IMS
2020

Roadmap on Innovation, Competence Development and Education

15 July 2010

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Acknowledgements

The consortium wish to thank the European Commission and, also, the Roadmapping Support Group listed below:

- Anci, Italy
- APS-Mechatronics, Germany
- Assoknowledge, Italy
- Barilla, Italy
- Base Protection, Italy
- BIBA (Bremer Institut für Produktion und Logistik GmbH), Germany
- BMW, Germany
- Bombardier, Switzerland
- Cambridge University, UK
- Cardiff University, UK
- CECIMO (European Committee for Cooperation of the Machine Tool Industries), EU
- Ceta Senai, Brazil
- Clariant, Switzerland
- Cranfield University, UK
- CSEM, Switzerland
- CSMT, Italy
- Daimler, Germany
- DIN, Germany
- Ecole Polytechnique Universitaire de Marseille, France
- FIDIA, Italy
- H3G SpA, Italy
- HEGAN, Spain
- Helsinki University of Technology, Finland
- Hilti, Liechtenstein
- Hong Kong University of Science and Technology, Hong Kong
- IBARMIA, Spain
- IBM, Italy
- ifak e.V. (Institut für Automation und Kommunikation), Germany
- Institute for Innovation and Development of University of Ljubljana (IRI UL), Slovenia
- Interlink Management Consultant, Australia
- ISVOR FIAT, Italy
- IT Partners Ltd, Bulgaria
- ITQ GmbH, Germany
- Jozef Stefan Institute, Slovenia
- KUHN Technology EOOD, Bulgaria
- KUHN Technology SRL, Romania
- Kühne+Nagel, Switzerland
- Kuleuven, Belgium
- Lappeenranta University of Technology, Finland
- LEIA Centro de Desarollo Tecnológico, Spain
- Loughborough University, UK

- Luleå University of Technology, Sweden
- Microelectronica, Romania
- MIT, US
- Nicolás Correa, Spain
- Norsk Industri, Norway
- Nottingham University, UK
- ONA Electroerosión, Spain
- Panství Bechyně a.s., Czech Republic
- Politecnico di Bari, Italy
- Prometeo , Italy
- Raufoss Technology & Industrial Management AS (RTIM), Norway
- Renault Consulting, Italy
- RMIT University, Australia
- SAP, Germany
- SCM Group , Italy
- SERCOBE, Spain
- Siemens, Germany
- Spiral Business Services Corp., Finland
- Stadler Stahlguss, Switzerland
- Swiss Association of Mechanical SME, Switzerland
- Tampere University of Technology, Finland
- Technical University of Berlin, Germany
- Tecnica, Italy
- Thales, France
- The Federation of Finnish Technology Industries (Techind), Finland
- Toolmakers cluster of Slovenia Zavod C-TCS Celje, Slovenia
- UCIMU, Italy
- UFRGS, Brazil
- Università di Bergamo, Italy
- University “Politehnica” of Bucarest, Romania
- VDI (The Association of German Engineers), Germany
- VDMA (Verband Deutscher Maschinen- und Anlagenbau - German Engineering Federation), Germany
- Wroclaw University of Technology
- WZL-RWTH Laboratory for Machine Tools and Production Engineering, Germany
- ZAYER, Spain
- ZENON, Greece
-

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1 Summary

The **IMS2020 Vision** describes a realistic and desirable future for manufacturing which can be achieved if the identified IMS2020 Research Topics and their supporting actions are put in place through international collaboration. The main elements of IMS2020 vision can be summarised as follows.

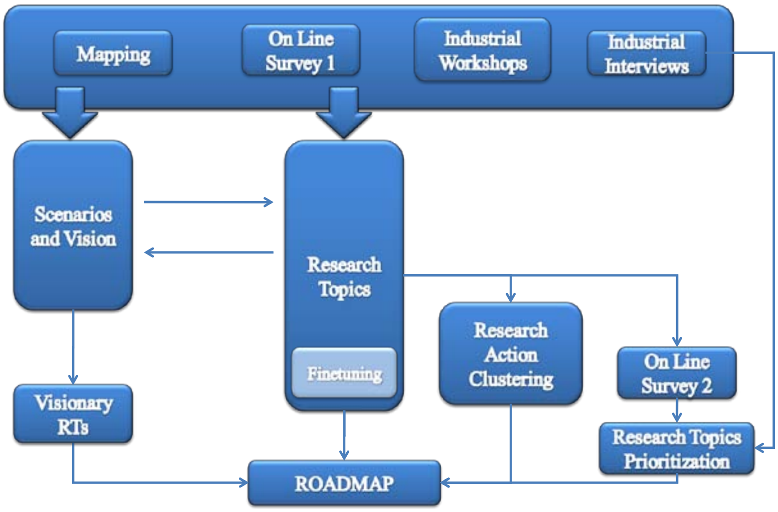
- *Rapid and adaptive user-centred manufacturing which leads to customised and 'eternal' life cycle solutions.*
- *Highly flexible and self-organising value chains which enable different ways of organising production systems, including related infrastructures, and reduce the time between engaging with end users and delivering a solution.*
- *Sustainable manufacturing possible due to cultural change of individuals and corporations supported by the enforcement of rules and a proper regulatory framework co-designed between governments, industries and societies.*

The **IMS2020 Roadmaps** describe a number of research topics and supporting actions which need to be fostered through international cooperation. These are critical Research Topics which - when implemented - will allow the achievement of the defined IMS2020 Vision and thus the shaping of manufacturing systems by the year 2020 and beyond.

IMS roadmaps have been developed to propose future research to meet the vision regarding the following IMS Key Areas

1. Sustainable Manufacturing , Products and Services
2. Energy Efficient Manufacturing
3. Key Technologies
4. Standardization
5. Innovation, Competence development and Education

The process of defining the Roadmaps is shown below.

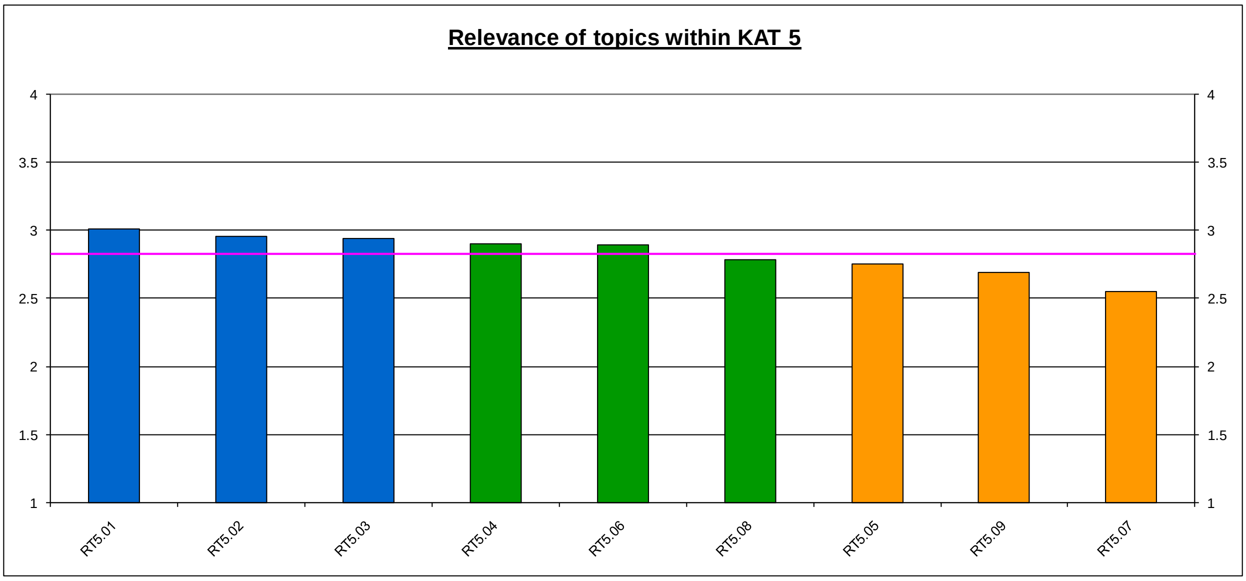


Human resources and competence for science and technology are vital to innovation and economic growth because highly skilled people create and diffuse innovations. In most countries, the demand for skilled workers is expected to increase owing to real growth in R&D and the growing application of advanced technologies in many industries. This reflects an increasing need for highly skilled workers across the economy as a whole (see Chapter 3). **Manufacturing** has moved from a pure technology view to a view integrating technology, business and management. The extended view on manufacturing reflects a need for a new competence for the industry. The future manufacturing engineer must be trained for the integrated view and must at the same time manage the societal needs for sustainability and environmental protection (see Chapter 4).

This report describes the **Roadmap** and the connections to the Key Areas Roadmaps. **9 Research Topics** have been developed:

- RT5.01 Teaching factories
- RT5.02 Cross sectorial education
- RT5.03 Communities of practice
- RT5.04 From tacit to explicit knowledge
- RT5.05 Innovation agents
- RT5.06 Benchmarking
- RT5.07 Serious games
- RT5.08 Personalized ubiquitous learning
- RT5.09 Accelerated learning

The overall relevance of the Research topics is shown below.



The Research topics are described in Section 5.1. Information on the relevance of each topic has been added based on the response to the questionnaire that was used for other areas.

Section 5.2 indicates which research topic that has been included in other Key Areas. They represent education related research – not as a standalone topic, but rather as an integral part of a technical topic.

During the industrial commenting phase, areas where the industry needs an internal update through training have been identified. This is training normally carried out in the enterprise with a clear objective of optimizing operation or enabling the implementation of new technology. The research topics that require industrial training are indicated in section 5.3.

Chapter 4 argues that the topic of education should be extended to cover competence development in the manufacturing industry. Competence is the driver of innovation processes which again pave the road for new products and processes in the enterprises. The ability to enhance innovation processes and to maximize benefit from the human capita of the enterprise is crucial for competitiveness and productivity improvement. Section 5.4 takes a fresh look at this and argues the need of a broader perspective on innovation, taking advantage of the modern communication technology and technology enhanced learning. A number of research topics have been developed based on literature review, own competence and input from related FP6 and FP7 research projects. These topics form a roadmap for research on innovation processes in the manufacturing industry.

More information on IMS2020 can be found www.ims2020.net
All IMS2020 Research Topics are available http://ims2020net.wik.is/

2 Introduction – how to read the report

The report describes the Roadmap for ***Innovation, competence development and education.*** The Roadmap proposes a number of Research Topics to be focused in future research in IMS and the EU. The challenges have been identified by industry and academia and have been collected using different methods (survey, workshops etc.) – see Chapter 6.

The ***Research Topics*** and relations with other Research Topics are described in Chapter 5.

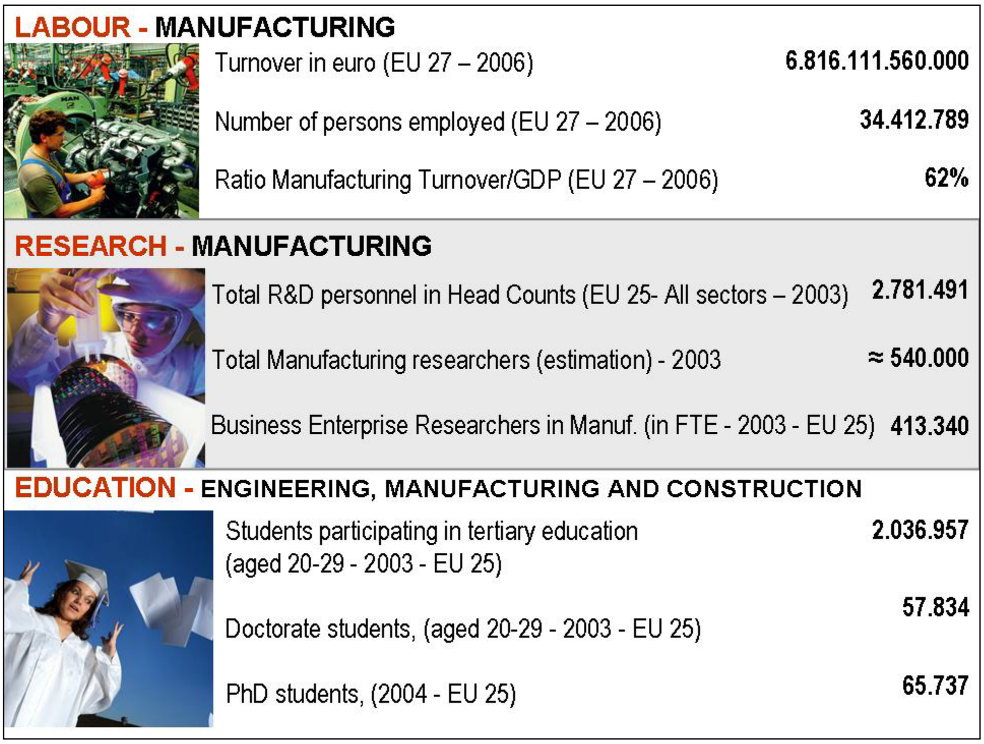
- Section 5.1 - describes the 9 Research Topics in detail
- Section 5.2 - describes how the Research Topics could be implemented in other Key Areas
- Section 5.3 – describes the need for learning and education in other Key Areas
- Section 5.4 – describes trends and needs for competence development and education in the innovation process

The importance of competence development and education in Manufacturing Industry in general is described and documented in Chapter 3, while the basic concepts for competence development are discussed in Chapter 4.

3 The importance of competence development in manufacturing – IMS2020 vision for education

3.1 Manufacturing competence development relevance

Education, vocational training and lifelong learning play a vital role in both an economic and social context of advanced countries.



LABOUR - MANUFACTURING

Turnover in euro (EU 27 – 2006)	6.816.111.560.000
Number of persons employed (EU 27 – 2006)	34.412.789
Ratio Manufacturing Turnover/GDP (EU 27 – 2006)	62%

RESEARCH - MANUFACTURING

Total R&D personnel in Head Counts (EU 25- All sectors – 2003)	2.781.491
Total Manufacturing researchers (estimation) - 2003	≈ 540.000
Business Enterprise Researchers in Manuf. (in FTE - 2003 - EU 25)	413.340

EDUCATION - ENGINEERING, MANUFACTURING AND CONSTRUCTION

Students participating in tertiary education (aged 20-29 - 2003 - EU 25)	2.036.957
Doctorate students, (aged 20-29 - 2003 - EU 25)	57.834
PhD students, (2004 - EU 25)	65.737

Figure 1 Education in manufacturing sector at European level.

Labour

Human resources for science and technology are vital to innovation and economic growth because highly skilled people create and diffuse innovations. In most countries, the demand for skilled workers is expected to increase owing to real growth in R&D and the growing application of advanced technologies in many industries. This reflects an increasing need for highly skilled workers across the economy as a whole. In the OECD area, employment in HRST occupations has outpaced employment growth overall, often by a wide margin.

The share of high-tech industry in total manufacturing value added is about 18.3 % in the US and about 12 % in the EU. Given the growing weight of high-tech sectors in the overall level of business R&D intensity, it is important to underline how the development of new competencies is contributing to such a trend.

During 2005, in the European manufacturing sector, the number of Science and Technology occupations was 6.8 millions with slightly more than half of these in (3.7 millions) high-tech and medium high-tech manufacturing. [1]

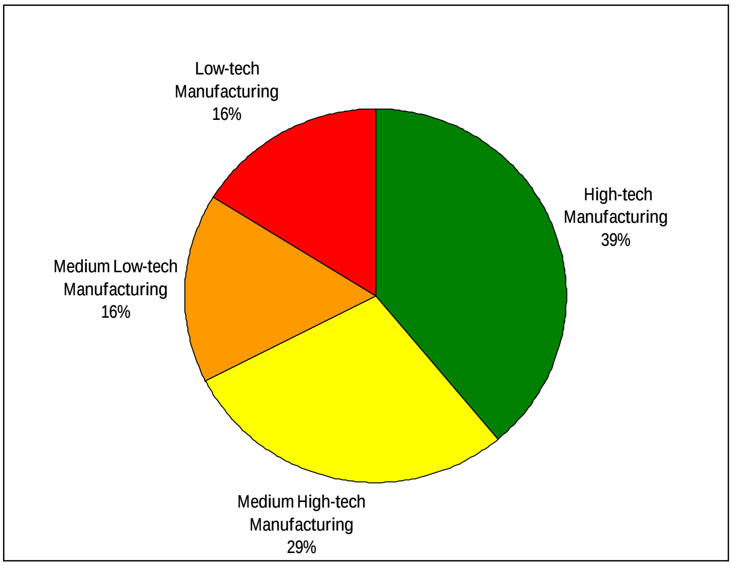


Figure 2 Human resources in science and technology intensity of employed people with S&T education (HRSTE) as a percentage of total employment, 25-64 years old - 2004 - EU 25

Innovation

Education can significantly contribute to the level of innovation in industries and in society. As a matter of fact, employment in medium-high and high-tech manufacturing, employment in high-tech services and Human Resources in Science and Technology are relevant indicators in performance for innovation in advanced countries at regional level [2]. Quantitative performances in such areas are based on the level of competences pursuable trough training programmes and on critical mass of employed owning such competences.

