International Journal of Engineering Education Vol. 29, No. 1, pp. 248–262, 2013
Printed in Great Britain

0949-149X/91 $3.00+0.00

Developing the Next Generation of Engineers for Intelligent and Sustainable Manufacturing: A Case Study*

GIUSTINA SECUNDO and GIUSEPPINA PASSIANTE
Department of Innovation Engineering, University of Salento, via per Monteroni s.n., 73100 Lecce, Italy.
E-mail: giusy.secundo@unisalento.it; giuseppina.passiante@unisalento.it

ALDO ROMANO and PASQUALE MOLITERNI
Dhitech S.c.a.r.l.—High-tech Technological District, via S. Trinchese, n. 61, 73100 Lecce, Italy.
E-mail: pasquale.moliterni@idf.dhitech.it; aldo.romano@dhitech.it

Promoting excellence in manufacturing emerges as a strategic goal for the years to come, both for industry and society; manufacturing education has been identified as a major driver to achieving this goal. However, the pace of economic, social and technological change has increased the gap between the competences needed by industry and those provided by the universities' curricula. This requires an increasingly integrated approach by academia and industry in order to afford the problem of engineering competences' obsolescence. Framed in the above premises, the aim of this paper is to present the results of a two year postgraduate training program aimed at developing a new archetype of human capital to face the requirements of Intelligent and Sustainable Manufacturing. The case study presented in the paper addresses the needs for providing manufacturing education to meet the challenges in terms of "who"—the profile for the next generation of manufacturing engineer; "what"—the new system for education and its contents, and "how"—innovative learning approaches and strategy to incentive the development of competence. The findings demonstrate the radical innovation in developing the next generation of engineers for Intelligent and Sustainable Manufacturing and the importance of a learning environment that is strictly based on virtuous industry–university partnerships.

Keywords: intelligent manufacturing; competences; manufacturing education; industry–university partnership; entrepreneurial engineer

1. Introduction

Manufacturing industry has played a fundamental role in economies since the industrial revolution and it continues to be one of the major sources of wealth generation for any nation. Manufacturing is defined as the process of converting raw materials into finished goods with the support of machines, tools, energy and labor to satisfy human needs [1]. Manufacturing is responsible of increasing wealth and the availability of affordable products for consumers who, in turn, demand even more products and services [2]. In the European Union, manufacturing activity represents approximately 21% of the GDP (Gross Domestic Product) and involves about 20% of all jobs. Moreover, manufacturing is considered the driving force for the "Europe 2020 Strategy", whose objective is to turn Europe into a *smart, sustainable and inclusive* economy, delivering high levels of employment, productivity and social cohesion [3]. The ManuFuture Platform [4] perfectly follows these guidelines. As soon as the innovative manufacturing system is established, it will realize a sustainable socio-technical economic system, as a part of the wider Sustainable Knowledge Society (SKS). In fact, the SKS has three long-term objectives [5]: innovation and growth in the economy; creativity and human development in society; protection and ecological balance in the environment. The SKS is expected to be a society with knowledge workers (brainworkers) who differ from traditional "instrumental" workers, both in their individual and social behavior. If knowledge is the primary factor in the SKS, the need for research, education and continuous learning pushes universities and, in general, the Higher-Education system, at the core of the growth process [6]. As a part of the SKS, manufacturing industry has to meet one of its major challenges, which is to design and to commercialize competitive, sustainable and environmentally friendly products and processes. This requires a new generation of methods and tools to support new product development, taking into consideration the whole product lifecycle, its costs and the environmental "footprint". The drivers for this industrial transformation are the ICTs (Information and Communication Technologies), which will lead towards a holistic perspective of lifecycle issues [7] and collaborative development of products in an inter-organizational value network. In addition, the scientific breakthroughs and the innovative products will be the result of the convergence between two or more disciplines [8]. The manufacturing of sustainable and intelligent products will require new approaches for engineering practices, which will

* Accepted 4 August 2012..

be more characterized by: the capacity to analyze and solve complex problems integrating technological issues with business and social ones; an interdisciplinary approach to developing new solutions to grand engineering challenges [9]; the capacity to have a holistic vision and, finally, the system perspective to analyze complex problems. This calls for the need for industries to recruit and attract a next generation of workforce that possesses a much broader multi-disciplinary and systems engineering perspective [10]. In order to respond to this role, manufacturing education should follow new approaches, so as to prepare industry for the next generation of innovation, and to support its growth [11].

It is within this debate, as an attempt to face the above challenges, that the case study of "Experiencing i-Design", a post graduate education and research project in the field of Intelligent Manufacturing, is framed. The case study aims to answer the following questions: (a) Which are the competences, skills and attitudes required for the next generation of manufacturing engineers? (b) How to develop in practice these competences in the perspective of lifelong learning? The aim is to contribute pragmatically to the current debate on how to develop the next generation of competences for Intelligent and Sustainable Manufacturing.

The paper is organized as follow. Sections 2 and 3 contain the literature review. Section 4 describes the research method. Section 5 illustrates the main findings in terms of radical innovation in the development of a new archetype of engineer who is able to operate in the field of intelligent manufacturing. Finally, the discussion and conclusion sections highlight the implications of the paradigms described from a theoretical and a practitioner's point of view.

2. Radical shifts in manufacturing industry: towards sustainable and intelligent manufacturing

Not only manufacturing industry is the engine for wealth creation in modern economies, but it is going to be recognized as the driving force for the creation of a sustainable society. Where manufacturing industry has been established in low-wages economies, developing countries increased their investments in R&D in order to offer their industries the opportunity to move up the value chain and to assume a prestigious role in the global economy. As an example, China's rate of investments in public R&D is much greater than any other country in the world [12]. In addition, new technologies, such as automation and robotic systems, allowed a significant increase in manufacturing productivity.

The radical shifts in manufacturing industry leading toward Intelligent and Sustainable Manufacturing can be recognized in the following facts:

- Material and energy resources are continually depleting; the need for renewable energy sources and reusable material bases becomes significant for economic and environmental sustainability, due to the growing needs of the society [13]. Sustainable agendas are those policies that are focused on technological changes that alter the ways that goods and services are provided and require the development of novel socio-technical systems involving both technological and organizational elements [14].
- The future of manufacturing systems should be carefully planned using new strategies and trajectories to connect economic issues with third millennium challenges. These challenges include climate change, the scarcity of strategic raw materials, overpopulation, an ageing population, loss of bio-diversity, soil loss and transport congestion and, no less important, employment, public health for all, poverty and the social exclusion [15].
- An international consortium represented by Europe, Japan, Korea, Switzerland and the USA is conducting a project, IMS2020, focused on the creation of roadmaps towards more sustainable and intelligent manufacturing by the year 2020. IMS2020 is a coordination and support action for strengthening international and interregional cooperation in Intelligent Manufacturing Systems through five main scientific and technical objectives [16, 17]: Sustainable Manufacturing, Products and Services, Energy Efficient Manufacturing, Key Technologies, Standardization and Innovation, Competence Development and Education.
- A European response to this is the ManuFuture Platform, which is implementing a strategy aimed at Competitive and Sustainable Manufacturing, capable of increasing the rate of industrial transformation in Europe in the future knowledge-driven economy [4].
- The "Factories of the Future" public–private partnership [15] initiative contributes to gaining a higher competitiveness for manufacturing systems, introducing technologies for redesigning the manufacturing processes in terms of cost efficiency, optimized consumption of resources, short time-to-market, adaptability, re-configurability and increased reusability of production systems.
- The "Factories of the Future" act on four R&D sub-domains: sustainable manufacturing, ICT-enabled intelligent manufacturing, high perfor-

mance manufacturing, and exploiting new materials through manufacturing.

