible curricula. This will substantially ease mobility among European production engineers and will also be a basis for higher standards in many European companies, especially SME. Today, the mobility among production engineers is very low, partly because the education and training level differs considerably among EU countries, being almost beyond comparison. The target for EPRODE will be concentrated to the lower/middle education and training level within PE.

The central issue in this debate is how education can contribute to the revitalization of European manufacturing industry. There is growing evidence that much improvement is possible in the short term, and that European companies of the future can be competitive in most basic industries if national technological and management resources are exploited and wisely orchestrated.

Although the details will vary with industrial sector, the factory of the future will challenge our long-held belief that high-volume runs of identical products are required to achieve low cost. It is conceivable that early in the next century computer-controlled flexible manufacturing systems will produce virtually all of the material goods required by society, except those with high artistic content [7].

A European education for Production Engineers (PE) will ensure both quality and high standard of the education and training. The specific objectives for EPRODE are:

- Define and understand the needs and demands for education and training for the manufacturing industry of the future.
- Develop and implement of a modular production engineering curriculum and education system for both undergraduate and for continuing education.

EPRODE covers four related topics:

1. Structuring the PE education system
2. Industry-University cooperation in PE education
3. Keeping updated in a PE career
4. European and National Priorities in PE education

Curriculum

In essence, the function of a unitary PE curriculum can be summed up as a clear and concise statement of what matters in PE education. This translates the EPRODE educational mission into concrete terms for key areas of learning and thus focuses teaching on shared goals. This orientation function benefits students, while also serving to improve the professional expertise of educators and the quality development at the institutional level.

The EPRODE curriculum focuses on modular programme of study, and outlines the intended knowledge, understanding, skills and attributes of a student completing that particular module. EPRODE curriculum consists of 12 modules, each of them rated at 15 ECTS (see Figure 2). EPRODE modules contain courses that cover major areas in production engineering and management. The production engineering “core” modules provides a common language and fundamental base for all production engineers (see Table 1). Technological disciplines are designed to be unique and specialized. To date, EPRODE encompasses three specializations: Manufacturing, Forming and Joining (see Table 1).

Module I, 15 ECTS	Module II, 15 ECTS	Module III, 15 ECTS	Module IV, 15 ECTS
Materials Engineering	Machining Technology	Integrated Product and Process Design	Quality Engineering
Module V, 15 ECTS	**Module VI, 15 ECTS**	**Module VII, 15 ECTS**	**Module VIII, 15 ECTS**
Information Technology and CNC	Manufacturing Systems	Forming Technology Sheet Metal Forming	Joining Technology Welding
Module IX, 15 ECTS	**Module X, 15 ECTS**	**Module XI, 15 ECTS**	**Module XII, 15 ECTS**
Production Management	Joining Technology Mechanical & Chemical	Manufacturing Technology	Forming Technology Bulk Forming

Figure 2: EPRODE modular curriculum

The role of information technology in manufacturing can be seen in the increasing use of computers to underpin product design and fabrication processes and to support related business processes such as sales and distribution. Information technology is integrated in the EPRODE modules to ensure a suitable foundation for advanced manufacturing technologies. Consortia of educational institutions and industry has been formed to improve and to develop new PE programme.

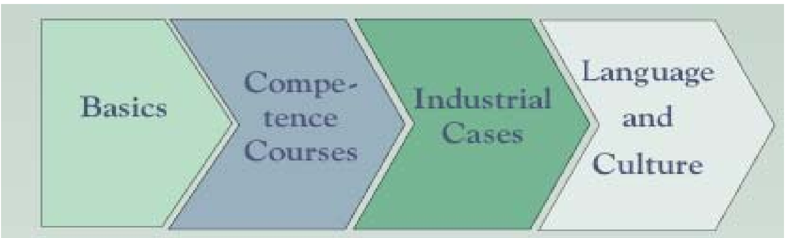

Figure 3 EPRODE module structure

EPRODE modular structure is based upon a unitary combination of theoretical or basic knowledge necessary to understand competence courses, practical activities perform in laboratory or industrial companies, language and culture courses to enlarge the European dimension (see Figure 3). Emphasis has also been placed on the communication skills of reading, writing, listening, and speaking in both technical and non-technical courses.

Table 1: Modules description

Module	Topics description	Learning Objectives	Areas of Skills acquired
Core Modules			
Materials Engineering	Engineering materials, Mechanics of materials, Engineering Mechanics, Manufacturing processes	Recognize that the utilization of materials is interdisciplinary in nature. Understand material properties and how to test. Make the student familiar with the fundamental knowledge about material, applications and traditional manufacturing processes.	Theory, technology, language
Quality Engineering	Statistics, Design of experiment, Quality assurance and control.	Statistical methods for quality control and improvement. Understand how quality planning and quality management are performed,	Theory, technology, management
Integrated Product and Process Design	Geometric dimensioning & tolerancing, Design paradigms. Product Information management, Product data models	Understand cross-disciplinary principles that addresses the production engineering and the design area. Train the student in systems design under economical and technological constraints.	Theory, technology, management
Information Technology	Virtual factory, reconfigurable factory, Computing in manufacturing, Manufacturing information system, CAD/CAM, Process planning. CNC programming	Apply modeling and simulation principles and tools. To be able to understand how CAD/CAM and CNC technique can be used in production. To apply geometric modeling. Understand advanced manufacturing technology infrastructure. Definition and signification of group technology.	Theory, technology, management.
Production management	Operations research, Global competitiveness, Life cycle management, Supply chains, Human resources	Understand and apply basic models. Relate production processes phases and marketing product stages in a dynamic environment. Design P/OM operating systems.	Theory, technology, management

Table 1 (cont.)