Manufacturing still occupies a relevant role in general innovation towards the market. In EU as a whole, the manufacturing sector had a higher proportion of innovative firms (37.4%) than services (33.7%), and firms with more than 250 employees had a higher propensity to innovate (49.2%) than small (33.2%) and medium-sized firms (39.6%).

Research plays a fundamental role in new assets on competition. A larger and more research-intensive high-tech industry in the US is the main reason for the R&D gap between the EU and the US manufacturing industry.

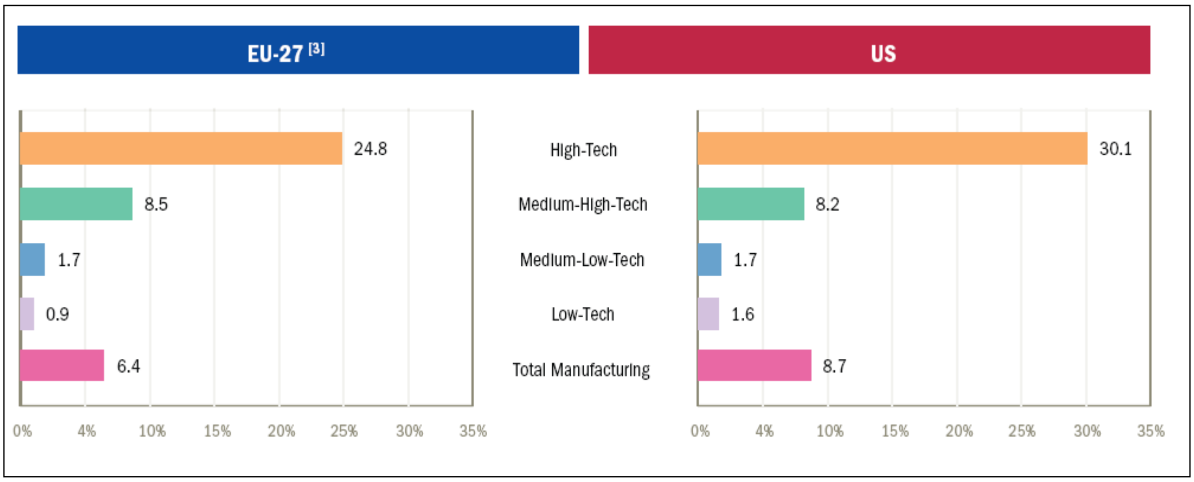


Figure 3 Manufacturing investments in research as % of manufacturing value added by type of industry 2003 [5]

Research

At OECD level manufacturing continues to account for the bulk of business R&D [3]. In Europe manufacturing researchers are close to 540.000 people. 72% of the EU-25 researchers in the Business Enterprise Sector work in manufacturing, engineering and technology, at the same time researchers constitutes 21% of total public researchers in EU-25. Finally, 80% of the EU private sector RTD expenditure is spent in manufacturing.

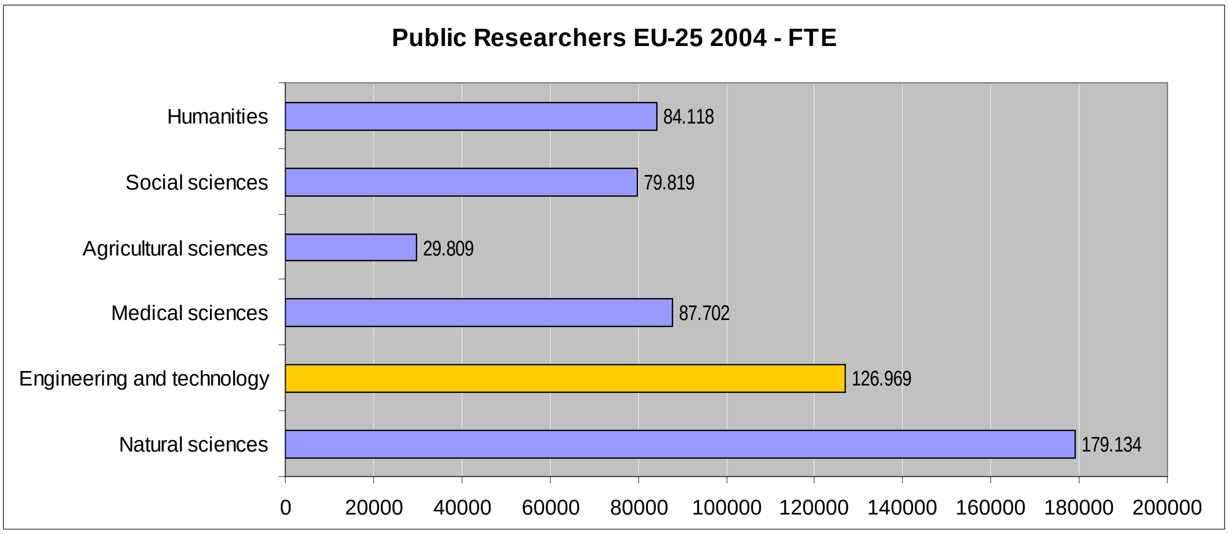
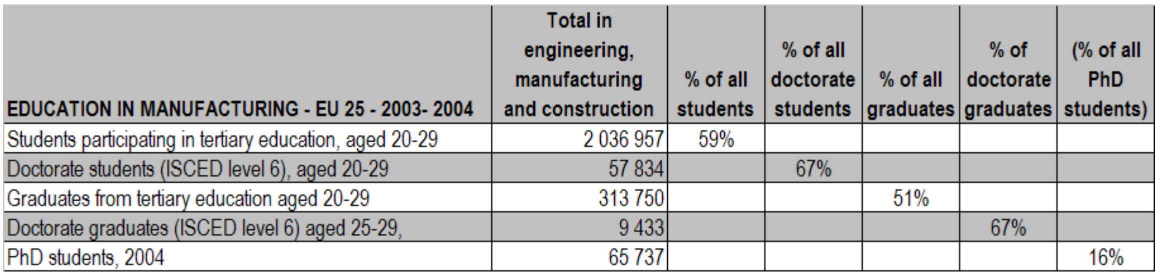


Figure 4 Public researcher in EU-25 in full time equivalent (2004)

Education

At EU-25 level it appears that, in 2005, 11 millions are qualified in "Engineering, manufacturing and construction" of the 57 million of HRSTE. EU countries still produce a greater share of science and technology graduates than Japan or the United States, despite the smaller share of researchers in the workforce: 27% of EU university graduates obtain a science or engineering degree

At European level in 2003, one student in four was following a course either in science, mathematics and computing or in engineering, manufacturing and construction At the same time European universities awarded 55% of all S&E doctorates. Europe's tertiary education institutions produced close on 2.5 million new graduates in 2003 in the EU. This compared to just over 1 million new graduates in Japan and over 2.3 million in the United States.



EDUCATION IN MANUFACTURING - EU 25 - 2003- 2004	Total in engineering, manufacturing and construction	% of all students	% of all doctorate students	% of all graduates	% of doctorate graduates	(% of all PhD students)
Students participating in tertiary education, aged 20-29	2 036 957	59%				
Doctorate students (ISCED level 6), aged 20-29	57 834		67%			
Graduates from tertiary education aged 20-29	313 750			51%		
Doctorate graduates (ISCED level 6) aged 25-29,	9 433				67%	
PhD students, 2004	65 737					16%

Table 1 Education in manufacturing in Europe

Manufacturing education in the general context

Growth of spending on R&D in the higher education sector across the OECD area and the EU-27 was 3.3% and 2.8%, respectively, between 2001 and 2006, or more than the growth rates in the business and government sectors. This strong growth in the higher education sector may reflect the growing recognition that R&D in higher education institutions is an important stimulus to economic growth and improved social outcomes.

At European Level doctoral programmes as yet involve only 3 % of enrolled students but, in many countries, student numbers are increasing faster than the global rate for tertiary education. Fields of science and technology are largely predominant between programmes. While people holding doctorates are still a minority in society (generally less than 1 % of people aged between 25 and 64) future graduates highly qualified in science and technology comprise nearly 39% of all students in advanced research programmes [4].

Moreover, at European level the number of graduates in ’mathematics, science and technology’, combining the fields ‘science, mathematics and computing’ and ‘engineering, manufacturing and construction’ in the 20-29 age group of the population is of special significance for the Lisbon strategy. It is one of the five benchmarks selected in the field of education and training: Between 2000 and 2010, the number of graduates in mathematics, science and technology should increase by 15 % [4].

3.2 Additional value of competencies in manufacturing sectors

A general change in range of competences involves a change also in the composition of the business sector trough the birth of new kb-firms and a higher share of high-tech companies and research-driven clusters [5].

At European level, a large majority of EU manufacturing and services sectors have become more R&D-intensive between 1995 and 2003. Business enterprise expenditure on manufacturing R&D in the EU has increased from 5.5 % of the total manufacturing value added in 1997 to 6.5 % in 2003.

This confirms the fact that the move to increase the knowledge content of large parts of the economy, such as manufacturing and services, tends to become a sustainable trend [6].

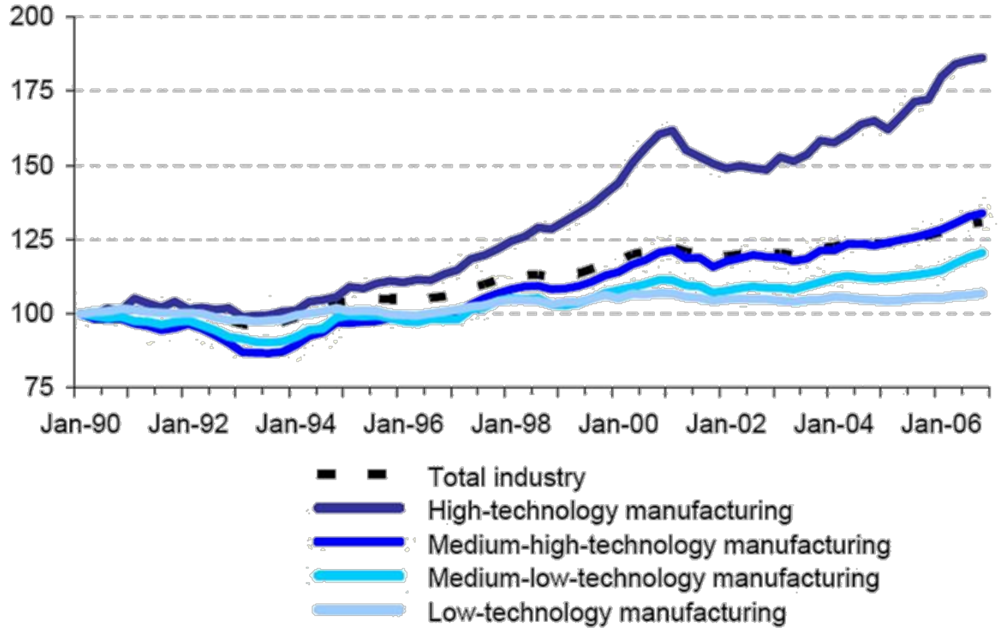


Figure 5 Evolution of production index - EU-27 seasonally adjusted figures Q1 1990=100. [6]

This trend is also confirmed by a general increase in the production index of high technology manufacturing compared to the general growth rate of the industry production index. There is a clear relation between technological intensity on the one hand and production growth on the other. The average growth rate of the production index for high-technology manufacturing activities was 4.0 % per annum between 1990 and 2006 in the EU-27, more than double the average rate for all industrial activities.

At the same time a general downward trend in employment levels across industrial activities were recorded in more sensible way among low-technology activities. These activities have been subject to either intense global competition or reduced demand that also resulted in falling production indices.

At OECD level in 2007 high- and medium-high-technology manufactures accounted for over 60% of the total manufacturing trade (23% and 39%, respectively). High-technology goods have been among the most dynamic components of international trade over the last decade. Trade in manufacturing was in fact mostly driven by high-technology industries over the second half of the 1990s and until the beginning of 2005. [7]

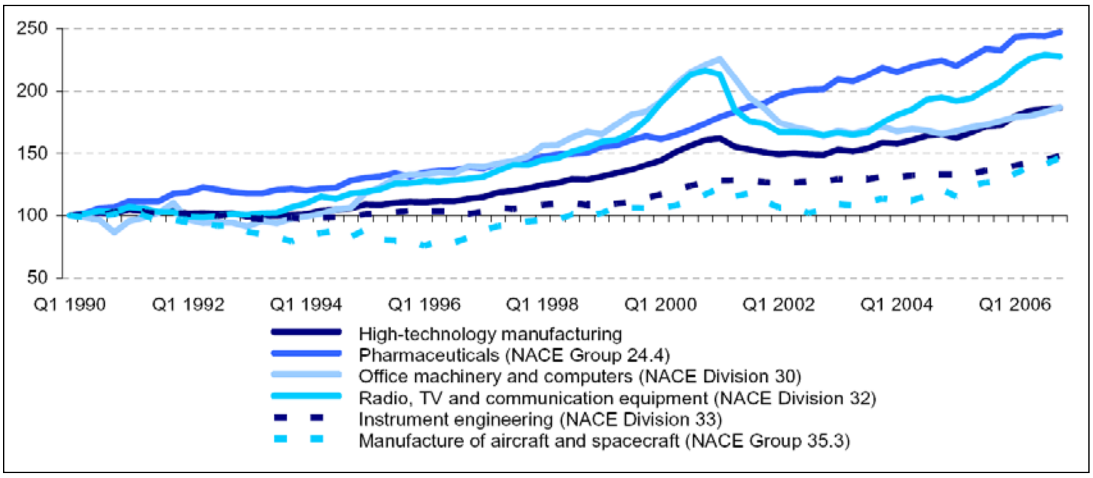


Figure 6 Evolution of the production index for high-tech manufacturing activities, EU-27 seasonally adjusted figures (Q1-1990 = 100) [6]

3.3 Relevant trends for competence development in manufacturing

Renewed globalization in R&D for manufacturing
In the past, cross-border R&D was largely aimed at adapting products and services to the needs of host countries; it was carried out close to “lead users” in order to adapt products and processes to local conditions. It also supported the local manufacturing operations of multinational enterprises (MNEs). At present, MNEs seek not only to exploit knowledge generated at home and in other countries, but also to source technology internationally and tap into centres of increasingly multidisciplinary knowledge worldwide. [3]

Globalization of manufacturing education seems to offer better job offers for students, more opportunities for research projects, and a more realistic understanding of the problems of manufacturing in a global environment [8].

ICT Contribution
The ICT sector invests heavily in R&D. In 2004, ICT manufacturing industries accounted for more than a quarter of the total manufacturing R&D expenditure in most OECD countries, and over half in Finland and Korea. The share of ICT in total patent applications rose in almost all countries from the mid-1990s to the beginning of the 2000s. [3]

Growth in S&E graduating and doctorates
In absolute terms, the number of students graduating in S&E increased. However, in relative terms, the share of S&E graduates decreased in 17 of the OECD countries. The supply of doctorates has increased in most OECD countries. [3]

Growth of Human Resources in Science & Technology (HRST)
Analysing the growth of HRST by OECD industry reveals that it increased more rapidly than the total employment in both the manufacturing and services sectors in most countries. In manufacturing, total employment fell in 14 out of 19 countries (i.e., in nearly

75%), but HRST employment grew to a similar extent. Manufacturing HRST in fact outpaced growth in services HRST in Spain, Ireland, Greece, Italy, Austria, Finland and Portugal. Canada was the only country in which the growth of total employment outpaced growth of HRST in manufacturing. [3]

Internationalisation of HRST and patents
Globalisation has made investments in knowledge much more attractive. Foreign talents contributes significantly to the supply of S&T personnel in many OECD countries. In the United States in 2003, for example, 26% of college-educated workers in S&E occupations were foreign-born as were 40% of S&E doctorate holders. [3]

At the same time patent data show significant internationalisation of research activities. On average, over 15% of the patents filed by an OECD country in 2004-06 under the Patent Co-operation Treaty (PCT) concerned inventions made abroad. Similarly, the share of inventions owned by another country accounted for just below 15% of all OECD filings. [7]

3.4 Technology transfer from research to industries

The contribution of innovation to growth and competitiveness remains a key issue for advanced countries but also for emerging economies. Advanced countries continue to reform their science, technology and innovation policies to improve the efficiency of their national innovation systems. When concerning R&D, more attention is assigned to the "demand" side of innovation, such as using procurement or standards, or lead markets to "pull" innovation. This is reflected in a move away from traditional "supply push" policies to commercialise or transfer public research results to industry, towards a model based on joint development, often via public-private partnerships and involving networks of firms even beyond national borders.