The concept's development of sustainable manufacturing is a part of the larger concept of sustainable development. Sustainable Manufacturing is a business practice in the industrial sector that expands all the company's processes and decisions into the broader social and natural environment in which the company operates and affects by its actions. This is executed with the explicit objective of reducing or eliminating any negative impact, while pursuing the desired level of technological and economic performance. Sustainable manufacturing is aiming for a balance in satisfying all three main components of sustainability: environment, economy and work [14].

Therefore, the new manufacturing industry factory will design and market competitive, sustainable and environmentally friendly products and processes that contribute to better environmental performance. This requires a shift in the perception and understanding of industrial production and the adoption of a more holistic approach to conducting business [18], along with a new generation of methods and tools to support product development, taking into consideration the whole product lifecycle. The driver for this industrial transformation can be identified in the ICTs, which will lead towards a holistic perspective of lifecycle issues [7]. *ICTs-enabled intelligent manufacturing* will guarantee the efficiency, adaptability and sustainability of production systems and their integration within agile business models and processes [15]. ICTs are the major contributors to manufacturing innovation, productivity and jobs because of their impact on industrial products, services and material processes [19]. As an example of excellence, the *aerospace industry* has emerged as one of the e-business leader sectors, characterized by the presence of a few large companies located worldwide, playing the role of orchestrators and leaders of aerospace programs. At the lowest level of the aerospace supply chain, there are small and medium enterprises (SMEs) that work as components or sub-system suppliers. Investments in ICTs applications by SMEs and large companies facilitating inter-firm collaboration are a necessary condition to improve the integration of the whole industry [20, 21].

3. Breakthroughs in manufacturing education for sustainable development

The introduction of breakthrough technologies and new product development methodologies, the attention to the environment and the scarcity of energy resources in the next generation manufacturing system, contribute to increasing the gap between human capital development processes in universities and industry's requirements in terms of updated competences. To remain competitive, manufacturing enterprises need to recruit engineers who will be able to operate in complex environments with knowledge and expertise to face the challenges of sustainability. The future requirements in manufacturing impose on university engineering curricula a constant pressure for change [2, 22, 23] as well as on development and implementation [24]. A number of works looking into the future of manufacturing education have appeared in the literature, discussing the challenges and goals and/or introducing future strategies and implementation road maps [1, 2, 17, 25, 26]. Radical innovation in human capital creation must permeate the engineering education system. A historical perspective will be given in order to understand the challenges faced by manufacturing education.

3.1 Engineering education: a historical perspective

The Engineering discipline was born in eighteenth-century France with the creation, in 1794 in Paris, of the first technical institute for the teaching of military engineering [27]. After the first and the so-called second industrial revolutions, the institutes began by teaching civil engineering and then gradually introduced other engineering disciplines.

Historically, the changes in society, economy and technology have directly impacted on education and, more precisely, on engineering education. In this respect, the Sustainable Knowledge Society (SKS) will also not be immune from the need to educate an innovative engineer professional profile. Table 1 illustrates the main changes relating to the evolution of engineering education.

In the *industrial economy* paradigm, automation together with computers and robotics allowed industries to adopt the strategy of mass production, so reducing the costs of market products. The availability of cheap products contributed to the rapid diffusion of general wealth and, in turn, to the fast growth of competition between enterprises. The enterprises were positioned to supply unexplored markets with a constant increase in product demand. The University was technically oriented and strongly related to the industrial practices, with the "how to" rule for teaching and without any consideration of physical and scientific phenomena associated with design; the theoretical toolbox was left in the hands of scientists. After decades, the customers acquired more and more economic power as the result of the worrying market saturation. This forced the mass production industries to

Table 1. Paradigm shifts in the economy and engineering education

	Industrial economy	**Digital economy**	**Drivers of change**	**Sustainable knowledge society**
Period	19^{th}—20^{th}	20^{th}—21^{st}	*Reduction of manufacturing costs, product development time*	21^{st} →
Manufacturing products	Low cost products	Customized products		Environmentally friendly products, high added value products
Technology	Automation, computer, robotic cells and systems	Information and Communication Technologies (ICTs)	*Repair–reuse–recovery–recycling of used products and materials*	Nano–bio–info–cogno and material technology
Engineering teaching	Technical institutes focused on industrial practices	Science in Engineering education: university and industry as different entities	*Technology breakthroughs* *Climate changes*	Research education–innovation integration
Engineer profile	General technologist, strong manufacturing skills	Scientific technologist, vertical specialization in a single engineering field	*World population growth* *Energy consumption*	Trans-disciplinary and problem solving oriented, holistic and system vision
Knowledge development process	Industrial practices	University degree, Master, Ph.D.	*Finite supply of critical resource* *Increasingly unemployment*	Lifelong learning approach

change. Production systems became more flexible and customer oriented, thanks to the advent of the ICTs. ICTs broke down the barriers among regions, and with the availability of new fertile markets in the developing countries, production soon became delocalized: this period is known as the *Digital economy.* The professional profile was a very specialized engineer with deep technical and scientific knowledge, without the transversal skills related to problem solving capacity, communication skills; this limit had been the greatest threat to profession sustainability in itself. Nowadays with the world crisis, increasingly attention to the environment and employment sustainability is moving the world towards a new economical paradigm: the *Sustainable Knowledge Society.* Future products will be rigorously designed to be environmentally friendly, green and clean; they will be related to the ambitious future challenges that require a synergic approach in the integration of diverse technical-scientific knowledge areas. The limit of the specialized and vertical engineer of the last decades should leave a place for an interdisciplinary approach, which is indispensable for overcoming the complex social, technological and economic challenges of society. The next generation of manufacturing engineer will design sustainable products using innovative production systems; he/she will hold, in their hands, the pencil and paper of the twenty-first century, better known as information and communications technologies [28].

This is also true for the aerospace industry, which is affected by the paradigm of leaner, meaner and greener due to the constraints of environmental issues and resources [10].

3.2 Challenges for Manufacturing Engineering Education

In literature, many case studies have shown the differences among university curricula and the skills expected at industry level and the tentative measures to reduce this gap. More recently, Lerman [29] has pointed to the need for critical analysis of targeted skills in education programs. He asserted that programs that continue to assume a needed skill set based on the data from decades ago cannot compete in today's competitive business environment. The conclusion is that the skills required for a given market must be actively identified together with the industry in order to provide an occupation-focused education plan.

The Clemson University in South Carolina (USA) has developed a specific curriculum in Automotive Engineering because of the transition of the automotive manufacturing industry from a central technical focus to an integrated and globally distributed supply chain [30]. Recent research managed by the "Programme for University and Industry Interface" at the University of Limerick, Ireland (PUII), was charged with identifying key skills and competences required by individuals in SMEs to ensure the employability of the future generation [31]. The Institute CIM for Sustainable Innovation (ICIMSI), being part of the University of Applied Sciences and Arts of Southern Switzerland (SUPSI), has developed various initiatives in engineering education involving industrial partners in their strategy [32]. Besides these contributions, the results of a survey on Manufacturing Engineering Education emphasized the importance of a broad education that is able to create engineers who are both specialists and generalists [33].

Starting from these analyses, some emerging trends and challenges for manufacturing education are arising in terms of "who"—the profile for the next generation of manufacturing engineer; "what"—the new system for education in manufacturing and its contents—and "how"—the learning approaches and strategy needed to incentivize the paradigm shift (cf. Table 2).