Module	Topics description	Learning Objectives	Areas of Skills acquired
Specialization in Manufacturing			
Manufacturing Technology	Rapid prototyping, Manufacturing processes, Powder technology, Surface technology, Abrasive machining, micromanufacturing. Manufacturing costs	Define and characterize different fabrication techniques. Select machine and processes. Calculate manufacturing process capability.	Technology, economy
Machining Technology	Machining theory, Mechanics of cutting, Economical cutting, Tool selections, machine-tool vibration, Process monitoring and control, capability analysis, engineering metrology.	Fundamental knowledge about different machining methods. Understand their applications, limitations and the deformation mechanisms behind them. Economic analysis concerning cutting. Knowledge about material and tool materials, their use and behavior under different conditions. Stability and process control.	Technology, economy
Manufacturing Systems	Production Planning, Principles of automatic control, Kinematics, dynamics and drives, Machine tools and industrial robots, Automatic control of machine tools and robots, Production control	Understand principles of production control in a manufacturing system.	Technology, management
Specialization in Forming			
Manufacturing Technology	Thermodynamics and heat transfer Manufacturing processes, metal casting processes and formability. Surface technology, friction, wear and lubrication.	Define and characterize different fabrication techniques. Select machine and processes. Calculate manufacturing process capability.	Technology, economy
Sheet Metal Forming	Sheet metal forming, Theory of plasticity, Bending, Stretching, Drawing, equipment and economics, drawing defects and residual stress.	Understand the basics of the theory of plasticity. Understand the difference between bending, stretching and drawing. Describe the deformation mechanisms for each method and identify main factors. Context in which each method is used. Calculate force and energy required.	Technology, economy
Bulk forming, Extrusion technology Hot extrusion, cold extrusion.	Bulk forming, Extrusion technology Hot extrusion, cold extrusion.	Describe and understand the difference between cold and hot rolling. Characterize extrusion as a process and in which context it can be used. Describe how the microstructure is affected during the deformation process. Die design.	Technology, economy

Table 1 (cont.)

Module	Topics description	Learning Objectives	Areas of Skills acquired
Specialization in joining			
Manufacturing Technology	Thermodynamics and heat transfer Manufacturing processes, Surface technology, quality assurance, inspection and testing.	Define and characterize different fabrication techniques. Select machine and processes. Calculate manufacturing process capability. Train the student in inspection and testing.	Technology, economy
Welding technology	Materials engineering, Metallurgy, Welding processes, Mechanical assembly, Fusion – Welding processes, Diffusion bonding.	Describe and characterize different assembly techniques. To Train the student in MIG, MAG, MMA and TIG. Understand why welding defects occur and what can be done to avoid them. Calculate the carbon equivalent, energy relationships and working temperatures.	Technology, economy

The degree of standardization of the European production engineering program will be reflected by curricula, educational material, resources, quality assurance system and the process for continual programme review. However, high flexibility is ensured to adapt to national industry demands and to shape student identities in the light of structural features of different national industry profiles.

Quality assurance

Given a European dimension to the production engineering education implies not only to guaranty a common level of knowledge and skills for the graduates but also to assure a high quality level of the trainers.

The primary purpose of European accreditation in PE is to ensure quality control and quality assurance, commonly with reference to a certification system in the areas of education and training. The role of quality assurance and accreditation of European production engineering institutions is reflected in the continuous quality improvements. Translated into assessment programmes, EPRODE educational system is used for education monitoring and the evaluation of accredited institutions. These serve to ascertain and assess learning outcomes, and this feedback function contributes to the output-driven management of the PE education.

If European production engineering education is to achieve its own identity as a unique European discipline in the future, it must assume the responsibility for developing not only of a common body of knowledge but also of a highly qualified faculty staff. Objectives, educational process, resources and quality assurance system must be periodically re-examined and renewed.

Conclusions
This paper underlines the importance of creating a unitary education programme for Production Engineers. This will substantially ease mobility among European production engineers and will also be a basis for higher standards in many European companies, especially SME. The target for EPRODE will be concentrated to the lower/middle education and training level within PE. The EPRODE programme has analysed the differences between Production Engineering Educations within Europe and has developed a modular curriculum with a core part and three specializations. EPRODE programme also gives details of assessment methods.

Acknowledgments
The authors would like to thank the Leonardo da Vinci programme and the Swedish National Agency (Internationella Programkontoret) in Stockholm for their financial support. This has made it possible for us to address a very important matter, namely the future European structure for Production Engineering Education.

References
[1] Karl-Erik Sveiby Jan, The knowledge company: Strategic formulation in knowledge-intensive industries. International Review of Strategic Management. Vol. 3, D. E. Hussey ed. John Wiley & Sons Ltd, 1992.
[2] Engineering Education and Practice in the United States. Engineering Technology Education. National Academy Press, Washington, D. C. 1985.
[3] MANUFUTURE, A Vision for 2020. European Commission, Report of the High level group. November, 2004.
[4] Communication from the Commission, Investing efficiently in education and training: an imperative for Europe. Brussels, 10.01.2003 COM(2002) 779 final.
[5] Engineering Undergraduate Education, National Research Council Staff. Washington, DC, USA: National Academy Press, 1986.
[6] Robert Aylett and Kenneth Gregory (editors), Evaluating Teacher Quality in Higher Education, The Falmer Press, 2004.
[7] Eversheim Walter, Schneewind Jorg, Advanced Education and Training of Manufacturing Engineers, SME Compendium of International Models of Manufacturing
[8] Brummet D. Forest, The U. S. Manufacturing Engineer: Practice, Profile, and Needs, Education for the Manufacturing World of the Future, Washington, DC, USA: National Academy Press, 1985.