Technology transfer, understood as the process of converting scientific findings from research organisations into useful products by the commercial sector, can take three main channels

- The creation of new companies (spin-outs), which often involves some transfer of personnel (mobility of researchers);
- Collaboration between universities, research organisations and industry notably via research contracts;
- Licensing of IP.

Studies have underlined the importance of adopting an institutionalized and strategic approach towards the commercialisation of research activities by universities. Such institutional strategies may cover institutional procedures, organizational structures or management processes that allow universities to exploit their R&D portfolio without hampering the fundamental university mission of teaching and research. [9]

3.5 Lifelong learning and vocational training

Nowadays “knowledge workers” are increasingly pivotal to economic success in developed countries. The potential for individuals and countries to benefit from this emerging knowledge economy depends largely on their education, skills, talents and abilities, that is, their human capital. As a result, governments are increasingly concerned with raising levels of human capital, chiefly through education and training, which today are seen as ever more critical to fuelling economic growth.

Knowledge economy demands that individuals continuously learn new skills or participate in life-long learning. All types of learning are valuable, since it prepares people for “learning to learn”. The ability to learn can then be applied to new tasks with social and economic benefits.

Rapid change of competence needs in industries and an increased average age of employees also require new education and training systems. Development of new training methods is viewed as a priority for education investment in most advanced countries. [10]

An objective of the European Union is to involve on average 12,5% of the adult workforce (age 25-64) in lifelong learning within 2010. Studies indicate that only in Europe 4 million more adults would participate in lifelong learning in 2010. However, lifelong learning participation is strongly correlated to the level of initial education reached by the workforce.

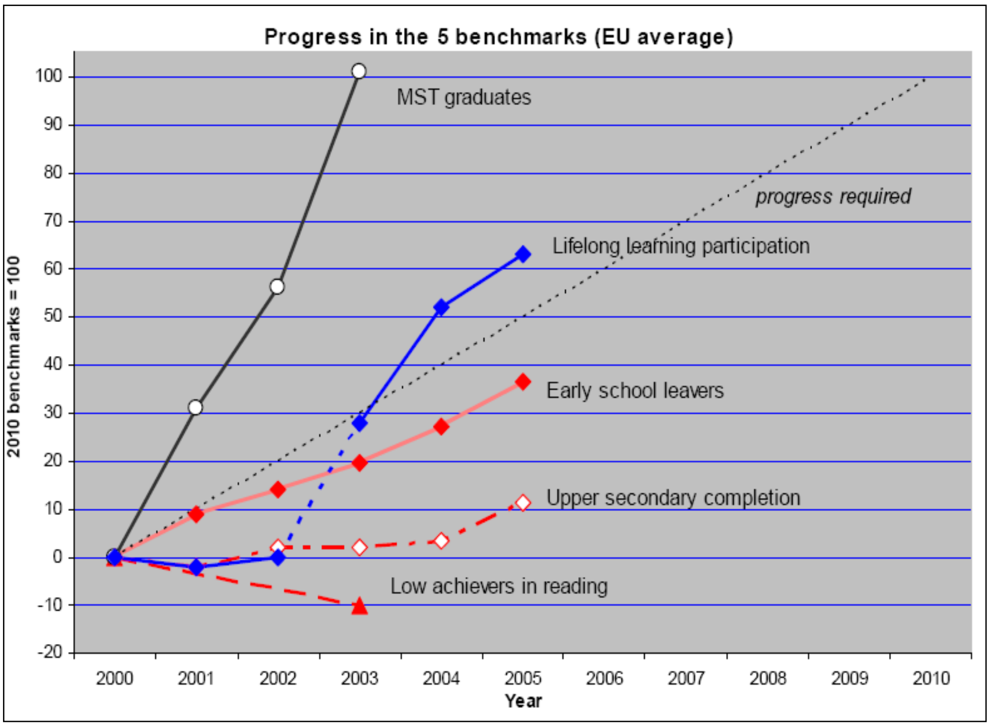


Figure 7 Overview on average performance levels in the fields of the five European benchmarks [9]

European studies show that adults with a high educational attainment level are more than six times as likely to participate in lifelong learning than low skilled; in non-formal education it is even ten times more. Furthermore, older age groups participate much less than the younger ones.

A further analysis shows that non-formal education was highly spread in current lifelong learning practices compared to formal courses. At European level participation of adults in non-formal education was more than three times higher (16.5%) than in formal education. In order to improve lifelong learning practices traditional barriers between the various parts of formal education and training and non-formal and informal learning ought to be overcome.

Another survey carried out by Eurobarometer on vocational training of 2004 also shows that skill appropriateness in relation to work skill and modality to merge training activity to work routines are relevant areas of action.

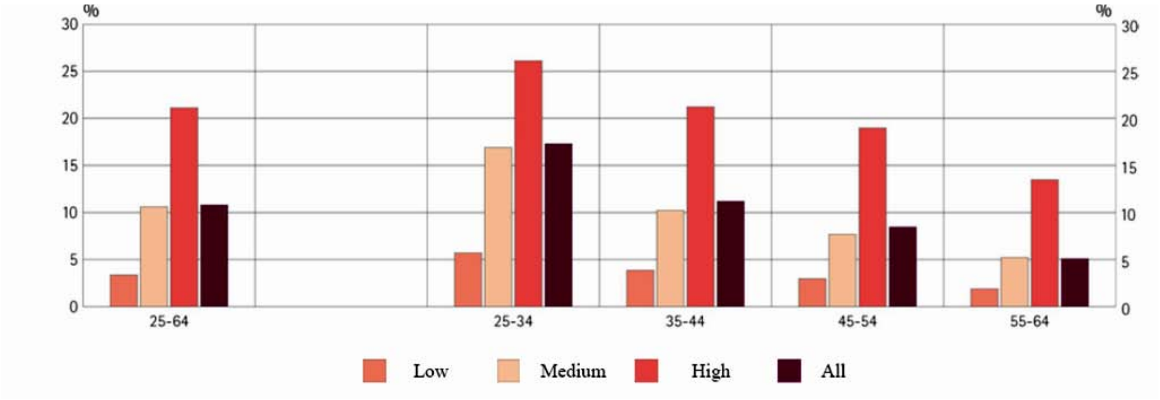


Figure 8 Participation in lifelong learning by age and educational attainment (2005) [11]

3.6 Enrolments of product chain stakeholders in manufacturing education policy

Specific actions for education oriented to manufacturing have to take account of spread impact along this context of application. In particular, different fields of application within product chains require dedicated approaches and competences.

Enabling competences in Product Life Cycles should affect not only traditional addresser of education policy, like researchers and engineers (i.e. competences in advanced technologies and new efficiency standards), but also life cycle stakeholders like designers, industry workers and technicians (i.e., skills in new technical applications and standards). A further extension of the knowledge system both to business level (i.e., business model for industrial sustainability) and to service level (i.e., understanding of added value) increases effectiveness of technology solutions.

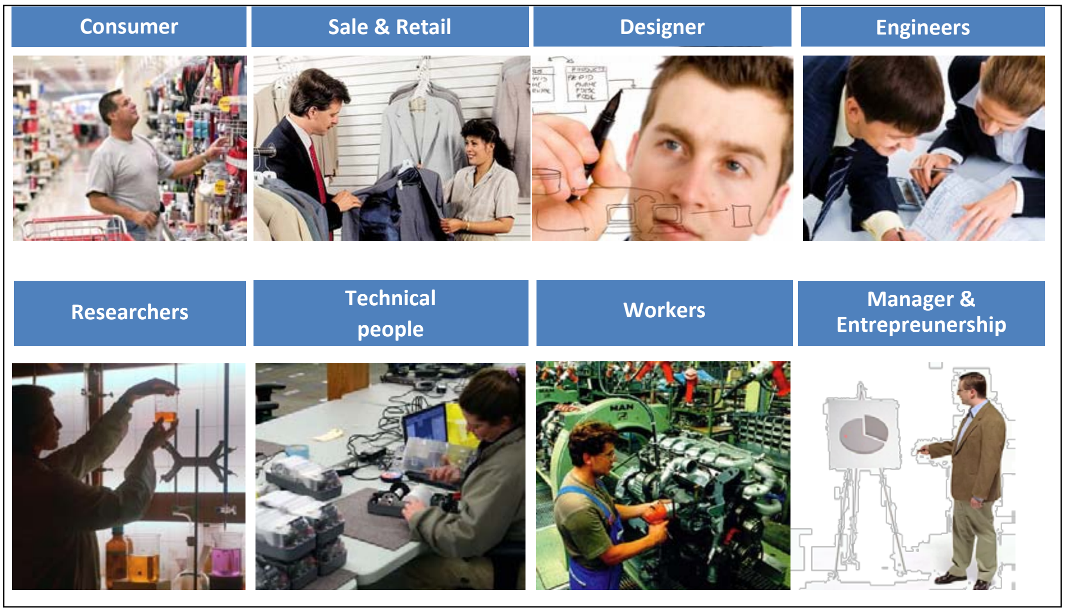


Figure 9 Level of action for education in manufacturing along Product Life Cycle

Moreover, changes in the character of competences and level of worker education require development of new tools and methodologies for knowledge transfer [12] [13].

At the same time increasing integration of management for different life cycle phases is translated in new transversal needs and approaches for traditional themes like education.

Different studies [14] [15] on product value chains have experimented in innovation of products with high benefits in final outcomes.

The focus on product life cycle involves also change in the nature of training methods. Product and service development needs a wider set of educational methods than traditional methods. Such competences are tightly related to the operational context, and it is widely agreed that such competences can only be efficiently learned through application. The PD6 method [16] enables new potential for learning and deeply understanding the consequences of decisions and the relation between theory and practice.

3.7 Horizontal actions

Horizontal actions are of capital importance in order to accelerate knowledge transfer within the manufacturing context. They are:

- New transversal methodologies and tools for competences creation and knowledge transfer (i.e., e-learning, visual learning, new format of contents etc.)
- Adequate adaptation to specific application fields (with particular reference to Product Life Cycle stages) and to specific matters dealt with.

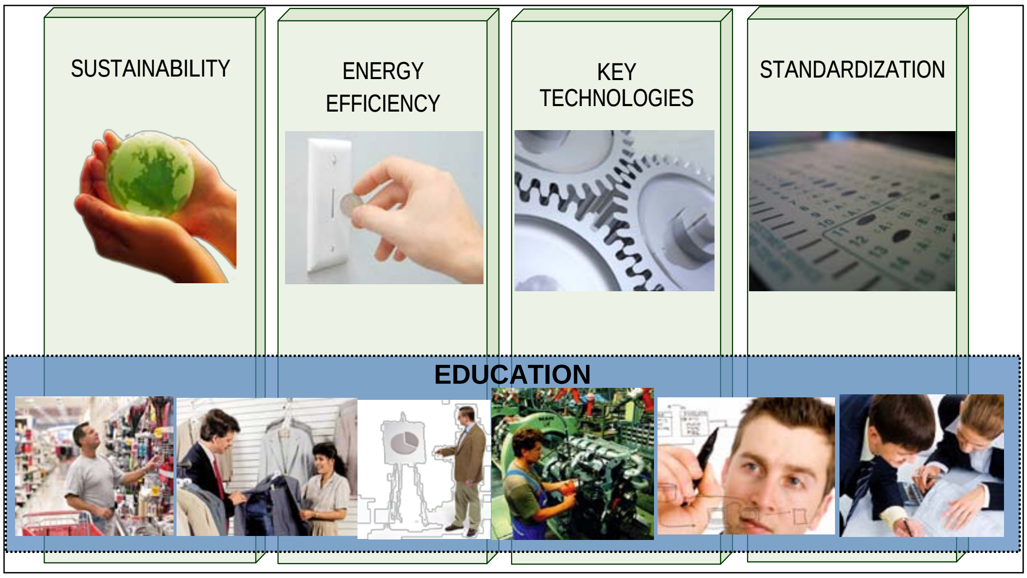


Figure 10 Horizontal and vertical actions in manufacturing context

The new knowledge society requires not only specific curricula but new transversal competences for all contexts in order to face increasing complexity of manufacturing systems [17].

Horizontal actions have then to focus on learning outcomes (i.e., on what a learner knows, understands and is able to do rather than the learning process itself) [18].

Horizontal actions should also be focused on transparency and standardization of qualifications in order to improve mobility of learners and workers between countries and their access to lifelong learning.

Moreover, a general rethinking of traditional infrastructures for knowledge transfer and impact assessments has to be considered (i.e., opening universities to non-traditional learners or the validation of non-formal learning).

3.8 Vertical actions

Vertical actions have to be focused on particular key educational areas responding to new societal and technological challenges related to manufacturing context. Four Key Areas may be indicated:

Sustainability

While industries are showing greater interest in sustainable production, and are undertaking a number of corporate social responsibility initiatives, progress falls far short of meeting these pressing challenges. Moreover, improvements in efficiency in some regions have often been offset by increasing consumption in other regions, while efficiency gains in some areas are outpaced by scale effects. Without new policy actions, recent OECD analysis suggests that global greenhouse gas emissions are likely to increase by 70% by 2050 [19].

Energy efficiency
Manufacturing is directly connected to natural resources and immediately affected by their diminishment. This dependence results in a necessity to reduce, with increasing product output, the amount of employed resources and thereby increase resource productivity. To achieve this, a paradigm shift is necessary: "maximum gain from minimum capital" has to be replaced by "maximum gain from minimum resources" [20].

Key enabling technologies
The shape and potential of industries worldwide will be transformed over the next 5 to 10 years. New goods and services will be created. A significant part of the goods and services that will be available in the market in 2020 are as yet unknown, but the main driving force behind their development will be the deployment of key enabling technologies (KETs). Those nations and regions mastering these technologies will be at the forefront of managing the shift to a low carbon, knowledge-based economy, which is a precondition for ensuring welfare, prosperity and security of its citizens [21].

Standardization
Standardization represents a relevant asset in view of the increasing integration of product life cycle phases. Relevant trends such as globalization and total quality of manufacturing phases (IQM) require easy and reliable information exchange among manufacturers and their suppliers and customers.

Standardization of information not only means to follow some standards on the implementation work of single enterprises, but requires a macroscopic standard, which will run through the whole process of particular projects, including design, implementation, evaluation, check-up, acceptance and feedback into the next cycle [22]. Standardization will also help to further improve the competitive position of the advanced economies industry. Lack of standardization will shatter resources and will make it easier for non-high tech manufacturers to penetrate the market [23].

3.9 New methods and tools

Reference models for skills development are today obsolete. Upcoming changes in manufacturing industry require not only adjustment in focus on competence but also new methods of transferring competence.

Skills
At industrial level new types of skills are required by manufacturing employees that will make their organization more agile – so called “intellective and connective” skills that create more mobile and adaptive knowledge workers.

As an example with the emergence of a more global economy in both supply and demand, coupled with ever-increasing availability of new information and communications technologies, the role of the manufacturing engineer has been transformed. The traditional role of the technician with various specialisations was replaced by the role of the systems integrator who has enough breadth of knowledge to cope with systems design in adequate terms [24].

Teaching methods

Within higher education there is presently a lot of attention paid to new Internet-based technologies and the possibilities that they offer for learning and teaching, particularly in terms of e-learning [25].

Web-based systems have radically changed knowledge transfer and learning acquisition within working environments [26] [27]. However, despite several developments in software and related tools, improvement in learning effectiveness for specific training areas is a concern. As an example, the use of different languages, tools, and experiences by new practitioners coming from different disciplines in manufacturing context is a further barrier in transfer of training contents [28].

Major challenges to face in terms of teaching methods are related to increasing competences to transfer, extended distance between students and teachers, remote control and feedback of learning processes, management of cooperative teaching, extended framework of application of teaching methods, standardization and certification of learning levels.

Mentionable reference infrastructures and methods for education in manufacturing are:

- *Asynchronous and synchronous learning* due to alternate use of ICT tools in educational programmes [24]
- *Teaching factory* understood as living laboratory able to integrate research, innovation and educational activities [24]
- *Learning Factories* understood as context-aware virtual factory for collaborative learning [29]
- *Serious games* understood as play methodology to learn about serious issues in manufacturing [24]

Expanded use of educational technology may in the future help create student interest in manufacturing and technical education. Increased incentives to support the use of educational technology tools can increase the productivity and reach of educational programs [30].