Who: Profile

In the past, changes in technology and society affected the engineering profession and engineering education through the creation of new curricula and the introduction of new disciplines. Nowadays, the scenario of society has changed. Manufacturing engineers need to be technically proficient at their jobs and at the same time need to understand the economic and engineering implications of their decisions [33]. The engineer of the future should possess *strong analytical* skills like engineers of yesterday and he/she should exhibit *practical ingenuity*, *creativity* in terms of invention, innovation and thinking outside the box, *communication skills*, *business* and *management* skills, *leadership*, a *high ethical standard*, *professionalism*, *dynamism*, *agility*, *resilience*, *flexibility*, and *lifelong learning* [34]. The new engineer is thus a "T-shaped" person whose "vertical" domain specialization (the "I-shaped") is integrated by a set of horizontal strategic skills and competences referred to Business Management, Professional skills and Entrepreneurial attitudes. The new era focuses on the development of the *Integration Engineer,* able to analyze and make decisions with innate knowledge of the decisions' effect on aligned systems [30]. However, succeeding in the SKS requires the development of a new archetype of human capital that is able to address societal developments and innovations with a constant focus on the issues of entrepreneurship. Such a new profile has been defined as an *Entrepreneurial engineer* [35]. The *Entrepreneurial engineer* (EE) must be able to identify, acquire, develop, protect, and transfer technology, manage projects and develop new ideas, generating new technology-based opportunities, in order to create economic and social value. In fact, entrepreneurial knowledge and competences are, like never before, the fundamental engine for economic growth. Entrepreneurial skills can reduce the so-called "valley of death" gap between the technologies and the market. These capacities and skills should also be possessed by engineers specialized in manufacturing in order to face the issues of employment sustainability.

What: Content

The solutions to the big engineering problems will be addressed with an interdisciplinary approach that goes beyond one or more disciplines. Educators in manufacturing engineering appear to be conservative in the courses they offer, and they miss the necessary changes to reflect new industrial trends [36]. Miller [37] highlighted the problem of lack of the "real-world" preparation of new engineering graduates going into industry, identifying a number of factors contributing to the disparity. Curricula have traditionally been slow to respond to industry's needs, particularly in manufacturing programs. This misalignment is caused by the increasingly distance between the educational system and the industry environment and by the obsolescence of competences. Raju [12] proposed a set of manufacturing competences that are in line with *Curricula 2015*, a curricular model developed by the Manufacturing Education and Research community within the Society of Manufacturing Engineers (SME) [38]. Similar recommendations are reported by the *Global Education in Manufacturing* (GEM) project under the initiative of the Intelligent Manufacturing Systems (IMS) [39]. Strategic core knowledge areas are presented as the results of an analysis of industry requirements together with a survey of manufacturing curricula from primary

Table 2. Trends and future challenges for manufacturing education

Item	Trends	Challenges
Who: Profile	Manufacturing education needs to create a *"holistic" engineer* profile with a system perspective view.	The engineer of the future should possess *business and entrepreneurial capabilities* to succeed in the sustainable and knowledge society.
What: Content	Manufacturing education needs to adopt an *interdisciplinary approach* to overcome the traditional separations among the disciplines.	University needs to design and manage learning patterns to dynamically integrate different *areas* of specialization ranging from *business to technology management.*
How: Learning approach	Manufacturing education now has to go beyond the passive learning approach and to be *project and action oriented.*	University needs to rethink teaching and learning approaches to provide future engineers to proactively *manage complex problems and systems.*
How: Strategy	The education system has to move with respect to complex networks and symbiotic relationship and *integration among research, education and innovation.*	Manufacturing education can only benefit from *partnership and networking with the industrial context,* to overcome the separation between education and research.

universities in the world and include: Development of Extended Products, Digital Business along the Supply Chain, Manufacturing Resources and Life Cycle Management, Intelligent Manufacturing Systems Design, Enterprise and Product Modeling and Simulation, Innovation, Entrepreneurship, Manufacturing Resources and Life Cycle Management [2, 22]. Apart from technical skills and foundations in engineering, it is relevant how *information and communication technologies* (ICTs) are included within each topic, adding "the digital" component to the business, creating "the intelligence" for manufacturing system design and processes, supporting modeling, simulation and life cycle management. Additionally *innovation*, *entrepreneurship* and *practical experience* assume a strategic relevance, allowing the engineer of the future to proactively design innovative and high-technology systems to satisfy the market needs.

How: Learning approach
Manufacturing education has to go beyond the passive learning approach and to be project based and action oriented. The future engineers' capabilities should be developed in practices to satisfy proactively the competences required from the industrial practices. In addition to the transfer of the foundations of the engineering disciplines, the universities should involves their students in projects through hands-on practical experience in companies, aimed at the development of their problem solving capacity in the design and manufacturing of complex products [30]. Of primary importance is incorporating industrial internships in the field of study to provide practical knowledge and understanding that is not attainable in the classroom. This will require a profound knowledge of complex systems management, a holistic vision and an integrated approach to problem solving. The students should consider all the management and technical factors associated with the product development—even using simulation tools—taking into consideration the issues of environmental impact, sustainability, looking at the product life cycle and a simplified supply chain. The integration of technical and organizational needs is at the basis of the development of the next generation of engineers to serve the aerospace industry. The importance of collaborative learning methods and project-based activities (i.e., the integration of education with industrial or practical influences) to improve the technical and professional skills of engineering students has been highlighted by many scholars [40, 41]. In addition to these aspects, a Problem and Project-Based Learning (PBL) Approach is useful to motivate group creativity in engineering education [42]. Collaborative design tools such as those in the product lifecycle management (PLM) are emerging as a necessary approach for managing aerospace developmental information.

How: Strategy
The model of a *Teaching Factory* and a *Learning Factory* reduces the increasingly gap between the competence required by the manufacturing sector and the engineer profile as a product of our university [2]. The "Learning Factory" has the objective of promoting knowledge, competences and best practices for advanced industry, through a context-aware virtual factory for collaborative learning [43]. Moreover, the "Teaching Factory" has the objective of promoting a high added value knowledge-based, competitive and sustainable manufacturing industry [1] involving students in the issues of capacity planning, supply chain management, product design and virtual suppliers. The virtuous cooperation between research, education and innovation, known as the knowledge triangle [44], is the solution to creating a new context in which the innovative and sustainable manufacturing sectors will operate. The triad will develop an incredible ecosystem that is able to act directly on human capital from the perspective of a *lifelong learning approach.* Modern learning techniques attempt to compensate for some of the shortcomings suffered by more traditional approaches by including real-life industrial problems in the academic environment [42].

4. Research design

As an attempt to face the above-mentioned challenges, the case study of the "*Experiencing i-Design*" postgraduate education and research project is presented. The aim is to contribute pragmatically to the current debate on how to develop the next generation of competences for intelligent manufacturing in the aerospace industry.

4.1 Research questions and method

The case study aims to answer the following questions: a) Which are the competences, attitudes and skills *required by the next generation of manufacturing engineers? b) How to develop, in practice, these competences in a lifelong learning perspective?*

To thoroughly understand these questions and analyze the phenomenon, a qualitative research method based on a case study [45] is better able to address the workplace realities than large-scale quantitative methods [46]. It allows an emphasis on processes and meanings [47] that is essential for this study, investigating innovative processes to develop competences. In general, case studies are the preferred strategy when "how" or "why" questions are being posed, and when the focus is on a contemporary phenomenon within some real-life context. According to [48], the aim of case study research is to discover "grounded theory". The study was based on participant direct observation [45] that allowed a qualitative analysis of facts to be investigated. The research followed an inductive approach based on a gap between the literature and on the observation of the organizational practices, from which the general principles and solutions have been developed [49, 50]. Evidence has been found and collected directly from the authors, who were acting as education program coordinator, director of the faculty, teacher, and finally as participant of the postgraduate education and research project. This allowed us to delve deep into the processes that were activated and to gather a variety of perspectives about the research questions.

4.2 Context of the "Experiencing i-Design" case study

The challenges of developing new competences that are suitable to meet the requirements of Intelligent and Sustainable Manufacturing has been afforded in a two-year research and training program "*Experiencing i-Design*", aimed at developing ten skilled "entrepreneurial engineers" specializing in methodologies and ICTs supporting the collaborative design of a product in an aerospace value network. The project is a postgraduate program associated with a research project "i-Design Foundation" (iDF) focused on *ICTs for innovating the design of sustainable and knowledge-intensive products in the aerospace industry"*. It is partly founded by the Italian Ministry of Innovation and Scientific Research (MIUR). The "*Experiencing i-Design"* project has been launched and managed by Dhitech (the Italian High-Tech District located in the Apulia Region) to promote innovation and diffuse technology entrepreneurship for increasing the competitiveness of the region and has been carried out by University of Salento (Italy) in collaboration with two Italian aerospace firms involved in the aero-engine and airframe businesses respectively (Avio SpA and Alenia Aermacchi). There were ten people in the program, engineering graduates (with specializations in manufacturing, automation, computer science, management and electronics); it had a total duration of two years (3840 hours), full time and started on January 2010, including the phase for the design and launch of the education activities. Three hundred and fifty-five applications were received for participation in the selection process for the ten available places. More than 35 professors were involved in the delivery of specialized seminars; there were academic professors but also managers or vice presidents. For each student one academic and industrial tutor were appointed to monitor and reinforce his/her activities on the project work. There were two members of staff to support the management and the organization of all the activities.

4.3 Data collection

Data were collected during the delivery of the "*Experiencing i-Design"* project from January 2010 till May 2012.

Data sources for this case study analysis included the following:

- Extensive semi-structured interviews with ten students and 35 faculty members and the Steering committee. The faculty explained their perceptions of the interdisciplinary features of the program in addition to the knowledge they expected all students in the program to master. The Steering committee, composed also of managers and vice presidents of companies, expressed its needs in terms of the competences needed to be developed in students to operate in their projects. Unstructured feedback collected by the program coordinator weekly from students completed the methodology. Moreover, they shared with the student focus group specific problems relating to the content organization of the program or the emerging knowledge needs according to the industrial requirements, completing the data collection.
- Field-based observations of the education experiences in action. The authors of the papers were involved in the case study as Program coordinator, President of the District and finally as participants of the program. This allowed them to take into consideration the different perspectives of the case study.
- Analysis of the Official documentations, including the required deliverables produced by students and reports about the project, the design of the education program and official communications of the program.
- Students' assessment was organized into:
  - *individual students' pre-assessment and post-assessment* obtained through surveys conducted by structured questionnaires filled in at the end of each Learning Module;
  - *students' group assessment,* conducted through the evaluation of work focused especially on case study analysis and the presentation for the learning modules related to Business Management. Each workgroup was evaluated by the teachers according to the contents elaborated during the classroom's discussion and to the analysis of the case study, as well as to the

communications skills of the group presentation. As for the content, the criteria used were the relevance of the analyzed topics, the degree of depth, the quality of the concluding remarks and the lessons learned; whereas for the group presentation, the aspects considered were the clarity and effectiveness of the talk, time management and question handling capabilities;

– *students' anonymous overall evaluation of the learning program* (mentor efficacy, learning strategy and learning content, collaboration), carried out through structured questionnaires with 22 statements, filled in by the students to express their feedback, suggestions and comments. Questions regarding the formal classroom curricula, research practices, collaboration during the classroom activities and the administration of such an interdisciplinary program were contained in the survey, which was collected monthly;
– *students' assessment of the achievement of the project work* objectives, realized by academic and industrial tutors.

The respondents included faculty, president of the *Dhitech*, administrative staff, the steering committee of the project and the program director of the *Experiencing i-Design program.* Whereas the direct observation and the feedback-capture sessions generated a researcher-mediated perspective of the phenomenon, the evaluation forms and written documents allowed a counterbalance to such views.

4.4 Data analysis

The inherently interrelated nature of the qualitative research process means that "data analysis" is not a process reserved for the end of data collection, but rather an ongoing, continually evolving process. We employed an inductive analytic approach [51, 52] informed by previous research on engineer innovative profiles, curriculum content, learning strategy and an approach that allowed us to search for patterns of meaning in the data collected. The frames of analysis related to these research areas were identified early in the research study. The *student interview protocol* focused on experiences in the core (formal) curriculum and activities in the research laboratory realized with peers and hybrid faculty composed of academic and industrial representatives. *Faculty interview protocol* included the innovative learning methodology adopted to deliver business and entrepreneurship content for engineers and the general experiences of teaching business and entrepreneurship to engineers. After each interview, we analyzed the transcripts to identify important concepts. Data drawn from interview transcripts were broken down into discrete codes. Systematic comparison across the various codes focused on similarities and differences within the data. This comparison resulted in themes by which findings, discussions and conclusions were organized. Students and faculty provided feedback on the development of emergent themes and categories, which contributed to the trustworthiness of the data. As for the *students' anonymous overall evaluation of the learning program, the* students gave their feedback about their relationships with teachers/tutors, the contents, the level of collaboration and interaction, and the educational strategy, for each learning module attended. A list of 22 statements, which formed the core of the survey, was prepared. The students were asked to express their opinion on a five-point Likert scale, checking 1 if their perceived judge was Very Low, 2 if Low, 3 if Medium, 4 if High, and 5 if their perceived judgment was Very High. The survey was anonymous. The choice of adopting a single-item measure minimizes respondent refusal, reduces the cost of data collection and data processing, and avoids common methods' bias. A questionnaire was filled in for each learning module and learning experience developed by the students. Data were collected and analyzed monthly.

Moreover, the assessment of students' performance related to group work, project work and to the individual performances allowed us to measure the impact of the innovative approach that was adopted to developing competence in intelligent manufacturing. The faculty was asked to express their opinion on a five-point Likert scale, 1 in the case of insufficient work and 5 in the case of good work. Ad hoc criteria were chosen to assess the quality of contents, the accuracy of the work, the quality of the references, the goal attainment of the work group, individual exercises and project work. The average score of the students' assessment was 4.3 points out of 5. This data is also confirmed by the positive comments and feedbacks provided by the students and reported in the "Discussion" section.

The next sections describe in detail the results of the data analysis in order to illustrate how the challenges and trends of the manufacturing engineering education have been afforded in the context of the *Experiencing i-Design* case study. Discussions and avenues for future research will conclude the paper.

5. Findings: Creating entrepreneurial engineers for intelligent manufacturing

The basic principles of the innovative approaches to human capital creation adopted by the Technologi-

Table 3. Trends and challenges in the "*Experiencing i-Design*" case study

Item	Trend	. . . in *Experiencing i-Design* project
Who: Profile	Manufacturing education needs to create a "holistic" engineer profile with a system perspective view.	1. The Innovator/ Entrepreneurial engineer specializing in *ICTs for design of sustainable and knowledge-intensive products in the aerospace industry*.
What: Content	Manufacturing education needs to adopt an interdisciplinary approach to overcome the traditional separation among the disciplines.	2. An interdisciplinary approach as a knowledge creation process for Intelligent Manufacturing.
How: Learning approach	Manufacturing education now has to go beyond the passive learning approach and to be practical and action oriented.	3. A competence development approach realized through a project-based learning strategy as a high profile human capital creation process.
How: Strategy	The education system has to move with respect to complex networks and symbiotic relationship among research, education and innovation.	4. Networking of Academic and Industrial Partners working together in a "Teaching Factory" and a "Learning factory".

cal District *Dhitech* and University of Salento are illustrated in Table 3. In particular, the findings derived from the data analysis are grouped into professional profile ("who"), knowledge contents ("what"), learning approach and strategy ("how"), adopted for the creation of the next generation of engineers in the field of intelligent manufacturing.