3.10 Education – a challenge for IMS

From an IMS perspective education is viewed as a horizontal theme of particular importance to Sustainable Manufacturing.

Education for Manufacturing Industry in particular represents a major challenge for international co-operation. The present and future economic success of firms is dependent on the knowledge-set of its managers and engineers. Manufacturing environments will change significantly in advanced countries in comparison to what exists today. Educators will need to learn about the changes taking place and adapt learning programs in universities so that appropriate skills are imparted to the leader in manufacturing of the future. [29]

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4 Innovation, competence development and education – basic concepts

Manufacturing is a field that has changed over the last decades. From being mainly concerned with metal cutting processes, the focus has shifted over to automation, supply chain and finally to sustainability. This is clearly demonstrated in the shift of the manufacturing research agenda. It is possible to recognize four generations of research focus areas (Rolstadas 2007):

- Machine focus
- Factory focus
- Supply chain focus
- Life cycle focus

In the machine focus, research activities were targeted at a single process element, e.g., around the cutting process in a single machine tool. Improved cutting data, cutting conditions, cutting materials, tools and capability of the machine tool are typical examples.

The second generation changed the focus from the single process element to the whole factory. Research focus was on industrial automation, robotics, CNC, flexible manufacturing, operations and process planning (such as the APT language) and in the end on CAD/CAM, CIM and intelligent manufacturing.

The third generation shifted the focus to the whole supply chain. In addition to the pure manufacturing technology, the research now also got a dimension on management and economics. One of the main enablers of this research is the availability of digital solutions for planning, control, management and business operation. The extended enterprise is a topic that received much attention (Jagdev, Browne 1998).

The fourth generation maintains the focus on the supply chain, but extends this into a full life cycle. The focus shifts to a certain extent from production to the product. The concept of extended products has been launched covering the whole life cycle from delivered product through use and maintenance to disassembly and recycling. This focus also addresses sustainability and energy efficiency as a major issue.

This development is also supported by the European Manufuture technology platform. Flegel (2008) describes a ladder spanning from process through operation, cell, line, building, plant to network of plants. He shows four major platforms for future manufacturing:

- Enabling technologies
- Engineering platform
- Manufacturing systems
- Management of business

This shows that manufacturing has moved from a pure technology view to a view integrating technology, business and management. The extended view on manufacturing of course reflects a need for a new competence for the industry. The future manufacturing engineer must be trained for the integrated view and must at the same time manage the societal needs for sustainability and environment protection.

A survey carried out in 2003 (Kvernberg, Andersen et al) in industries in Europe, USA, Canada, Japan, Korea and Australia also indicated the need for competence in three main areas:

- Technological competence
- Humanistic competence
- Business competence

A survey from 2004 shows that existing university curricula do not adequately cover this integrated view. Hence there is a need for an educational program to supply the manufacturing industry with the competence it needs for future operation. Westkämper (2008) claims that the future competence should be developed by industries, research institutes and universities in cooperation. He defines a knowledge triangle as shown in Figure 11.

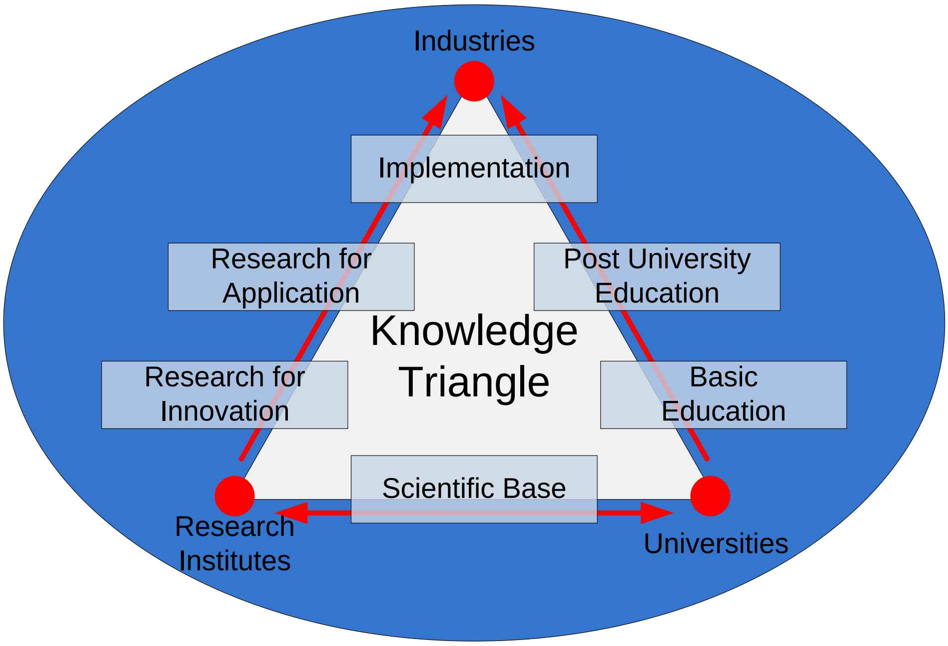

Figure 11 The knowledge triangle (Westkämper)

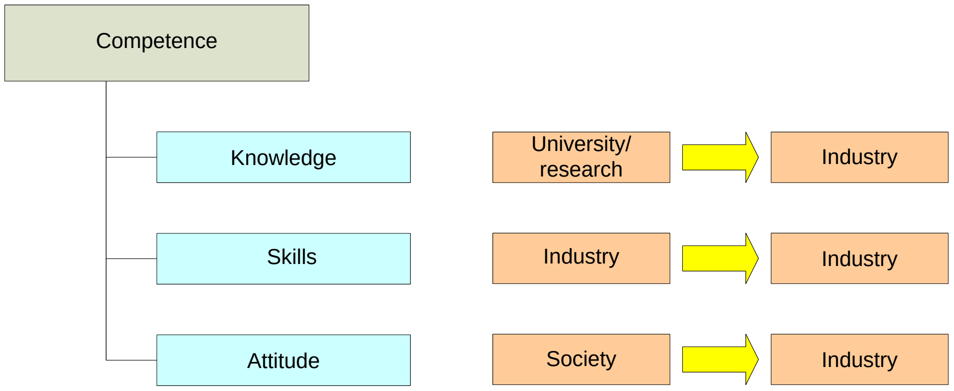

Figure 12 Competence transfer

The key question is linked to how the manufacturing industry can obtain the competence it needs to meet the future challenges. Competence is a combination of knowledge, skills and attitude. This is illustrated in Figure 12 on the left hand side. Knowledge can be obtained from existing literature or through research and development. The right hand side of Figure 12 shows how knowledge is implemented in or transferred to industry. Normally this is through a learning process where universities or other academic institutions provide the knowledge. Such institutions develop knowledge from research – often in cooperation with industry.

Skills are obtained from practicing. Thus, skills in the manufacturing industry are developed on the job and through the daily activities. However, skills can also be obtained virtually, for example by using simulators or serious games. To obtain the necessary skills is also a learning process. This process is either internal in the company or between companies.

An attitude is a hypothetical construct that represents an individual's degree of like or dislike for an item (Wikipedia 2009). Attitudes are generally positive or negative views of a person, place, thing, or event. Attitudes are judgments. A person’s attitude influences on how a job is done or how an issue is managed. Thus it is an important part of the competence. It represents a sort of ethics for how to apply knowledge and skills. It is normally transferred to the industry from the society at large.

Attitude influence the culture of sustainability concerns in manufacturing and design. This relates to the attitude of customers and consumers as well as the attitude of the designers and manufacturers. When sustainability concerns become market qualifiers rather than market winners a virtuous circle is developed and a new paradigm is established.

Competence can be enhanced through learning processes. There are three different types of learning processes:

- Education
- Training
- Technology transfer

Education (developing new knowledge) is delivered by academic institutions at three levels. It is based on cutting edge research. The student is normally full time on a campus. It mainly addresses young people aiming to qualify themselves for a carrier.

Training (developing skills and targeted knowledge) is normally company internal activities (corporate universities). It may also have the form of a cooperation between companies (often sector specific), or between industry and academic partners. It is usually part time studies. It addresses both young and experienced people and is targeted to specific industrial needs.

Continuous learning among the work force is essential. The importance of continuously training and educating manufacturing engineers and other personnel is being understood by industry. Concepts such as the House of Quality and tools such as continuous quality improvements are successfully being applied. In parallel university curricula must also be subject to continuous revision. Universities must work with industry to formalize continuous learning requirements, and students must learn to understand the importance of lifelong learning.

Technology transfer (exploitation of research results) is often executed in an industry-academia partnership, for example in the form of a research contract. It may also be executed in cooperation between different industries.

Development of competence is part of the innovation process in any company. Innovation is the process of making changes to something established by introducing something new that adds value to customers (O'Sullivan and Dooley 2009). The innovation process is an interaction between four key sub-processes:

- Idea generation
- Opportunity recognition
- Development
- Realization

Opportunity recognition is influenced by organizational goals and available resources. The whole innovation process is supported by learning processes. There are different approaches to learning. Some of the most important concepts are:

- The threshold concept which is an essential conceptual building block in progressing in the knowledge of a particular domain. A threshold concept involves a conceptual and ontological shift in the individual's understanding. Once acquired, an individual cannot forget a threshold concept, neither return to her previous understanding of the knowledge domain. It reveals hidden knowledge and the inter-relationships between existing concepts. On first encounter, a threshold concept is counter intuitive and alien to an individual's common sense. It usually connects knowledge spaces.
- Cognitive load theory which basically states that a learner's attention and working memory is limited. This limited amount of attention can be directed towards intrinsic, germane, or extraneous processing. Intrinsic processing describes a learner's focus on the learning content and its key features; it is determined by the

intellectual demands of learning content. Germane processing describes a deeper processing of the content by its organization to cognitive representations and its integration into existing representations (integrating previous knowledge). Finally, extraneous processing describes cognitive demands during learning, which do not foster the actual objectives of the learning material.

- Learning communities which uses activity theory and the seminal work of Wenger (1999) on communities of practice as the underlying framework (Engstrom 1987). In this perspective, "communities of practice can be thought of as shared histories of learning".
- Serious games which are digital games that are driven by learning objectives. In fact, serious games can be deployed (Oliveira et al. 2006) as testbeds for experience management that are highly motivating and emotionally engaging causing high and long knowledge retention.

Technology, the fast outdating of knowledge and training, the desire for just-in-time training delivery, and the continuous hunt for cost-effective methods to meet learning requirements have redefined the processes of design, development, and delivery of training and education (Urdan and Weggen, 2000). For the manufacturing industry, an important option to deliver education and training is the concept of E-learning. Delivery of E-Learning relies heavily on Internet-based technologies (Rolstadås, 2002; Lefrere, 2007).

Delivery of E-Learning content can be synchronous or asynchronous. The alternate use of video, audio, pictures, text, (interactive) animations, quizzes and chat, and discussion boards should assure that both styles can be covered (Rolstadås and Hussein, 2002). Whatever the choice of learning communication, the learning success heavily depends on the actual form of mediation. According to Dale (1969), passive learning activities like reading texts or watching a demonstration result in the fact that just 10% (reading) or 30 % (watching) of the content is remembered afterwards. Active involvement within the learning process, like participating in a discussion, leads to the fact that the learners can remember about 70 % of the related content afterwards (Dale, 1969). Accordingly, content needs to be delivered on the basis of active learning.

A powerful concept for delivery is hybrid learning published by Rolstadås and Hussein (2002). They claim that this type of mixed instructional delivery has proved to be an effective tool for enhancing the learning value for the workforce. Applying this approach may also lead to significant reduction in learning time. The hybrid solution is well suited for large organizations distributed over a large geographic area. Thus, the target group may be characterized by diverse social, cultural, and academic background. Therefore, it is important that the model enables multiple learning styles.

The hybrid model is based on a mixture of on-campus plenary learning sessions (face to face), self-paced learning using rich media through virtual classroom, and collaborative group work using collaborative ICT tools included in the virtual classroom.

In chapter 5 the research topics are presented as part of the road-mapping process. Nine research topics have been identified. Many of these are already integrated into the roadmap covering other Key Areas, either as research ideas or as defined need for education and training. In addition a specific roadmap on research on enhancing the innovation process in manufacturing industries with focus on competence development has been prepared.

Fundamental to future technology development, both with respect to the economic, environmental and social aspects of manufacturing is innovation, competence development and education. Technologies, methodologies, facilities and interaction areas for competence development are necessary fundamentals of a dynamic and evolving manufacturing environment. Figure 13 shows how the roadmap fundaments the sustainability and research model embracing economy, ecology and society aspects of other Key Areas.

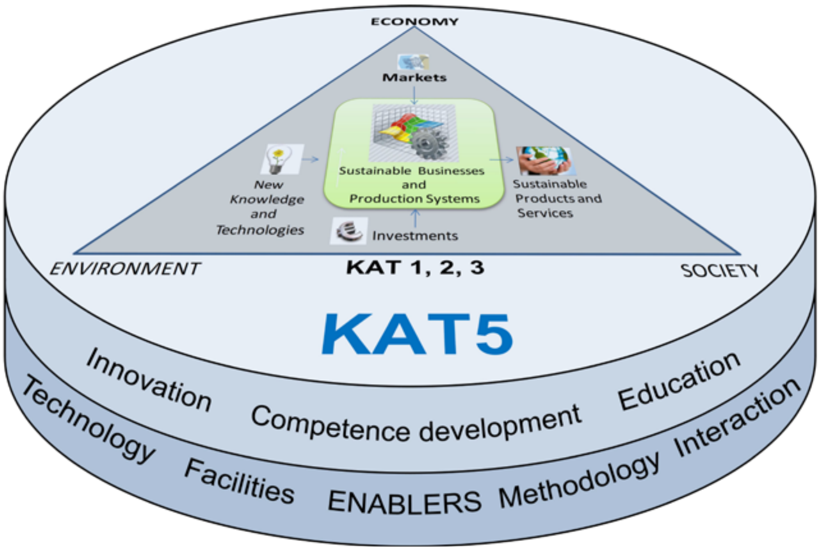

Figure 13 Connection between roadmap and other Key Areas roadmaps.

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5 Action roadmap on innovation, competence development and education

As discussed in the previous section, the research topics span across the topics of other Key Areas. This section will show a roadmap as well as summarizing research included in the other existing roadmaps.

There are four subsections:

- An overview of the 9 research topics developed through literature review, workshops, interviews and comments on the Wiki.
- An overview of related research is embedded in other Key Areas research topic.
- An overview of where there are training needs identified in other Key Areas.
- An amendment with research topics targeted at enabling innovation processes in manufacturing industry.

Section 5.1 presents the nine research topics using the standard form that was developed. These topics are the ones that have been included in a more focused way in the other Key Areas roadmaps. They are supported by level relevance derived from the same questionnaire as was used for other Key Areas roadmaps.

Section 5.2 indicates which research topic that has been included in the other Key Areas. They represent education related research – not as a standalone topic, but rather as an integral part of a technical topic.

During the industrial commenting phase, areas have been identified where the industry needs an internal update through training. This is training normally carried out in the enterprise with a clear objective of optimizing operation or enabling the implementation of new technology. The research topics in other Key Areas that require industrial training are indicated in section 5.3.

Chapter 4 argued that the topic of education should be extended to cover competence development in the manufacturing industry. Competence is the driver of innovation processes which again pave the road to new products and processes in the enterprises. The ability to enhance innovation processes and to maximize benefit from the human capita of the enterprise is crucial for competitiveness and productivity improvement. Section 5.4 takes a fresh look on this and argues the need of a broader perspective on innovation taking advantage of the modern communication technology and technology enhanced learning. A number of research topics have been developed based on literature reviews, own competence and input from related FP6 and FP7 research projects. These topics form a roadmap for research on innovation processes in the manufacturing industry.

5.1 KAT 5 research topics

The nine research topics developed are presented in the following using the standard form that was developed for all Key Areas. Information on the relevance of each topic has been added based on the response to the questionnaire that was used for other Key Areas.

Figure 14 shows the overall relevance of the topics. They fall into three groups. The blue group represents the topics of highest industrial relevance. These are

- RT 5.01 Teaching factories
- RT 5.02 Cross sectoral education
- RT 5.03 Communities of practice

The green group represents the topics of middle industrial relevance. These are:

- RT 5.04 From tacit to explicit knowledge
- RT 5.06 Benchmarking
- RT 5.08 Personalized ubiquitous learning

The yellow group represents the topics having less industrial relevance. These are:

- RT 5.05 Innovation agents
- RT 5.09 Accelerated learning
- RT 5.07 Serious games

The difference in relevance is not significant. This indicates in reality that all topics have good industrial relevance. Since they were collected from industrial workshops and interviews, this could be expected.