Who: Professional profile

The *Experiencing i-Design* project aims to develop a new professional profile, the Entrepreneurial engineer specializing in *ICTs for innovating the design of sustainable and knowledge-intensive products in the aerospace industry,* able to: a) design and implement complex and integrated systems to manage the product life cycle in the aerospace industry; and b) to manage the product configuration in the aerospace value network. This professional profile is characterized by four areas of competences and skills in which the technical competences are complemented by competence in business management, attitudes to technology entrepreneurship and professional skills (cf. Table 4).

What: Contents—Program knowledge architecture

An interdisciplinary approach characterizes the "*Experiencing i-Design"* program architecture. Knowledge coevolves with the context of application, dynamically and beyond the contribution of any single discipline. The focus is an integrated offering of various disciplinary fields, through integrative modular program design, rather than offering semester length courses in particular specialist topics [53]. The curriculum is structured in the building blocks illustrated in Table 5, coherent with the four competences areas of the professional profile (Business Management, Technological Entrepreneurship, Professional skills and ICTs for Sustainable Manufacturing). The curriculum has been designed according to the industry needs

Table 4. The competence framework profile of an Entrepreneurial Engineer in Intelligent Manufacturing

Business competences	Entrepreneurship attitudes	Professional skills	Technical competences on ICTs for Intelligent manufacturing
Develop a holistic vision of business	Strategic thinking	Systemic and holistic thinking	Design of informative systems supporting collaboration in PLM
Understand the socio-economic phenomenon	Opportunity and risk identification	Analysis and synthesis capacity	Implementation of systems supporting collaboration in PLM
Analyze the competitive scenario	Risk taking and proactivity	Leadership	Development of knowledge strategy for PLM
Analyzing and modeling of business processes	Goal orientation	Communication	Design of technological architecture for KM in PLM
Design the business transformation	Turning problems into opportunities	Project and program management	Management of PLM
Business management and development	Autonomy	Collaboration and international approach	Configuration management for extended products
Business plan development	Capacity to afford uncertainty and complexity	Practical ingenuity	Development of applications for design in CAx
Evaluating the multi-stakeholders business performance	Motivation, empowerment	Creativity	ICTs for NPD in aerospace value network
	Problem solving	Vision and foresight	Extended product design

Table 5. The *Experiencing i-Design* curriculum knowledge architecture

Program building blocks			
MA1. Technological Entrepreneurship	**MA2. R&D Project Management**	**MA3. Business Management**	**MA4. ICTs for Intelligent Manufacturing**
LM1.1 Technology foresight and global technology breakthrough LM1.2 High tech entrepreneurship for scientist and engineers LM1.3 Intellectual property protection LM1.4 Finance for technological entrepreneurship LM1.5 Design and launch the technology venture LM1.5 Strategy for technology start up	LM2.1 Project management LM2.2 National and International funding LM2.3 R&D project management LM2.4 Innovation management LM2.5 Leadership and communication LM2.6 Team building	LM3.1 Holistic approach to business management LM3.2 Measuring business performance LM3.3 Business planning LM3.4 Knowledge management LM3.5 Business process management LM3.6 New product development LM3.7 Operation management Aerospace industry trends	LM4.1 Intelligent manufacturing systems design LM4.2 Intelligent manufacturing processes LM4.3 Enterprise and product modeling and simulation LM4.4 Extended product life cycle management LM4.5 NPD in Aerospace industry LM4.6 ICTs for NPD in aerospace

expressed by the IDF partner companies' representatives, including general managers, IT Director and CEOs. Knowledge areas have been split as follows: 50% was related to ICTs for Intelligent and Sustainable Manufacturing; 15% was related to Business Management; 20% was related to Technological Entrepreneurship and, finally, 15% was related to Professional Skills developed through specialized seminars with a psychologist and researchers. Each building block (MA) was divided into Learning modules (LM) that were developed not in a sequential way, but allowing the right alternation between the developed courses. All modules were compulsory and common for all the students in order to allow the development of such competences. The personalization of the learning patterns was allowed though the project work activities developed within the research laboratories of companies, where people learned and immediately applied what they learned, performing specific project tasks in collaboration with private and public stakeholders.

The knowledge architecture of the project has been developed in the following learning phases during which the learning modules have been organized:

- Phase 1 (3 months duration): Explore the Global Business and Engineering scenarios. During this phase the participants were involved in work group activities finalized to understand the global scenarios, the convergence of technologies (nano–bio–info and cogno), the evolution dynamic of the human capital to succeed in the SKS, the international trends related to the engineer's profile. These explorations provided the enabling conditions to identify the area of potential technological opportunities and the rationale of the entrepreneurship process. Learning methods included mainly case studies used to describe real or hypothetical situations, pertinent to their learning experience, in which students were asked to identify/solve a problem.
- Phase 2 (3 months duration): Understand the extended enterprise management in the aerospace value network. This phase has been devoted to the acquisition of competences related to business management. An action learning methodology allowed students to acquire the main concepts through seminars held by outstanding managers coming from the industrial world and professors coming from international universities. Real case studies and the interactions with experts and company managers allowed students to look in depth into the analysis of the aerospace supply chain and collaboration for the new product development. Moreover, the exchange of ideas, sharing of experiences and defending individual positions allowed students to develop their critical thinking.
- Phase 3 (3 months duration): Technology Business Venture Planning. The design and implementation of technology entrepreneurship attitudes needed a valid roadmap and method. A set of scientific insights and market perspectives given by domain experts and researchers coming from international renowned institutes, business angels and investors, provide the "Risky Business Venture" and stimuli needed to activate the entrepreneurial process. The learning method mainly adopted has been the role play. The students have been involved in practicing on real situations to include the following rules, decision making, team working and attaining a

goal. The co-presence of public and private stakeholders contributed significantly to assessing the feasibility of business ideas, ensured market acceptability, and finalizing the entire business model.

- Phase 4 (3 months duration): Design and use of IT technologies for collaborative new product development in the aerospace value network. Technical track courses on ICTs for collaborative new product development have been presented to students using several product platforms to manage the product data. In particular, the main technologies for PLM (Product Life cycle Management) have been introduced to the students using a "training on the job" methodology. Automation, supply chain and intelligent manufacturing concepts have been illustrated, and all concepts reinforced with industry interaction (tour or in-class discussion) or simulations, including a computer-based scaled-down representation of real-life situations that allowed students to practice in safe environments.
- Phase 5 (12 months duration in mobility): Development of research and innovation projects in the research laboratories of companies. The concepts learned during the overall learning modules have been applied in company research laboratories where students were introduced with an open-ended design problem, spanning multiple domains of specialization. The emphasis was on global IT system design to support the knowledge security exchange during the NPD in aerospace. During this phase, participants contributed to developing competences defined in collaboration with the companies partners of the iDF projects in the domain of: PLM data model, IT solutions for Engineering Collaboration, Evaluation and selection of a Test Data Management System using a Fuzzy Extended AHP (Analytic Hierarchy Process) method, PLM—SDLC: System Development Life Cycle, PLM—Product Structure & Configuration Management, Platform Management System and Electronic Engine Control, Product requirements for Intelligent manufacturing.

How: Learning approach—Competence development

A *competence development approach* has been taken in the context of the research projects and it has provided learners with the support to interact with successful entrepreneurs, outstanding researchers and international experts who were the animators and the mentors of the overall learning experiences [54]. The work of the projects in which the students were involved was designed in collaboration with the public and private stakeholders partners of the education project providing the real competence needs of the companies. They become the contexts in which talented people and researchers learned and developed new competences, experienced theoretical concepts, carried out research, experimented, interacted with active end-users, prototyped and tested innovative concepts and, finally, innovated products and services as well as processes. The *projects* were organized in mobility among the research laboratory of Avio SpA, Alenia Aermacchi and University of Salento in Italy. The project activities represented 50% of the total program time and were monitored by an academic and an industrial tutor to guarantee the complementarity between academic research and industrial applications.

How: Strategy—Industry focus

Networking of Academic and Industrial Partners working together in a "Teaching Factory" and a "Learning Factory" acted as "incubators" of Entrepreneurial Engineers [35], allowing the creation of scientific, managerial and entrepreneurial backgrounds for launching new technology-based start-ups, research spin-offs and innovative spin-outs.

Collaborative partnerships between the industry and university enhanced the engineering curriculum and offered a complementary learning experience for students [55]. A Steering Committee operated like a hybrid faculty. It comprised eighteen academic researchers and professors, managers and entrepreneurs, and representatives of public institutions and it guided and provided strategic direction to the education activities in order to guarantee the complementarities between the scientific knowledge developed in the academic context and the experiments. Periodically, all the students' results were presented to the steering committee, which provided new insights and useful directions to the learning patterns according to the industry's needs. The heavy industrial involvement in the program was accomplished not only through course development input, but also by direct contributions to Learning Modules in the forms of guest lectures, sponsored factory tours and in-kind equipment and software donations. In addition, the industrial collaborators provided real-life case studies for the students to analyze and propose solutions; such activities included past and current challenges within the aerospace industry. Finally, an aligned intelligent manufacturing research plan was carried out with industrially-sponsored projects.

6. Discussions

The first results of the two years experimentation of the "*Experiencing i-Design*" projects shows the valuable approach adopted to develop high value human capital, demonstrated by the satisfaction shown by the students and others stakeholders involved in the projects (companies, managers and entrepreneurs, international expert and steering committee). In the learning experiences developed by the *Dhitech* for managing the *Experiencing i-Design* project, the industrial learning activities focused on the provision of engineering competences for Intelligent and Sustainable Manufacturing, allowed the implementation of innovative aspects. This framework emphasizes the role of industrial learning as a key enabler for "bridging" the gap between industrial research and product/process innovation. As regards the innovative profile, at the beginning of the project not all the students realized the importance of developing entrepreneurial attitudes in such learning projects focused on manufacturing. Most of them felt the necessity to acquire more specialist competences to be able to operate in an industrial context instead of focusing on learning modules related to understanding the global business scenario, technological trends and the entrepreneurial process. Their opinion changed when they had the opportunity to spend a period of time in the research laboratory of a company . . ." *the attitudes such as risk taking, opportunities generation, entrepreneurial mindset, problem solving are really relevant especially in the context of business development when identifying opportunities for new product development".*

The key features of the competence development process adopted in the project are coherent with the lifelong learning approach, as conceived by OECD [56]. First, it offers a systemic view of learning covering the whole lifecycle and comprising all forms of formal and informal learning, integrating education and research. Students were able to understand the deep strategic issues for the aerospace companies as they had been involved in their laboratories working on real projects for the PLM. As affirmed by one student . . . "*The alternation between seminars held at University by professors and managers and projects work activities in companies' research laboratories allowed me to go in deep in some knowledge to be applied in practice*". Secondly, it emphasizes the centrality of the learner and the need for personalization of the learning patterns in the research laboratory to cater for the diversity of learner needs in terms of background and previous professional experiences. Students were involved in individual project work covering the strategic area of the companies. Each of them was involved in a work package aimed at finalizing the activities of the PLM Teamcenter. . . ." The deep involvement in the team of Alenia working on Teamcenter Engineering Data model allowed me to acquire more knowledge on topics studied during the seminars related to Product Technologies" affirmed one student. Thirdly, the approach emphasizes the motivation to learn, and draws attention to self-paced and self-directed learning as especially occurring in the first three phases of the knowledge architecture. The learning strategy adopted in the experimentation, combining action learning, project-based learning, apprenticeships, combination of on the job training with classroom instruction, and simulation tools, are common learning processes for highly skilled manufacturing. Aerospace companies contributed with knowledge coming from their industrial experiences and practices, while academia contributed with their scientific excellence. As stated by another student ". . . *in the experiential workplace I have been assessed by my academic and companies' supervisors on the basis of the competences acquired during the development of project' deliverables. The Program coordinators asked me and my colleagues for feedback for curricular change that have been taken into consideration to address our needs*". The research output developed within the industrial projects could be concurrently fed back to industry and academia. At the end of the project, main advancements in industry competences have been realized in the area of Product life cycle management with reference to Product Structure & Configuration Management, PLM System Development Life Cycle, Virtual and Physical Prototyping & Simulation.

At the end of the training program, two main technological ideas have been identified and analyzed to transform them into an opportunity for an innovative "technology" product. After a meeting with two business angels and venture capitalists, one business plan was drafted to develop innovative technologies for product data management in the aerospace industry. Six months before the end of the education program, 40% of students have been hired by the companies' partners of the project as a result of the competences acquired while working in their research laboratory. Moreover, another student was hired from one of the company partners of the project. This demonstrates that today knowledge should be acquired by manufacturing engineers during the development of capstone projects in companies, making the competences acquired immediately more usable to industry.

The strategic role of the Teaching Factory as the suitable learning environment in which research and education are strictly integrated to assist engineers and workers to keep up with the rapid pace of changes, can be highlighted as the most important requirement for successful initiatives of such complex human capital profile development. The cooperation between the university, industry, government and the community can help achieve the primary missions of the university while better meeting the needs of its stakeholders [57]. In the triple-helix concept [58] the university has a "third mission" beyond education and research, i.e. the activation of entrepreneurial dynamics. This implies valorizing the results of research and giving rise to public–private stakeholder networks to promote economic development and social wealth. The entrepreneurial university model becomes the center of economic development, knowledge creation and diffusion in both advanced industrial and developing societies [58].

7. Conclusions

This paper raises the importance of introducing radical innovations in manufacturing engineering education in order to create the next generation of competences that are suitable to meet the challenges of Intelligent and Sustainable Manufacturing in the aerospace industry. The requirements of Manufacturing Engineering Education need to be better applied in the new context in which the integration between the university and industrial practices allow the student to bridge the gap between the needs of the companies and the knowledge developed within academia. The findings of the case study demonstrate that: (a) Manufacturing education needs to create a "*holistic" engineers' profile* with a system perspective view. Such a profile has been called an *Entrepreneurial engineer* specialized in "ICTs for design of sustainable and knowledge-intensive products in the aerospace industry". (b) Manufacturing *curriculum contents* need to be based on an interdisciplinary approach to overcome the traditional separation among the disciplines related to intelligent manufacturing. (c) The most suitable *Learning approach* is a competence development process realized through a project-based learning strategy. Finally, (d) The education system has to move versus symbiotic relationship between research, education and innovation.

A set of guiding principles useful to design innovative learning experiences can be drawn from the results of the *Experiencing i-Design* project, described in the paper: 1) a focus on a learning and research environment (such as research laboratories, industrial hand-on projects) rather than a teaching environment; 2) a major emphasis on industrial needs with projects and the ongoing involvement of students in company research laboratories; 3) the support of participants to develop the capabilities to meet the challenges of future manufacturing, developing a holistic approach and a system integration perspective; 4) the creation in future engineers of the necessary attitude for entrepreneurship to be able to transform technological opportunity into economic and social value; and 5) the development of the soft and professional skills necessary to design and manage complex projects.

Future education in manufacturing strategy must build engineering competence by providing a learning atmosphere supporting the cooperation between academia and industry.

From a theory perspective, the identification of such an innovative profile, called an "Entrepreneurial engineer", the learning approach and strategy, and the learning contents for developing the next generation of competences for Intelligent and Sustainable Manufacturing is an attempt to advance the discussion on models and strategies for manufacturing education in engineering contexts. It incorporates the need to expand the vision of entrepreneurial attitudes to developing economic and social value. For practitioners, the paper provides evidence of how to develop an innovative engineer profile specializing in ICTs for Intelligent Manufacturing in the aerospace industry, designing a curriculum that virtuously integrates the building blocks of Business Management, R&D management with ICTs for Intelligent Manufacturing, and introduces elements of Technological Entrepreneurship within training programs grounded in the engineering domain. The limitations of the study are in the specific context of application, i.e. the industrial manufacturing engineering field, and that the student sample was small in size. Future research will be dedicated to assessing the effectiveness of the approach for applications in other engineering domains, such as chemical engineering, infrastructure engineering, bioengineering and computer science engineering.