The relevance is also indicated with a number of green balls on each research topic form.

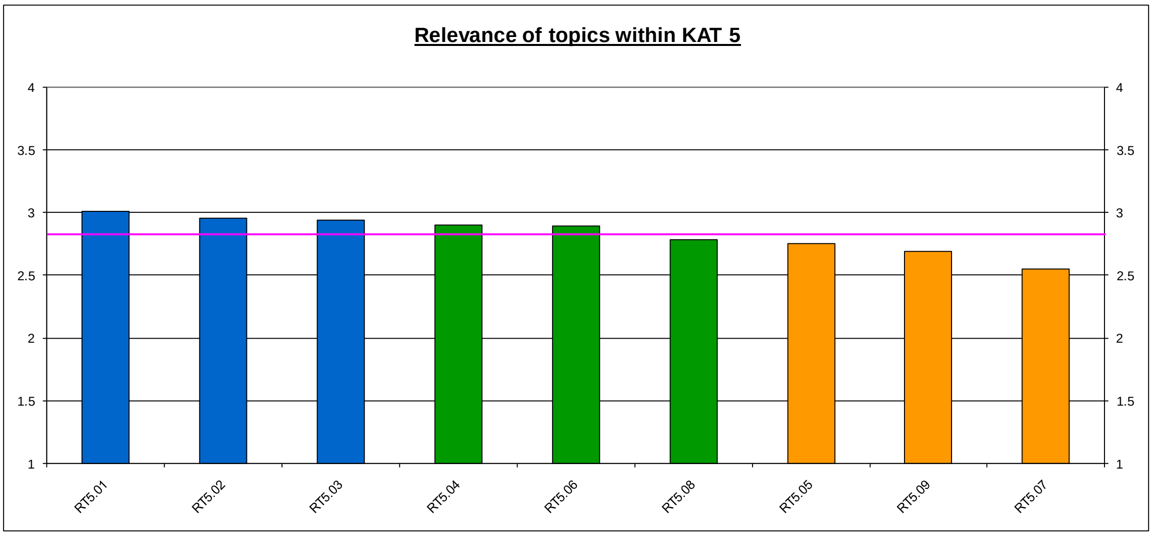


Figure 14 Overall relevance of the Research Topics

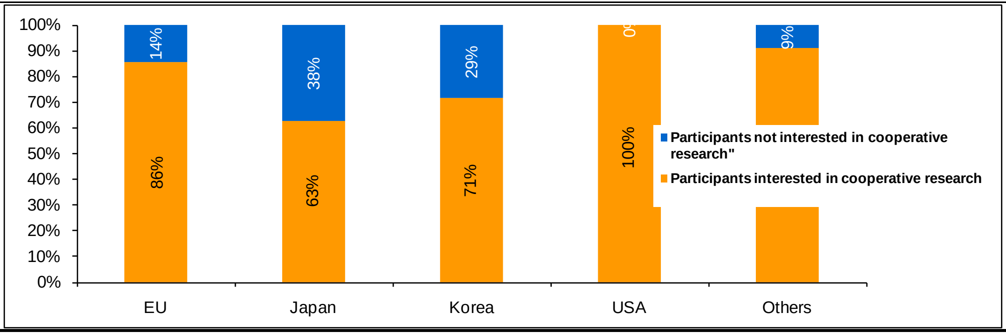
5.1.1 RT5.01 Teaching factories

ABSTRACT:	Teaching factories are real production facilities developed for education and training purposes for students and workers, which will significantly reduce the gap between academia preparation and industrial needs, and improve the

<table>
<tr><td></td><td>life long learning effectiveness of skilled workers.</td></tr>
<tr><td>Technical Content and scope:</td><td>Research and development to develop and validate teaching factories, i.e. infrastructures in the form of producing factories that also can be used for education, training and lifelong learning. Students and workers will come to the factory and learn theory and practice in a real manufacturing environment, where new products are continuously conceived, designed, manufactured and delivered. Therefore it must include all actors from design, development to manufacturing and shipment. Furthermore, teaching factories are supposed to be part of a real industrial value chain, involving suppliers of technologies, components and materials, as well as retailers and vendors. Such a real world value chain will be involved in the teaching factory innovation processes, assessing new solutions and contributing to the technology transfer action of such infrastructures. Teaching factories may be also innovative experimental set ups for product innovation, supporting the continuous product innovation by means of exploitation of new concepts, design, components, materials and manufacturing technologies for the development of prototypes and samples, as well as small series. There should be agreements with schools/universities as well as companies to use this infrastructure for educational and training purposes.

Related research topics will be: new conception and design technologies, new cad-cam instruments, new manufacturing technologies, new ERP, MES and PDM tools, new supply chain schemas, new vending concepts and tools.</td></tr>
<tr><td>Expected results and impact, with special focus on the industrial interest:</td><td>Competence development and training in an industrial environment which is closely adapted to the industrial needs. This can support introduction of new technology in SME and provide opportunities for learning between enterprises, with reference to CAD-CAM, ICT and data management, as well as automation and manufacturing technologies. Particularly, teaching factories will significantly reduce the gap between academia preparation and industrial needs, reducing the insertion time of new workers in manufacturing industries to zero, and improving the life long learning effectiveness of skilled workers.</td></tr>
<tr><td>Specific Features:</td><td>Competence development through education, training and lifelong learning of both students and workers.

Teaching Factories should be established in close cooperation with relevant universities and industries representing special sectors or SME`s in general.</td></tr>
<tr><td>Suggested Scheme:</td><td>Topic to be included within large collaborative projects as an education related activity necessary to transfer new research results in industrial practice or specific small SME targeted projects aimed to set up pilot factories exploiting new technologies which are suitable also as teaching factories.</td></tr>
<tr><td>Additional Information from IMS Regions:</td><td><table><tr><th>Region</th><th>Why / Reference</th></tr><tr><td></td><td></td></tr></table></td></tr>
</table>

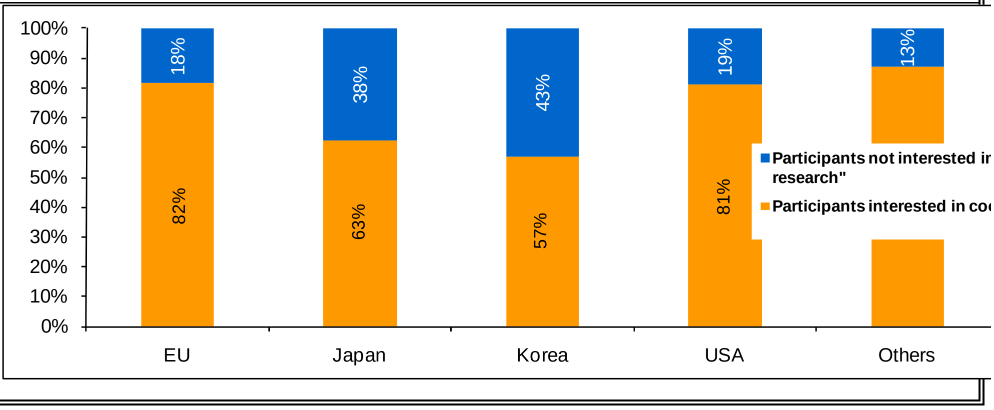
	EU+CH+Norway **US** **Other (Brazil)**	The Microelectronics Teaching Factory at Arizona State University has been operating since 1996, and is a potential research partner, but may also possibly provide extensive input and empirical data. The teaching factory concept is closely linked to activities within the concepts of Learning Factory (University of Stuttgart and Fraunhofer Institute of Manufacturing Engineering and Automation, both Germany and Pennsylvania State University, US), Integrated Learning Factory (University of Washington, US). Potentially, the gaming-based Model Integrated Factory approach being developed at the University of Sao Paulo in Brazil may provide valuable input to combining real with virtual factory education facilities.
Timeline:	Short (next 1-2 years) and medium (next 2-5 years)	
Dependencies:	No dependencies	
Topic Relevance Indicator:	●●●	
Regional Interest for Collaboration:		

5.1.2 RT5.02 Cross sectoral education

<table>
<tr><td>ABSTRACT:</td><td>The manufacturing industry is in constant need for updating their competence across many disciplines as new enabling technologies and global (cultural and societal) development constantly provide new opportunities and challenges. There is a serious need for research to understand how professionals and enterprises can most efficiently acquire such cross sectoral competence on a continuous basis, particularly in SMEs where individuals often need to stay up-to-date in many disciplines.</td></tr>
<tr><td>Technical Content and scope:</td><td>In manufacturing industry there are many cross sectorial education needs, related to understanding of societal and cultural trends, identification of consumers and market opportunities, exploitation of new global business paradigms as well as of innovative materials, ICT and manufacturing technologies. Particularly, bio and sustainability issues as for processes and products require a new culture and manufacturing approach to be disseminated. Safety and well-being of future workers demand also for new cross sectorial education actions, as well as the manufacturing of a new generation of healthy and green products for final consumers. The mentioned education actions are expected to be devoted to different professionals in manufacturing industry: from designers, to engineers, to manufacturers, to suppliers, to retailers and vendors. There is a serious need for research to understand how enterprises can create and increase awareness of these topics and how they could be addressed along the manufacturing value chain in multiple sectors.

Specific related research topics will be: new society needs, new business paradigms, new materials, ICT and manufacturing technologies, sustainable processes and products, safety of workers, well-being of consumers.</td></tr>
<tr><td>Expected results and impact, with special focus on the industrial interest:</td><td>Improved ethical standard of manufacturing enterprises and stronger focus on perspectives of social nature, considering sustainability as well as well-being of workers and consumers. Serious reduction of emissions and resources consumption, improvement of workers safety and consumers well-being.</td></tr>
<tr><td>Specific Features:</td><td>Education and competence development of managers, professionals and workers in manufacturing industry.</td></tr>
<tr><td>Suggested Scheme:</td><td>RTD topic to be included within large collaborative projects as an education related activity necessary to transfer new research results in industrial practice in order to improve sustainability of manufacturing industries as well as well-being of workers and consumers in various sectors.</td></tr>
<tr><td>Additional Information from IMS Regions:</td><td><table><tr><th>Region</th><th>Why / Reference</th></tr><tr><td>US</td><td>Another specific application discussed was how current nanotechnology can be reapplied in ferrous materials

Interviews conducted in the US evidence also the need for advances in this topic, especially the area of Energy</td></tr></table></td></tr>
</table>

	Efficient technologies reapplication – cross industrial sectors. Cross sectoral education is also recognized as Cross-disciplinary Education, Multi-disciplinary education, Inter-disciplinary education etc. Lehigh University (US) has 25 years of experience in bringing cross sectoral education through distance learning to industry personnel. Southern Utah University (US) also has experience with extensive cross-disciplinary training for manufacturing engineers.
Timeline:	Short (next 1-2 years) and medium (next 2-5 years)
Dependencies:	No dependencies
Topic Relevance Indicator:	●●●
Regional Interest for Collaboration:	

5.1.3 RT5.03 Communities of practice

ABSTRACT:	The understanding of the important processes in which individuals develop, use and communicate innovative and dynamic knowledge, outside of the traditional knowledge management systems, is immature. Communities of practice can provide more structure to these knowledge exchange processes within and across organizations, there is a need to better understand how these processes and methods may be established and maintained to make exchange of best practice efficient and sustainable.
Technical Content and scope:	Learning is becoming an urgent topic and even more important is how to learn in innovative ways. Knowledge is a key source of competitive advantage in the business world, but we still have little understanding of how to create and leverage it in practice. Knowing is an enacted, communicated process that is difficult to observe, let alone manage, in organizations. Traditional knowledge management approaches attempt to capture existing knowledge within formal systems, such as databases. But innovative and dynamic knowledge that makes a difference in practice requires the participation of people who are fully engaged in communicating and using knowledge. We frequently say that people are an organization's most important resource. Yet we seldom understand this truism in terms of the communities through which individuals develop and share the capacity to create and use knowledge. This research project would focus on: 1. What is communities in practice 2. How to build such communities 3. The importance of communities in practice; 4. How to make communities in practice grow and sustain. Through case studies of best-practice in the manufacturing industry and other industries, as well as state-of-the art within literature, researchers and the industry would together - through communities in practice - develop a future understanding of communities in practice. This would give the manufacturing industry a new learning method for the future. **1) Defining Communities of Practice** Members of a community are informally bound by what they do together—from engaging in lunchtime discussions to solving difficult problems—and by what they have learned through their mutual engagement in these activities. Communities of practice develop around

things that matter to people. As a result, their practices reflect the members' own understanding of what is important.

2) How to build communities of practice in organization

Communities of practice exist in any organization:

Within businesses: Communities of practice arise as people address problems together;

Across business units: Important knowledge is often distributed in different business units;

Across company boundaries: In some cases, communities of practice become useful by crossing organizational boundaries. For instance in fast-moving industries, employees form a community of practice to keep up with constant technological changes.

Through this research we would find knowledge about how to build communities in practice in and between organizations.

3) The importance of communities to organization

Communities of practice are important to the functioning of any organization, but they become crucial to those that recognize knowledge as a key asset:

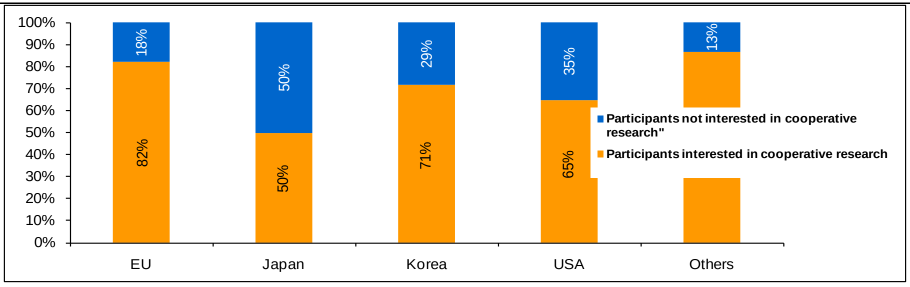
- Communities in practice are nodes for the exchange and interpretation of information;
- Communities of practice preserve the tacit aspects of knowledge that formal systems cannot capture;
- Communities of practice can keep the organization at the cutting edge;
- Communities of practice are organized around what matters to their members, and are therefore a very important source of learning.

To be able to understand why the manufacturing industry should pay attention the communities in practice, we would have to find out more about the importance of communities to organizations.

4) How to make communities in practice grow and sustain

Technology and the internet can facilitate the development of communities in practice, and can help apply knowledge to practice situations. Virtual communities and the internet allow employees in the manufacturing industry to engage in mutual learning not constrained by time and place. There are also many other tools and methods to make

<table>
<tr><td></td><td colspan="2">communities in practice grow and sustain, which would be important to search into. (Source: Etienne Wenger)</td></tr>
<tr><td>**Expected results and impact, with special focus on the industrial interest:**</td><td colspan="2">This research will give the manufacturing industry a **new learning method**: how to *learn from the best (best practice), learn faster, solve problems and be more innovative* through the use of communities in practice.</td></tr>
<tr><td>**Specific Features:**</td><td colspan="2">Education and competence development</td></tr>
<tr><td>**Suggested Scheme:**</td><td colspan="2"></td></tr>
<tr><td rowspan="7">**Additional Information from IMS Regions:**</td><td>**Region**</td><td>**Why / Reference**</td></tr>
<tr><td></td><td>In literature, Communities of practice is a term related to Industry clusters, University-industry clusters, Inter-organizational networks and Knowledge networks.</td></tr>
<tr><td>**EU+CH+ Norway**</td><td>The East Midlands Knowledge Network (UK) has been established as a Community of practice within manufacturing, involving ten universities cooperating towards industry. The Manufacturing, Innovation & Design Partnership is an EU funded knowledge network for SMEs in UK.</td></tr>
<tr><td>**Japan**</td><td>Research on Networking for technology acquisition and transfer is found at the Yokohama National University.</td></tr>
<tr><td>**Korea**</td><td>Seoul National University is conducting research on the establishment of knowledge networks in the manufacturing sector, in turn intended to provide valuable input into the establishment of a National Innovation System. The Information and Communications University is carrying out empirical research on the Daegu industry cluster.</td></tr>
<tr><td>**US**</td><td>Interviews conducted in the US evidence also the need for advances in this topic, especially the area of workforce awareness – Education "Corporate citizenship". Academia focus: Document successful business cases - Competitiveness vs. sustainability “cost”
CAPCE at University of Wisconsin (US) has established a web-based global knowledge network for knowledge (research) exchange with industry.</td></tr>
<tr><td>**Others (Canada)**</td><td>The Waterloo Manufacturing Innovation Network in Canada is an existing knowledge network with empirical experience in joining experts and industry.</td></tr>
<tr><td>**Timeline:**</td><td colspan="2">Short (next 1-2 years) and medium (2-5 years)</td></tr>
</table>

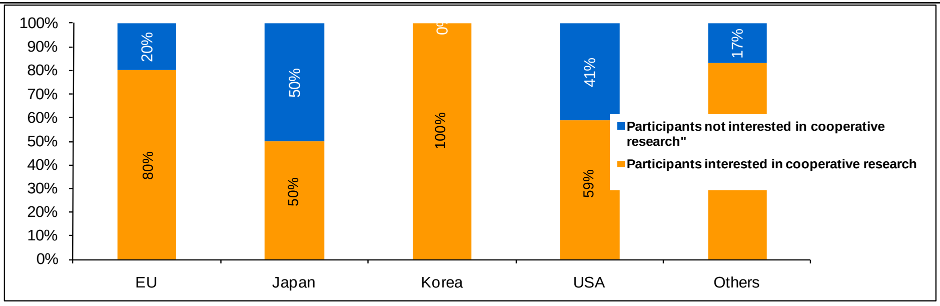
Dependencies:	No dependencies
Topic Relevance Indicator:	● ● ●
Regional Interest for Collaboration:	

5.1.4 RT5.04 From tacit to explicit knowledge

ABSTRACT:	Individuals' tacit knowledge is a crucial component of the enterprises' knowledge base. However, traditional knowledge management systems are not suitable for capturing and externalizing tacit knowledge, a problem particularly critical to SMEs which are vulnerable to loss of core competence when individuals leave the company. Research into how emerging technologies (unstructured tagging, weblogs, wikis, etc.) may help capture tacit knowledge, in conjunction with understanding how this knowledge may be socialized, e.g., through communities of practice, may help companies to better utilize tacit knowledge.
Technical Content and scope:	When Polyani presented his theory of personal knowledge in 1958, he introduced the distinction between tacit and explicit knowledge. He described the nature of tacit knowledge as personal and context-bound and linked to action – hard to articulate and communicate, whereas the explicit knowledge is easier to articulate and communicate. Since then, and particularly over the past decade, the interest in attempting to capture, document and share tacit knowledge as part of the businesses' knowledge management, has flourished. Tacit knowledge has been recognized as being essential for any business in creating business value and sustaining competitive advantage. However, the many failures experienced by companies attempting this may partly be due to the diversity of concepts and tools, partly a lack of understanding of the sometimes complex socio-technical factors which influence the externalization of tacit knowledge (e.g., when using Groupware), and partly due to the often easy and simplistic receipts offered by consultants. The research field is characterized by fuzzy terms, used inconsistently by the many communities that engage in it, partly caused by the various disciplines engaged in it, and the lack of integrative theories for socializing and externalizing tacit knowledge. SMEs are particularly vulnerable to loss of tacit knowledge, as the knowledge is spread across fewer individuals than in a larger enterprise. SMEs often also suffer from not being able to formally document explicit knowledge, such that even the potentially external knowledge remains with the individual employee. Current knowledge management systems often require implementation and maintenance resources that SMEs cannot sustain. The consequence is that SMEs in this situation are unable to make the full use of their people in innovation and improvement projects, impairing not only the company itself, but also its ability to communicate with actors both upstream and downstream in the value chain. Research aiming to mend the problems particular to SMEs is scarce, and even more so when concerning manufacturing SMEs, which is often characterized by highly computerized and automated production systems, in turn representing special challenges in the externalization of tacit

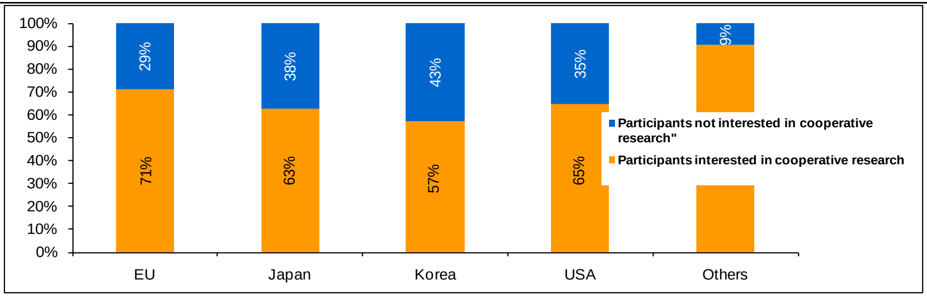
<table>
<tr><td></td><td>knowledge (e.g., “hard” operator skills). Research is required to identify acceptable ways to both socialize and externalize SME competence promoting more effective and efficient organizational learning. Research into hybrid socio-technical systems for knowledge socialization and externalization in SMEs is particularly interesting, as features of new emerging technologies – unstructured tagging, weblogs, wikis and such – show strong promise in overcoming some of the obstacles of documenting knowledge as they exploit digital representation of less formal language than traditional knowledge management systems.

However, the technology alone is insufficient. In close conjunction with the technology development, there is a need for development of conceptual frameworks adapted to manufacturing SMEs:
social interaction and engagement mechanisms for knowledge socialization and externalization;
analyzing, assessing and improving quality of the knowledge socialization and externalization process;
procedures for continuously eliciting both personal and organizational tacit knowledge into the common organizational memory, by continuously updating the quality of the explicit knowledge from the tacit knowledge pool;
incentive mechanisms for knowledge sharing.</td></tr>
<tr><td>Expected results and impact, with special focus on the industrial interest:</td><td>Externalization of tacit knowledge in SMEs to reduce the vulnerability to loss of core competence, and to make the full use of employees’ knowledge in innovation and improvement projects.</td></tr>
<tr><td>Specific Features:</td><td></td></tr>
<tr><td>Suggested Scheme:</td><td></td></tr>
<tr><td>Additional Information from IMS Regions:</td><td><table>
<tr><th>Region</th><th>Why / Reference</th></tr>
<tr><td></td><td>Research activities into externalizing tacit knowledge is widespread worldwide, also within engineering disciplines. Below are examples of universities with research activities within this area shown:</td></tr>
<tr><td>EU+CH+ Norway</td><td>Nancy University (France)</td></tr>
<tr><td>Japan</td><td>Aichi Prefectural University</td></tr>
<tr><td>Others (Australia)</td><td>Monash University and University of Wollongong</td></tr>
</table></td></tr>
<tr><td>Timeline:</td><td>Medium (next 2-5 years)</td></tr>
<tr><td>Dependencies:</td><td>No dependencies</td></tr>
</table>

Topic Relevance Indicator:	● ● ○
Regional Interest for Collaboration:	

5.1.5 RT5.05 Innovation agents

ABSTRACT:	Global innovation agents represent actions in finding and developing innovation and ideas globally, and implementing the new ideas to the manufacturing industry, making sure that innovation and research in the manufacturing industry represent the latest and most innovative areas. Research within this area needs to focus on innovation agents as a concept for learning, and how this may be implemented in the manufacturing industry, e.g., through the identification of state-of-the-art and empirical evidence.
Technical Content and scope:	The term **innovation** means a new way of doing something and refers to changes in thinking, products, processes, or organizations. In many fields, something new must be substantially different to be innovative. In economics the change must increase value, customer value, or producer value. The goal of innovation is positive change, to make someone or something better. Innovation leading to increased productivity is the fundamental source of increasing wealth in an economy. An **agent** is an entity that is capable of action, working on behalf of someone else. A global innovation agent would represent action in finding and developing innovation and ideas globally, implementing the new ideas to the manufacturing industry. Research on the topic global innovation agents and engagement in a development and employment of innovation agents in practice represent a revolution to the manufacturing industry. The global innovation agents role would be to - Accompany enterprises and organizations in the implementation of innovative ideas and models in the manufacturing industry. - To promote constant innovation in enterprises in the industry The research would be focused on the following areas: 1) Look at innovation agents as a method and concept of learning. 2) Search into what has been done regarding innovation agents earlier. 3) Find the latest and most innovative research and development. 4) Implement innovation agents and innovative research in the manufacturing industry.
Expected results and impact, with special focus on the industrial interest:	To establish a network of global innovation agents in the manufacturing industry. The expected results would be new ideas, innovative products and new revolutionary ways of producing in the industry. The industrial interest in such consequences would be growth in income due to customer satisfaction and new sales, and reduced costs due to far more effective ways of producing in the manufacturing industry.

<table>
<tr><td>Specific Features:</td><td></td></tr>
<tr><td>Suggested Scheme:</td><td></td></tr>
<tr><td>Additional Information from IMS Regions:</td><td><table><tr><th>Region</th><th>Why / Reference</th></tr><tr><td>EU+CH+Norway</td><td></td></tr><tr><td>Japan</td><td></td></tr><tr><td>Korea</td><td></td></tr><tr><td>US</td><td></td></tr></table></td></tr>
<tr><td>Timeline:</td><td>Short (next 1-2 years) and medium (next 2-5 years)</td></tr>
<tr><td>Dependencies:</td><td>No dependencies</td></tr>
<tr><td>Topic Relevance Indicator:</td><td>● ○ ○</td></tr>
<tr><td>Regional Interest for Collaboration:</td><td>
</td></tr>
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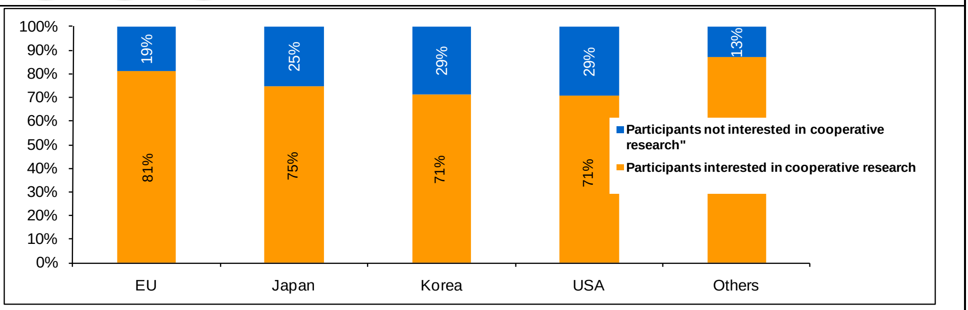
5.1.6 RT5.06 Benchmarking

ABSTRACT:	Benchmarking as a tool is well established, but still lacks refinement to present a powerful mechanism for learning, however, benchmarking has a clear potential as a systematic learning methodology. The proposed research will investigate how benchmarking can be converted into a systematic approach for learning, identify the necessary infrastructure to attain this, as well as undertake pilot implementations to evaluate the effects.
Technical Content and scope:	Benchmarking is a well-documented and tested method to improve performance of companies. It is used to define areas for improvement and gaps in technology and developments of the enterprise. The approaches for conducting benchmarking have evolved; from a strictly quantitative comparison of performance levels to more qualitative comparison of business process and practices. However, even though two authors in the mid-1990s suggested redefining the term benchmarking to *benchlearning*, less focus has been put on the use of benchmarking as a learning and competence development tool. Benchmarking studies primarily emerge as a response to specific improvement needs of an enterprise, often designed as one-way learning efforts where only the initiating organization harvests the benefits, and very rarely look beyond this immediate comparison exercise. Benchmarking has a clear potential as a more systematic learning methodology where a community of enterprises can benefit from practices and solutions to problems created and tested by others. This requires a systematic approach that at the same time both creates the best possible access to best practice learning while protecting the interests and possible intellectual property rights of the inventors of best practices. Attempts have been made at creating “benchmarking clubs” and on-line benchmarking services, but none of these have yet proven highly successful, perhaps because they have been characterized more by commercial interests than the intentions of creating genuine learning systems.
Expected results and impact, with special focus on the industrial interest:	Research in this area should aim to develop a new type of benchmarking approach and infrastructure to support the use of benchmarking as a tool for learning and knowledge sharing among organizations; an improved learning processes based on benchmarking. Research has shown that inside one enterprise or in one sector or region, if those companies performing below average improved their performance to average levels, there would be large gains in effectiveness, efficiency, less environmental impact, etc.
Specific Features:	A new benchmarking approach like the one proposed will require a framework that ensures intellectual property rights and makes it “safe” for enterprises to participate. This might require public intervention or

<table>
<tr><td></td><td>contributions from trade organizations or other parties capable of taking such a neutral mediator role.</td></tr>
<tr><td>Suggested Scheme:</td><td>Establishing such a new benchmarking approach will likely require both a small project to research the new methodology as well as a collaboration project to establish the infrastructure and tests.</td></tr>
<tr><td>Additional Information from IMS Regions:</td><td><table><tr><th>Region</th><th>Why / Reference</th></tr><tr><td></td><td>Benchmarking research is widespread, but rather absent when concerning benchmarking for use in education within the manufacturing industry.</td></tr></table></td></tr>
<tr><td>Timeline:</td><td>Short term (next 1-2 years)</td></tr>
<tr><td>Dependencies:</td><td>No dependencies</td></tr>
<tr><td>Topic Relevance Indicator:</td><td>● ● ○</td></tr>
<tr><td>Regional Interest for Collaboration:</td><td>
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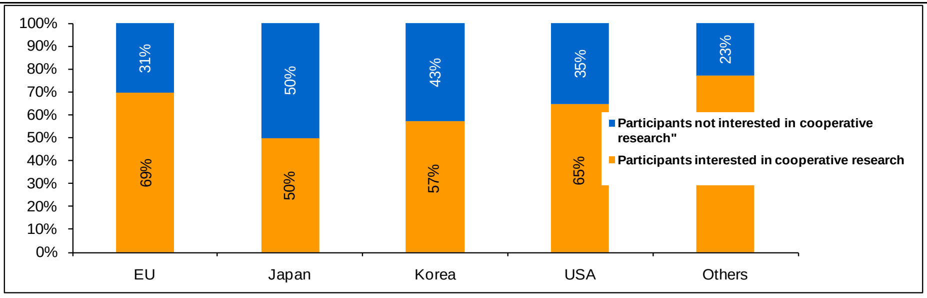
5.1.7 RT5.07 Serious games

ABSTRACT:	In the knowledge society, human capital has become of strategic importance for enterprises and there is a need for more effective technologies and methodologies to support rapid competence development, knowledge externalization and knowledge transfer. The use of serious games for game-based learning empowers enterprises with greater agility in responding to market pressures and needs.
Technical Content and scope:	The existing manufacturing industry is at a crossroads, being threatened by global market pressures and the industry from emerging economies such as Brazil, China and India. Therefore the implementation of paradigms, such as sustainable manufacturing that supports highly personalized products that are customer-oriented whilst remaining environment friendly products, are necessary to keep global competitiveness. However, these new paradigms require the development of human capital, which are afflicted by difficult challenges to overcome such as the ever increasing growth of knowledge; the continuous shortening of acquisition time for new knowledge; the knowledge gap that continues to widens as tacit knowledge is lost with the departure of key individuals; the increased need of working in multi-disciplinary teams in varied geo-political landscape; the need for greater leadership, entrepreneurship and innovation; the understanding of emerging paradigms such as product disassembly, the customer involvement in co-creation of products and services, and energy efficiency manufacturing processes. The research should focus on the creation of innovative competence development platforms (e.g. using serious games) that reinforce the synergy of the individual and organization for learning and creativity. The platforms are to be integrated into existing enterprises, namely their organizational processes, workflows, competency management and knowledge management. A successful project must address clear needs within industrial environment that otherwise cannot be resolved with traditional approaches to knowledge management and competence development.
Expected results and impact, with special focus on the industrial interest:	The expected impact of this topic will significantly contribute to the global competitiveness of European enterprises in a global market place. The results will increase the employability of individuals and empower enterprises with greater agility that enables them to be more effective in their response to market pressures and needs. The use of serious games will also contribute to the gap reduction between large enterprises and SMEs in knowledge management, thus instigating an increase in competitiveness.
Specific Features:	To demonstrate the industrial relevance and impact of the research, projects must have strong industrial participation, namely SMEs that are to have a significant representation with active involvement in research