References

1. G. Chryssolouris and D. Mavrikios, Education for Next Generation Manufacturing, ftp://ftp.cordis.europa.eu/pub/ims/docs/gc_to_ims visionforum2006-paper.pdf, Accessed 14 November 2011.
2. D. O'Sullivan, A. Rolstadås and E. Filos, Global education in manufacturing strategy, *Journal of Intelligent Manufacturing*, **22**(5), 2011, pp. 663–674.
3. European Commission, Europe 2020: A European Strategy for smart, sustainable and inclusive growth, Brussels, EU, 2010.
4. F. Jovane, E. Westkämper and D. Williams. *The ManuFuture Road: Towards Competitive and Sustainable High-Adding-Value Manufacturing*, Springer, Berlin, 2008.
5. E. Fontela, *Toward a Sustainable Knowledge Society*, Reports of Expert Group in Key Technologies for Europe, Brusselles, EU, 2005.
6. E. Fontela, Beyond the Lisbon Strategy: Information Technologies for the Sustainable Knowledge Society, *The Future of the Information Society in Europe: Contributions to the Debate*, Brussels, EU, 2006, pp. 93–110.

7. M. Abramovici and E. Filos, Industrial integration of ICT: opportunities for international research cooperation under the IMS scheme, *Journal of Intelligent Manufacturing*, **22**(5), 2011, pp. 717–724.
8. NAE—Committee on Facilitating Interdisciplinary Research, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, *Facilitating Interdisciplinary Research*. National Academy Press, Washington, 2004.
9. NAE—National Academy of Engineering, www.engineeringchallenges.org, Accessed 16 November 2011.
10. J. H. McMasters, Thoughts on the engineer of 2020—An early 21st century (aerospace) perspective, Boeing Corporation, Chicago, 2006.
11. D. Mavrikios, N. Papakostas, D. Mourtzis and G. Chryssolouris, On industrial learning and training for the factories of the future: a conceptual, cognitive and technology framework, *Journal of Intelligent Manufacturing*, 2011, http://dx.doi.org/10.1007/s10845-011-0590-9.
12. V. Raju, Role of Education in the Future of Manufacturing, 2009, http://www.meteconline.org/resources/role_of_ed._in_the_future_of_manufacturing.pdf.
13. I. S. Jawahir, K. E. Rouch, O. W. Dillon, L. Holloway and A. Hall, Design for Sustainability (DFS): New challenges in developing and implementing a curriculum for next generation design and manufacturing engineers, *International Journal of Engineering Education*, **23**(6), 2007, pp. 1053–1064.
14. N. A. Ashford, Major challenges to engineering education for sustainable development, *International Journal of Sustainability in Higher Education*, **3**(4), 2004, pp. 239–250.
15. Factory of the future, factories of the future public–private partnership strategic multi-annual roadmap, Brussels, EU, 2010.
16. A. Rolstadås, IMS 2020 roadmap for sustainable manufacturing research, *Proceedings from the IMS2020 Summer School on Sustainable Manufacturing*, Zurich, Switzerland, 2006.
17. IMS2020, Roadmap on innovation, competence development and education, IMS 2020 Supporting Global Research for IMS2020 Vision, 2010.
18. D. Maxwell, W. Sheate and R. Van der Volst, Functional and systems aspects of the sustainable product and service development approach for industry, *Journal of Cleaner Production*, **14**(17), 2006, pp. 1466–1479.
19. M. Abramovici, Manufacturing innovation growth engines: a European perspective. *Proceedings of the IMS Vision Forum 2006*, Seoul, Korea, 12–13 April 2006, pp. 98–114.
20. eBusiness Watch, *ICT and Electronic Business in the Aeronautics Industry*, The European eBusiness Market Watch, 2005.
21. M. Lazoi, F. Ceci, A. Corallo and G. Secundo, Collaboration in an aerospace SMEs cluster: innovation and ICT dynamics, *International Journal of Innovation and Technology Management*, **8**(3), 2011, pp. 393–414.
22. A. Rolstadås and S. Dolinšek, Global education in manufacturing: basic framework, industrial survey and possible implementation, *International Research Journal on Managing Global Transition*, **4**(3), 2006, pp. 261–278.
23. S. Dolinšek, A. Starcic and J. Kopac, Education for manufacturing—from discipline to the competency based approach, *Proceedings of International IMS Forum 2004*, Como, Italy, pp. 1354–1362.
24. G. Cerinšek and S. Dolinšek, In a search for competent engineers . . . competence framework in the field of sustainable manufacturing, *Proceeding of IEEE Global Engineering Education Conference (EDUCON)—"Learning Environments and Ecosystems in Engineering Education"*, Amman, Jordan, April 4–6 2010, 2011, pp. 865–870.
25. G. Chryssolouris and D. Mourtzis, Challenges for manufacturing education, *In Proceedings of CIMEC 2008*, CIRP International Manufacturing Engineering Education Conference, Nantes, France, October 2008.
26. J. Y. Shen, D. Dunn and Y. Shen, Challenges facing US manufacturing and strategies, *Journal of Industrial Technology,* **23**(2), 2007, pp. 1–10.
27. Z. Tadmor, Redefining engineering disciplines for the twenty-first century, *The Bridge*, National Academy of Engineering, **36**(2), 2006, pp. 33–35.
28. C. M. Vest, Educating engineers for 2020 and beyond, *The Bridge*, National Academy of Engineering, **36**(2), 2006, pp. 38–44.
29. R. I. Lerman, Building a wider skills net for workers: A range of skills beyond conventional schooling are critical to success in the job market, and new educational approaches should reflect these non cognitive skills and occupational qualifications, *Issues in Science and Technology*, **24**(4), 2008, pp. 65–72.
30. L. Mears, M. Omar and T. Kurfess, Automotive engineering curriculum development: case study for Clemson University, *Journal of Intelligent Manufacturing*, **22**(5), 2011, pp. 693–708.
31. I. Hunt, E. O. Brien, D. Tormey, S. Alexander, E. Mc Quade and M. Hennessy, Educational programmes for future employability of graduates in SMEs, *Journal of Intelligent Manufacturing*, 2011, doi: 10.1007/s10845-011-0519-3.
32. C. Boër, L. Canetta, P. Pedrazzoli and C. Radaelli, Academic–industrial international cooperations for engineering education, *Journal of Intelligent Manufacturing*, 2011, doi:10.1007/s10845-011-0545-1.
33. G. Mason, Results of an industry survey on manufacturing engineering and manufacturing engineering education, *Journal of Engineering Education,* **87**(3), 1998, pp. 211–214.
34. NAE—National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*, National Academy Press, Washington, 2004.
35. G. Elia, A. Margherita, G. Secundo and K. Moustaghfir, An "activation" process for entrepreneurial engineering education: the model and application, *Journal of Enterprising Culture*, **19**(2), 2011, pp. 147–168.
36. D. O'Sullivan, J. Browne and L. Dooley, Manufacturing engineer or architect, *Proceedings of the International Conference on Issues and Challenges of Manufacturing Education*, University of Patras, Greece, 1997.
37. M. H. Miller, Industry internships as a tool for curriculum development, ASEE, Seattle, Washington DC, 1998.
38. H. Jack, R. Mott, V. Raju, G. Conkol, M. Stratton, P. Wladrop, K. Wosczyna-Birch and S. Bates, *Curricula 2015—A Four Year Strategic Plan for Manufacturing Education*, Society of Manufacturing Engineers (SME), 2011.
39. A. Rolstadås and B. Moseng, Global education in manufacturing GEM. CIRP International Manufacturing, Education Conference CIMEC 2002, 2002, http://ctt1.transfer.edu.pl/gem/Global%20Education%20in%20Manufacturing.pdf.
40. D. Guerra-Zubiaga, H. Elizalde, C. I. Rivera, R. Morales-Menendez and R. Ramirez, Product life-cycle management tools and collaborative tools applied to an automotive case study, *The International Journal of Engineering Education*, **24**(2), 2008, pp. 266–273.
41. N. Fang, Improving engineering students' technical and professional skills through project-based active and collaborative learning, *The International Journal of Engineering Education*, **28**(1), 2012, pp. 26–36.
42. C. Zhou, A. Kolmos and J. D. Nielsen, A Problem and Project-Based Learning (PBL) approach to motivate group creativity in engineering education, *The International Journal of Engineering Education*, **28**(1), 2012, pp. 3–16.
43. C. Constantinescu, V. Hummel and E. Westkämper, collaborative learning factory for advanced industrial engineering, *LEAF aIE, International Seminar on Manufacturing Systems*, Ljubljana, Slovenia, June 2006.
44. E. Westkämper, The potential of regional manufacturing networks in Europe. Presentation at *ManuFuture Conference*, St. Etienne, France, December 8–9, 2008.
45. R. K. Yin, *Case Study Research: Design and Methods*, 3rd edn, Sage Publications, Thousand Oaks, CA, 2003.
46. M. Kodama, Knowledge creation through networked strategic communities case studies on new product development in Japanese companies, *Long Range Planning,* **38**(1), 2005, pp. 27–49.
47. N. K. Denzin and Y. S. Lincoln, *Handbook of Qualitative Research*, Sage Publications, Thousand Oaks, CA, 1994.
48. B. G. Glaser and A. L. Strauss, *The Discovery of Grounded*