<table>
<tr><td></td><td>activities and decision process.</td></tr>
<tr><td>Suggested Scheme:</td><td></td></tr>
<tr><td>Additional Information from IMS Regions:</td><td>
<table>
<tr><th>Region</th><th>Why / Reference</th></tr>
<tr><td>EU+CH+Norway</td><td>Serious games for industrial purposes are in rapid development generally. The EU funded project PRIME looks into serious gaming as a means to train professionals within the manufacturing industry of Central and Eastern Europe. In a commercial context, IBM is developing software for serious gaming, and VOLVO (Sweden) has successfully conducted initial serious gaming trials.</td></tr>
<tr><td>US</td><td>Interviews conducted in the US also indicate the need for advances in this topic, especially to strenghten the sustainability concept and awareness in the workforce</td></tr>
</table>
</td></tr>
<tr><td>Timeline:</td><td>2 Medium (next 2-5 years)</td></tr>
<tr><td>Dependencies:</td><td>No dependencies</td></tr>
<tr><td>Topic Relevance Indicator:</td><td>● ○ ○</td></tr>
<tr><td>Regional Interest for Collaboration:</td><td>


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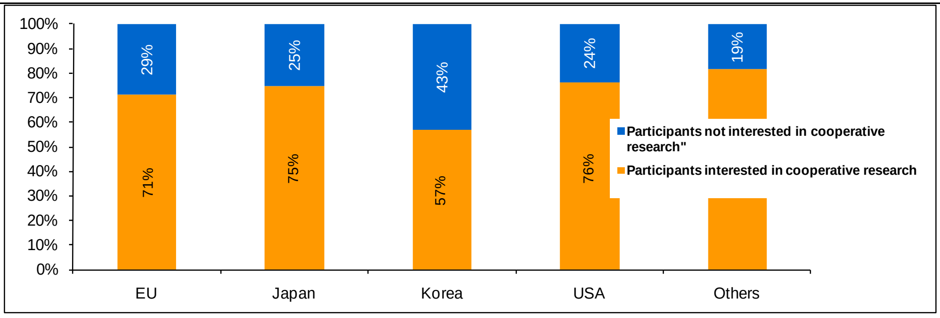
</table>

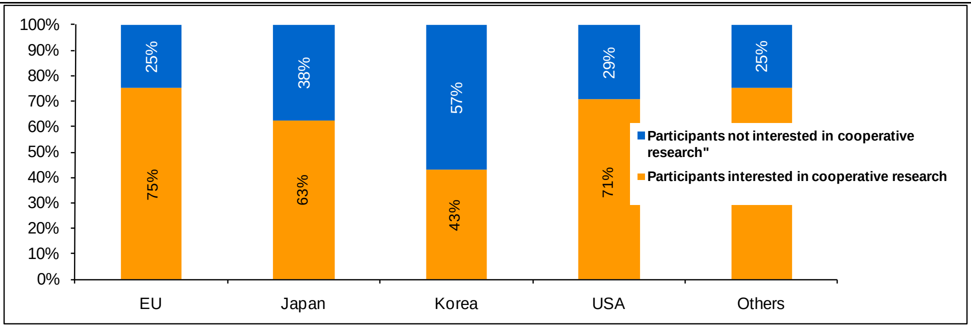
5.1.8 RT5.08 Personalized and ubiquitous learning

ABSTRACT:	Flexible and targeted training of individuals, permitting individuals to choose when and where to learn, is preferable when individuals are required to stay up-to-date in their fields when faced with tight schedules and high workload. Digitalized course module repositories for manufacturing, supported by tutoring systems can be developed and adapted to mobile technology to allow tailored and individualized learning paths, made available through the use of, e.g., mobile technology.
Technical Content and scope:	To stay competent and updated in a world where technology rapidly changes, employees need to continuously upgrade their specific knowledge and expertise. Large corporations often demand that their employees regularly attend courses. Many large corporations have even developed tailor made courses and lecturers themselves. SMEs are rarely in this situation. Their employees are often faced with a high workload dictated by tight schedules. For this category of people, the traditional fixed curriculum is unsuitable, as it is not tailored to the SME's or the individuals' particular needs. Traditional courses are normally comprehensive and may go far beyond the need of the learner, and may also contain a lot of material that the learner is already familiar with. Flexibility in terms of adapting curricula to individual needs, as well as the opportunity to choose when and where to learn, are highly preferable learning characteristics in this context. The idea behind the popular terms eLearning, Technology Enhanced Learning (TEL) and ubiquitous enriched learning is to provide opportunities that may meet the flexibility demand. A framework for creating pedagogically sound mobile services suitable to support ubiquitous enriched learning experiences is under constant development (e.g., in the EU projects - MOBIlearn, WearIT@Work and Natacha). However, the mobile technology's aim is only to support flexible learning. Thus, course contents must be adapted to the new learning situation and the mobile technology. Manufacturing course modules need to be created, digitalized and standardized, e.g., according to the SCORM standard. The courses need to be modularized into so-called learning objects, including learning object metadata for indexing and searching. The metadata need to describe, e.g., difficulty levels of learning objects, preferable learning order of objects, prior knowledge required for the learning object, and learning outcome. Learning objects may in turn be assembled into a learning object repository for manufacturing that provides extended sharing and searching features. The learning object repository must also provide a tutoring system. This should allow individuals to identify gaps in current competence, rank the degree of relevance of learning objects to their intension and preference, and establish, from the provided metadata, an individualized learning path.

<table>
<tr><td></td><td></td></tr>
<tr><td>Expected results and impact, with special focus on the industrial interest:</td><td>Making training on the job more efficient and targeted to the needs of the individual.</td></tr>
<tr><td>Specific Features:</td><td></td></tr>
<tr><td>Suggested Scheme:</td><td></td></tr>
<tr><td>Additional Information from IMS Regions:</td><td><table><tr><th>Region</th><th>Why / Reference</th></tr><tr><td></td><td>Research within Personal and ubiquitous computing is widespread, however, limited within applications for the manufacturing industry.</td></tr></table></td></tr>
<tr><td>Timeline:</td><td>Medium (next 2-5 years)</td></tr>
<tr><td>Dependencies:</td><td>No dependencies</td></tr>
<tr><td>Topic Relevance Indicator:</td><td>● ● ○</td></tr>
<tr><td>Regional Interest for Collaboration:</td><td>
</td></tr>
</table>

5.1.9 RT5.09 Accelerated learning

ABSTRACT:	Systematic learning from experiences and from exploring new ideas, through Problem Based Learning, has a great potential for enabling faster and better take-up of new technology, products and services in the manufacturing industry. Research needs to focus on two parallel activities, i.e., the development of a problem based learning approach enabling training of employees, experience exchange and cooperation within and between organizations, and the development of inter-company exchange programs for stimulating collaborative learning.
Technical Content and scope:	In many European industrial enterprises quality and speedy deliveries have increased markedly in the past decade. However, systematic learning from experiences and from exploring new ideas has not been developed despite its great potential for enabling enterprises to cope with dynamic and complex environment. A key element in this effort is the empowerment of employees to become more self-driven to the extent that they can take initiative to solve complex problems, alone and in cooperation with peers and technical staff. This will require the development of supportive organizational processes aimed at stimulating collaborative learning including explicit as well as tacit knowledge. A successful research project should explore means for carrying out two parallel streams of activities: • a number of development projects to be carried out in industrial enterprises Each project is based on the Problem Based Learning framework and may address issues in a workshop or a whole plant dealing with quality, delivery, productivity issues, among others. A Problem Based Learning approach will provide specific issues to train employees, to exchange experiences, and to stimulate cooperation between universities and enterprises. • inter-company exchange programs During the company development projects an exchange of ideas, methods and results will be organized between projects. This will serve as a stimulus for collaborative learning. Some of the means of such exchange programs are visits to participating companies to audit and benchmark the ongoing development projects, and e-learning systems to support distributed exchange.
Expected results and impact, with special focus on the industrial	The expected impact is to enable enterprises to learn from its learning processes by developing self-driven operators through accelerated learning. This will increase the speed of adapting to new technology by at least 20%. At the same time it will decrease the experimental effort to obtain a solution

<table>
<tr><td>interest:</td><td>can operate with the stability required for maintaining a competitive position. It will also help launching new products or features or services rapidly into emerging markets.</td></tr>
<tr><td>Specific Features:</td><td>This topic is suited for enterprises that are undertaking development projects.</td></tr>
<tr><td>Suggested Scheme:</td><td></td></tr>
<tr><td>Additiona Information from IMS Regions:</td><td><table><tr><th>Region</th><th>Why / Reference</th></tr><tr><td>US</td><td>Interviews conducted in the US evidence also the need for advances in this topic. In particular the role of academia to develop guidelines on evaluation of projects on sustainable business practices / standardize documentation</td></tr></table></td></tr>
<tr><td>Timeline:</td><td>Medium (next 2-5 years) anf long (next 6-7 years)</td></tr>
<tr><td>Dependencies:</td><td>No dependencies</td></tr>
<tr><td>Topic Relevance Indicator:</td><td>● ○ ○</td></tr>
<tr><td>Regional Interest for Collaboration:</td><td>
</td></tr>
</table>

5.2 Research actions connected to other Key Areas

5.2.1 Introduction

The Research Topics (RT) developed are described in Section 5.1. All RTs have been developed to meet the needs and requests for better education and competence development in the Manufacturing Industry.

A specific deliverable (see www.ims2020.net) describes the roadmap for future research development in the areas of – *Sustainable Manufacturing, Energy Efficient Manufacturing and Key Technologies.* There are many links between the proposed research topics in these areas. This means that elements, methodology, results etc. from the Research Topics could be used and implemented in other Key Areas. In some cases RT5 implementations are needed for success in the RTs of other Key Areas. In other cases RT5s is necessary to obtain a good platform for realizing innovation and effective competence building. This is a Key Areas topic where mechanisms for innovation, competence development and education are the core of the research problem.

5.2.2 How could research actions be implemented

The relations (32) between the current Key Area and other Key Areas are shown in Table 2. All Research Topics have relations to the others belonging to different Key Areas . Most relations are identified in RT5.03 Communities of Practice. Use of Serious Games has been evaluated as a promising method for realizing new and better decision making in 5 application areas in other Key Areas.

No	Research Topics	Relevance	No of references to KAT1-3	Others Research Topics
RT5.01	**Teaching Factories**	1	**3**	RT1.13 Maintenance Concept for Sustainability RT1.26 Lean Management for Service Industries RT3.09 Cooperative and Mobile Manufacturing Systems
RT5.02	**Cross Sectoral Education**	1	**3**	RT2.11 Green Manufacturing' for Future Vehicles RT3.08 Model Based Engineering and Sustainability RT3.17 Engineering Asset Management
RT5.03	**Communities of Practice**	1	**7**	RT1.05 Sustainability Workshops RT1.09 Sustainable Packaging RT2.05 Intelligent Utilization of Waste Heat RT2.06 Framework for Collaboration in the Alternative Fuel and Raw Material Market RT2.09 Emission Reduction Technologies RT3.15 Semantic Business Processes RT3.18 Semantic Based Engineering

RT5.04	**From tacit to explicit knowledge**	2	**5**	RT1.08 Predictive maintenance based on embedded information devices RT1.18 Integrated Service Supplier Development RT3.11 Model-Based Manufacturing RT3.15 Semantic Business Processes RT3.18 Semantic Based Engineering
RT5.05	**Innovation Agents**	3	**3**	RT1.06 Cost-Based Product Lifecycle Management (PLM) RT1.07 Remanufacturing for Sustainable Resource Management RT2.04 Energy Autonomous Factory
RT5.06	**Benchmarking**	2	**3**	RT1.22 Alignment of IT and Business Strategies RT1.24 Integrative Logistics Tools for Supply Chain Improvement RT2.11 Green Manufacturing' for Future Vehicles
RT5.07	**Serious Games**	2	**5**	RT1.12 Sustainable SMEs RT1.21 Sustainable Supply Chain Design RT1.23 Multi-dimensional Inventory Management RT3.04 Lower Labour and Energy Cost Performance RT3.13 High Resolution Total Supply Chain Management
RT5.08	**Personalized and ubiquitous Learning**	2	**1**	RT1.15 New workplaces for Aging and Disabled Workers
RT5.09	**Accelerated Learning**	3	**2**	RT1.17 Exploiting Disruptive Innovation for Sustainability RT2.02 Integrating Energy Efficiency in Production Information Systems

Table 2 Overview of KAT5 Research Topics implemented in KAT1-KAT3

Short descriptions of how the different Research Topics have been implemented in other Key Areas are given in the following.

RT5.01 Teaching Factories

Teaching factories are real production facilities established and organized to suit education and training purposes. Such factories aim to close the gap between training capabilities and industrial needs. This was suggested to be especially applicable in three of the RTs of other Key Areas.

Management skills are easier acquired when training is performed in a real environment. The results of management decisions appear as successful or unsuccessful process outcomes. In RT1.13 suggests to set up a teaching factory for developing a concept for maintenance sustainability, and RT1.26 suggest to set up teaching factories to cover lean management of services. Developing and implementing lean management in the service industry requires both motivation and learning. For such problems learning by doing has proven quite effective and a teaching factory concept is recommended. A specific type of service based on research to a showcase must be selected.

RT3.09 outlines new factory concepts based on interaction between robots and human workers. Teaching factories will provide real working environments facilitating concurrent management, operation, testing and training.

RT5.02 Cross Sectoral Education

Many technologies are developed and applied in a number of different industries. Business paradigms evolve on industry specific demands and appear applicable to other industries. At such conditions cross sectoral education is appropriate, and the development of such mechanisms was found to be highly relevant in three of the RTs of other Key Areas.

In RT3.08 the benefits of model-based engineering concepts is highlighted. Such engineering models can usually be adopted by different industries and sectors, and education tools with cross sectoral application will benefit a number of industries. RT2.11 focuses specifically on green manufacturing for the automotive industry. Whilst this is one of the major industries of the IMS regions, we need tools to enable knowledge sharing between car producers and other industries. The purpose is to facilitate cooperation and identification of new ideas for greener manufacturing. Education and training of engineers and managers on holistic approaches; energy related evaluation competence; energy waste awareness, and green manufacturing mindset are necessary.

RT3.17 highlights the emerging inter-disciplinary field of engineering asset management. This combines technical issues with financial and managerial requirements. Engineering asset management creates a need for cross sectoral education related to understanding of societal and cultural trends, identification of consumers and market opportunities, exploitation of new global business paradigms as well as of innovative materials, ICT and manufacturing technologies. Safety and well-being of future workers as well as the manufacturing of a new generation of healthy and green products for final consumers calls for new cross sectoral education actions. Research is needed to understand how enterprises can create and increase awareness of these topics and how they could be addressed along the manufacturing value chain in multiple sectors.

RT5.03 Communities of practice

As described in Section 5.1, Communities of practice is a mechanism for sharing of best practice that will work on an industry wide arena. This mechanism was identified as particularly relevant in seven of the Key Areas RTs.

For the *RT1.09 Sustainable Packaging* this has been identified as a very feasible mechanism. Packaging is used in most industries and sectors, and some industries have given attention to the sustainability aspects of packaging for some time. In order to develop sustainable packaging systems, cooperation between stakeholders throughout the supply chain is required. Such cooperation can be implemented by the use of Communities of Practice, involving packaging suppliers, packaging equipment manufacturers, users of packaging, return logistics providers, government and research organizations. Similarly will multiple organizations and the society as a whole benefit from a widened knowledge base related to technologies for emission reduction (RT2.09) and waste heat utilization (RT2.05).

RT5.04 From tacit to explicit knowledge

This mechanism was reported to be highly relevant to five of the RTs of other Key Areas. The purpose of turning tacit knowledge into explicit knowledge is to increase availability of experience, knowledge and understanding. Eliciting and externalizing tacit knowledge to reduce the vulnerability to loss of core competence and to allow SMEs to make full use of employees' competence in improvement and innovation projects is at the core of this concept.

The concept of moving knowledge from tacit to explicit is identified as particularly relevant in for instance the *RT1.18 Integrated Service Supplier Development*. Service supplier relationships offer great opportunities for networking and sharing of knowledge and competence between the network of buyers and providers of services. However, much of the knowledge on what, why and when services are needed are not explicitly expressed, but rather exist as tacit knowledge held by a limited number of operators. This knowledge cannot lead to service improvements unless it is disclosed. A systematic approach for transforming tacit knowledge to explicit knowledge available to all network members should be addressed.

In addition to methods and arenas for exchange of knowledge between humans we see an increasing number of technologies that are used to acquire knowledge that would over time become tacit in an operator's daily work. Typically, these are semantic based (RT3.15, RT3.18) and embedded data collection technologies (RT1.08). While they are designed to transform information into knowledge we still need to prepare arenas for the acknowledgement and distribution of this information.