Theory: Strategies For Qualitative Research, Aldine, Chicago, 1967.
49. A. Bryman and E. Bell, *Business Research Methods*, Oxford University Press, Oxford, 2007.
50. D. Thomas, A general inductive approach for analyzing qualitative evaluation data, *American Journal of valuation*, **27**(2), 2006, pp. 237–246.
51. J. Cresswell, *Research Design: Qualitative and Quantitative Approaches*, Sage Publications, Thousand Oaks, 1994.
52. A. Strauss and J. Corbin, *Basics of qualitative research: Techniques and procedures for developing grounded theory,* 2nd edn, Sage, Thousand Oaks, CA, 1998.
53. G. Secundo and G. Passiante, An innovative approach to creating business leaders: evidence from a case study. *International Journal in Management in Education*, **1**(3), 2007, pp. 214–230.
54. I. F. Oskam, T-shaped engineers for interdisciplinary innovation: an attractive perspective for young people as well as a must for innovative organizations, 2008, http://www.sefi.be/wp content/abstracts2009/Oskam.pdf.
55. A. See, O.S. Geok C. Nair and J. Lai, Bilateral Collaborative Partnership—Joint Industry/University Perspective, *The International Journal of Engineering Education*, 23(5), 2007, pp. 973–980.
56. OECD, Lifelong learning. Policy brief, http://www.oecd.org/dataoecd/17/11/29478789.pdf, 2004.
57. R. M. Counce, P. R. Bienkowski, S. P. Singh, J. D. Randolph, R. T. Jubin, B. E. Lewis, L. C. Markel, R. A. Reimer, B. E. Murphree, R. A. Heckrotte and B. W. Anderson, University partnerships with industry and government, *The International Journal of Engineering Education*, **24**(3), 2008, pp. 480–487.
58. H. Etzkowitz and L. Leydesdorff, The dynamics of innovation: from national systems and 'Mode 2' to a triple helix of University–industry–government relations, *Research Policy*, **29**(2), 2000, pp. 109–123.

Giustina Secundo is Assistant Professor and Senior Researcher in Management Engineering at University of Salento (Italy). Her research is characterized by a cross-disciplinary focus, with a major interest towards areas such as human capital creation, management development and knowledge management in new product development. These research activities have been documented in more than 70 publications, including book chapters and publications in international journals and conference proceedings. Currently, she manages a research and education project focused on hi-tech entrepreneurship and entrepreneurial engineering in collaboration with leading Italian aerospace companies and Dhitech (an Italian High-Tech District located in Apulia Region). In addition, she leads a research project focused on "Methodologies and Technologies supporting collaboration in the new product development process in Aerospace Value Network" in collaboration with Italian aerospace companies. She is actively involved in other research projects, at national and international level, in collaboration with worldwide leading companies, universities and research centers on the topics of Technology Innovation Management. She has been a lecturer of Innovation Management and Technological Entrepreneurship at the Faculty of Engineering of the University of Salento since 2001.

Giuseppina Passiante is Full Professor of Innovation Management at the Department of Innovation Engineering of the University of Salento (Italy). She is coordinator of the research area on Open Networked Business Management at the Euro-Mediterranean Incubator—University of Salento (Italy). Currently her research focus is on the topics related to virtual clusters, digital business ecosystems, e-business adoption in the SMEs, communities of knowledge practice and technological entrepreneurship. She is also expert in the development of local systems, and complexity in economic systems. In these research fields she is the coordinator of many national and international research projects involving both public and private partners and she has published several papers. She is the coordinator of the Ph.D. program in Intelligent Management and she has been a lecturer on Innovation Management at the Faculty of Engineering of the University of Salento since 1997.

Aldo Romano is Emeritus Professor of Business and Management Engineering, Former President of Dhitech, a Technological District in the Apulia Region in Italy and former Director of the Euro-Mediterranean Incubator in Business Innovation Leadership of Scuola Superiore ISUFI at the University of Salento (Lecce, Italy). Aldo Romano's activities cover the general areas of Research in High Energy Physics at the Department of Physics at the University of Bologna and the University of Bari (Italy). He has participated in numerous scientific experiments at the European Organization for Nuclear Research (CERN) in Geneva. He has a scientific, cultural, and political commitment to the development of innovation, especially in the south of Italy. In 1981, as Visiting Professor at Stanford University (California, USA), he studied the phenomenon of Silicon Valley. This experience represented the basis for the foundation of the First Italian Scientific and Technological Park (Tecnopolis Novus Ortus) in 1984. He has a scientific and operative commitment to issues concerning Internet-enabled organizational changes, with special reference to the analysis of the "Digital Divide." This scientific activity has been documented in books, publications in international journals and leading conference proceedings. In acknowledgment of his scientific achievements, Aldo Romano has been awarded the Gold Medal of Merit for Culture, School and Arts by the President of the Italian Republic.

Pasquale Moliterni received both his B.Sc. in Computer Engineering and his M.Sc. in Systems and Control Engineering from the University of Pisa. During his university studies, he was a visiting scholar at the Technical University of Delft. In the last two years, he has been a research fellow at Dhitech S.c.a.r.l.—High-Tech Technological District (in Italy), where he attended the post-degree training program "Experiencing i-Design". He was part of the project's team *Turbine Control System Trainer* for naval applications at the Electronics & Electrical Systems Division (DEES) of Avio SpA (in Italy). He has also collaborated with senior researchers and professors of the Euro-Mediterranean Incubator in e-Business Management at the University of Salento (Italy) on the research topics of competence development for Intelligent Manufacturing System. Currently, he is working as a Systems and Control Engineer in the Electromechanical Department and Diagnostic Solutions for Railways Applications of MerMec SpA. His main research interests are in robotics, as well as ICTs and innovative technologies applied to education, knowledge and competence development.