RT5.05 Innovation Agents

Global innovation agents represent actions in finding and developing innovation and ideas globally, and implementing the new ideas to the manufacturing industry, making sure that innovation and research in the manufacturing industry represent the latest and most innovative areas. Research within this area needs to focus on innovation agents as a concept for learning, and how this may be implemented in the manufacturing industry. Use of different innovation agents would be useful to meet challenges in management of knowledge in several areas (RT1.06, RT1.07, RT2.04 and probably more).

Use of multi agent approaches to obtain cost and "green" data from a complete product life cycle (RT1.06, RT2.11) will involve different types of agents - innovation agents (human resources) as well as product agents. Methodology to retrieve, analyse, manage and reuse these data will result in cost effective and "green products" and benefit for the users.

The objective of RT2.04 is to reduce energy consumption and to guarantee a reliable energy supply by developing technologies and frameworks for production-sites, which enable self-dependent energy generation according to the actual on-site demand and facilitate the use of renewable energy sources. To achieve these goals, it is necessary to create new innovation processes. These processes need to combine different skills in order to boost creativity. A good learning effect in this context could be obtained using the concept of innovation agents. An innovation agent should be appointed in the flagship project. He or she will have a special responsibility of promoting and facilitating innovation.

In RT1.07 use of multi agent approaches to obtain data for sustainable remanufacturing could involve innovation agents of different kinds. Also human agents will be needed to modify, evaluate and conclude on optimal solutions and decisions. Methodologies to retrieve, analyse, manage and reuse these data will result in benefit for the users and the society.

RT5.06 Benchmarking

Benchmarking as a tool is well established, but still lacks refinement to present a powerful mechanism for learning, however, benchmarking has a clear potential as a systematic learning methodology. The research will investigate how benchmarking can be converted into a systematic approach for learning, identify the necessary infrastructure to attain this, as well as undertake pilot implementations to evaluate the effects.

RT1.22 *Alignment of IT and Business Strategies* addresses the lack of knowledge regarding the ability to measure the indirect contribution of the IT department to the success of an enterprise. How to set up control and measurement standards to align IT activities to strategic company goals is a big challenge. To facilitate a good learning process, benchmarking may be applied. However, new benchmarking tools need to be researched and developed for this purpose to have easy access to best practices. This is proposed to be done in RT5.06.

Local optimizations in the logistics chain often lead to inefficiencies at another place. Therefore, tools to cooperate within a supply chain, to harmonize the logistics, and to improve the overall performance have to be found, implemented and summarized in a tool box (RT1.24). A benchmarking model developed as a generic learning system will be beneficial to members of supply networks including the end customers also. A generic learning tool will be applicable across industry sectors.

Taking into account the interdependencies of product design and the manufacturing process, new possibilities of car-manufacturing due to new product architecture of “green cars” (e.g. hybrid, electrical cars) should be analysed and new energy efficient production concepts developed (RT2.11). Green manufacturing need focus on different research areas (technology, sustainability, cooperation etc.). Benchmarking with other sectors is needed to identify and implement best practice.

RT5.07 Serious games

The mechanism of “Serious Games” was identified to be of high relevance to five of the RTs of other Key Areas. The concept has evolved as a result of acknowledging the need for innovative competence development platforms that reinforce the synergy of the individual and organization for learning and creativity.

In contexts where combinations of multiple factors influence the outcome, simulation techniques are often found very valuable, see for instance *RT1.21 Sustainable supply chain design, RT1.23 Multi-dimensional inventory management* and *RT3.13 High resolution total* *supply chain management.* A Serious Games approach is a powerful simulation technique. A virtual business environment is established to facilitate playing with different solutions to identify those who will work under different conditions. Moreover, the use of a serious games technique will stimulate learning and reflection.

RT5.08 Personalized and ubiquitous learning

Flexible and targeted training of individuals, permitting individuals to choose when and where to learn, is preferable when individuals are required to stay up-to-date in their fields when faced with tight schedules and high workload. Digitalized course module repositories for manufacturing, supported by tutoring systems can be developed and adapted to mobile technology to allow tailored and individualized learning paths, made available through the use of, e.g., mobile technology.

RT1.15 focuses on *New workplaces for Aging and Disabled Workers*. In the aging society also workers in manufacturing companies are affected. Moreover, integration of disabled people is starting to be an important issue. Considering these social aspects companies have to renew the work processes. For this reason new approaches have to be developed using new tools (design for all), workplaces, working methodologies or special training. To face these changes, companies need to redesign their working environment and processes. They have to consider the "design for all" paradigm when designing new tools, equipment and machines. To complement the redesigned working environments, personalised learning schemes for aging and disabled workers must be developed. These workers have different learning needs based on for instance medical diagnosis, education and former work experience, thus, the learning schemes must be flexible and tailored to the specific conditions and pre-qualifications of the individual worker.

RT5.09 Accelerated Learning

Systematic learning from experiences and from exploring new ideas, through Problem Based Learning, has a great potential for enabling faster and better take-up of new technology, products and services in the manufacturing industry. Research needs to focus on two parallel activities, i.e., the development of a problem based learning approach enabling training of employees, experience exchange and cooperation within and between organizations, and the development of inter-company exchange programs for stimulating collaborative learning.

Manufacturing companies need to change their approach to innovation if they want to face the current turbulent market. When developing new solutions companies need to take into account sustainability issues. Research is needed to develop methodologies and tools to manage and run simultaneously incremental and disruptive innovation, to exploit their potential for sustainability (RT1.17). The new approach to innovation will most probably use workshops to discuss ideas and experience from on-going innovation projects in the organization. This could lead to projects directed at developing new products or services, or projects addressing new manufacturing technology or systems. These projects could be used across the organization and also external organisations to stimulate learning processes. The learning should be targeted at a special field, for example, how to resolve quality issues in assembly of complex products. The participants should exchange ideas, methods and results from their on-going projects of relevance to the selected learning topic. This will serve as a stimulus for collaborative learning.

RT2.02 describes a novel framework that manages and optimizes energy efficiency with respect to production planning and control. This needs to be developed and implemented in enterprise control and information systems, such as Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), and Distributed Control Systems (DCS). In order to incorporate environmental concerns into the production planning systems it is fundamental to establish company cultures of awareness and continuous improvements. Programmes on accelerated learning should be developed where all the processes from product design to assembly and packaging are reconfigured by a lean approach to achieve fewer, faster and more energy efficient solutions. Such programmes will maintain a continuous attention to the environmental concern of the production system.

5.3 Needs for training and education in other Key Areas

5.3.1 Introduction

The manufacturing industry faces huge technical challenges as it pursues the development of new processes and products. In this pursuit, the availability of skilled Human Resources is of vital importance. Training activities are then essential in order to create a critical mass of valuable competences able to induce sustainable innovation in industries.

Specific research targets related to advanced manufacturing systems produce a double influence on training activities.

A “pull” action is related to the introduction of new technologies at industrial level. Such introduction has the effect of skill-biased technological change, shifting relative demand towards highly educated workers. The reason for such a bias is that in order to deal with the various problems resulting from the introduction of a new and unfamiliar production technology, along with scientific knowledge, logical reasoning and cognitive skills are required. The pursuing of new technological targets then requires specific competences to be transferred to manufacturing workers and stakeholders.

A second “push” action is related to the availability of skilled workers, new teaching methods and actions aimed at competence transfer. Such capability to create and transfer new competence can significantly reinforce innovation actions. Moreover, training actions are specifically required to put in practice new technologies. Training activities are thus integral part of research and development actions. In particular complex innovation targets, exceeding traditional boundaries of application, are oriented to a holistic approach: such targets are based on training actions to create common knowledge environments where coordinated actions have to be developed. Push actions also require improved delivery mechanisms in order to face the increasing amount of competences to be implemented. Such mechanisms must be focused on learning effectiveness and on fast reusability of educational formats in order to rearrange the mix of required educational contents.

In the following paragraphs several specific training needs will be identified following the IMS 2020 vision. Such an analysis will be carried out with reference to training in specific key areas and to expected pull/push impacts of training in such areas.

Secondly, a review on enhanced learning and delivery mechanisms addressed by new educational needs will be dealt with.

5.3.2 Training areas addressed by research needs

Different research topics require on one side development of new competences and on the other side specific training actions in order to implement related innovation actions. For each proposed research topic the key competences needed and the related specific training activities have been identified.

Moreover, the relevance of training is indicated with respect to the IMS Research topics as follows:

- low relevance is related to general absence of foreseen training mechanism,
- medium relevance is related to soft action on knowledge transfer (e.g. standardization activities, guidelines etc.) combined with general training on high level competences.
- high relevance is related to necessity of specific “ad-hoc” actions combined with adoption of new tools and methodologies for Knowledge transfer and training.

Sustainable Manufacturing

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT1.01 - Quality Embedded Manufacturing	3	Implement and use of following technology by production personnel: Remote monitoring, Quality management methods and tools (internet, wireless mobile telecommunication technologies, wireless sensors, machine-to-machine communication, Radio Frequency Identification, micro-electromechanical systems, various sensors), Product identification technologies (smart tags, Auto-IDs, Product Embedded Information Devices), and intelligent product design.	Learning about implementation of new technologies in production environment. Tools, cases and demos to visualize and perform good training need.	High
RT1.02 - Green Controller for Machining	1	Physics of the machining processes, environmental impacts of production processes and their monitoring and control.	No training action foreseen	Low
RT1.03 - Real-time Life Cycle Assessment	3	Lifecycle data information, Life Cycle Costing, Life Cycle Assessment, Product life cycle standard.	Ad-hoc delivery mechanisms (tutorials, practical examples, serious games, etc.) to allow designers to understand the importance of the new tools and how to use them. A tool, such as a “teaching design department” has to be set up to allow training of designers; this can be supported with a serious game/simulation of designing with special problems to be addressed using the new tools. The concept of communities of practice should be applied to support knowledge and experience exchange between designers both within and across companies.	High
RT1.04 - Sustainability Metrics	2	Metrics of products and processes oriented to sustainability, Environmental and performance standard, Lifecycle data information.	No training action foreseen	Low
RT1.05 - Sustainability Workshops	3	Sustainability technologies, business models and solutions, sustainability issues for manufacturing.	Learning industrial communities using collaborative ICT tools in order to exchange of best practices and ideas between industries and research. Training for Designers and production engineers in order to adopt developed standards and procedures and identify what kind of standards are still missing. Training oriented to initiate citizen awareness actions.	High

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT1.06 - Cost-Based Product Lifecycle Management (PLM)	3	Multi-agent approaches applied to Life Cycle Costing, RFID (Radio Frequency Identification), sensor technologies, wireless network/internet infrastructures, Lifecycle data information, and methodologies for retrieve, analyze, manage and reuse of quantitative lifecycle data.	Stakeholders and users along a product life cycle (design, production, maintenance, user, recycling etc) need to be trained in cost relevant perspectives to obtain new mindsets.	Medium
RT1.07 – EOL Management Supporting Technologies	1	Multi-agent approaches, Radio Frequency Identification, real-time information management, Design for Disassembly, sensor technologies.	No training action foreseen	Low
RT1.08 - Predictive maintenance	2	Closed-Loop PLM based on Embedded Information Devices, Embedded Information Devices, Data-Information-Knowledge, Lifecycle data management	Training for designers, production engineers and business managers in order to adopt developed methods and tools.	Medium
RT1.09 - Sustainable Packaging	1	Environmental Assessment criteria, Green materials, Standards and regulation. Packaging prevention, minimization, reuse/return, recycling, energy recovery and disposal.	Communities of Practice, involving both packaging suppliers, packaging equipment manufacturers, users of packaging, government and research organizations.	High
RT1.10 - Optimization of Electronic Sustainability	1	Advanced identification (RFTags) technologies, New advanced materials Advances, Material recyclability, Standards and regulation for materials, Lifecycle data management.	No training action foreseen	Low
RT1.11 - Materials re-use optimization	1	Self disassembly technologies, de-manufacture methods, technologies for composite materials, IT tools, material recycle and reuse, Environmental standards and regulation.	Creation of a community to share know how and best practices. Definition of new standard as vector of training.	High
RT1.12 - Sustainable SMEs	3	Sustainable business models for SME framework, methodology and tools to perform simulation of strategies and models of sustainable SMEs, Managerial techniques for the sustainable management. New standard tools and indicators (KPI) for sustainability tacking, i.e. to monitor and assess 'sustainable' performances of enterprises	Educating, training and developing SME employees to have long life learning attitude and skills. Sustainability education and training of employees New methodologies for education/training based on new IT tools. Sustainable leadership education curriculum to enable business leaders to turn sustainable strategies into a competitive edge with increased revenue potential by intensively working with concepts around the Triple Bottom Line of sustainability, Corporate Social Responsibility (CSR) and sustainability tracking.	High
RT1.13 - Maintenance Concept for Sustainability	2	New evaluation concepts integrating sustainability related aspects (e.g. Total Cost of Ownership (TCO) calculations, energy efficiency) into maintenance management, machine energy and resource consumption, sensor technologies, data interfaces	Demonstration activities, including pilot implementations in industrial settings. Besides validating the achieved research results these industrial settings should reveal optimal approaches of training employees and students in the field of maintenance for sustainability. The setup of teaching factories will provide a valuable means of training students and employees in sustainable maintenance concepts.	High
RT1.14 - Additive Forming Processes for Manufacturing	1	Additive manufacturing of products components, new business models, environmental impact evaluation , design for light and performing products with low resources usage, methodologies and tools for mass customization and consumer design.	The research has to develop proper education/training material for designers and consumers to properly use the new design methodologies and tools.	Medium

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT1.15 – New workplaces for Aging and Disabled Workers	1	New tools (design for all), ergonomic workplaces, new working methodologies, New business models, personalised learning schemes for aging and disabled workers	Learning schemes must be flexible and tailored to the specific conditions and pre-qualifications of the individual worker. New training material for ageing / disabled workers has to be developed.	High
RT1.16 – Resource Recovery from Alternative Fuels and Raw Materials	1	Recovery of elements contained in product material streams, material recycling, energy recovery, waste treatment, mining.	No training action foreseen	Low
RT1.17 – Exploiting Disruptive Innovation for Sustainability	2	Analysis of the market fringes, existing technologies and existing corporate activity. Methodologies and tools for recognizing discontinuous events and disruptive technologies. Methodologies and tools for developing alternative strategic frames. Methodologies for decentralised resource allocation strategies, Tools to monitor idea portfolio. New organizational methodologies, Technological tools for supporting scenario analysis, benchmark tool.	Engineers and managers need to be trained to adopt developed instruments.	Medium
RT1.18 – Integrated Service Supplier Development	3	Standardized methods and tools for the definition of the relevant interfaces,	Soft action - Need of institutionalized standardization to guaranty for reference processes, interfaces and common performance indicators.	Medium
RT1.19 – Product-Service Engineering	3	Integrated product and service engineering, Business models and KPI measures for Product-Service businesses, Architectures, systems and tools to be used as framework for product-service businesses, Standards for description of the solution components (products and services), their interfaces and the underlying processes. Product data models and product and process specifications.	Soft action - Standardization process should develop a standardization community	Low
RT1.20 - Sustainable Data Management	2	Electronic exchange of information and order related documents, enterprise resource planning, standardization of exchange data in vertical and horizontal directions.	No training action foreseen	Low
RT1.21 - Sustainable Supply Chain Design	3	New methods for the calculation and comparison of all aspects of production, new holistic decision model, product complexity, customer requirements, variability regarding customer and environment	In Serious Games approach a virtual business environment is established to facilitate playing with different solutions to identify those who will work under different conditions. Moreover, the use of a serious games technique will stimulate learning and reflection. Serious game technique can be applied irrespective of industry and education level.	High
RT1.22 – Alignment of IT and Business Strategies	2	IT department measurement, IT-product catalogues and standards, Business management, model of description for IT performances.	No training action foreseen	Low

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT1.23 – Multi-dimensional Inventory Management	2	Supply chain management, Emerging technologies that support higher information flow, cost-benefit-sharing model	Demonstration activities need to incorporate the development of a game based tool able to visualize the cost reduction impact of such a general model. Applying this tool in a specific supply chain needs to show the concrete benefits for every single stage. Such a simulator will illustrate the supply chain perspective and aid in the work of building a common basis for overall optimization and the use of incentive mechanisms.	High
RT1.24 – Integrative Logistics Tools for Supply Chain Improvement	3	Supply chain management, tools for cooperation within a supply chain, tools for logistics harmonizing, tool for evaluation and optimization of supply chain performance	No training action foreseen	low
RT1.25 - Sustainable Supply Chain Design	1	Integrated analysis of the product life cycle, Technologies and methodologies to measure and assess footprint of manufacturing on the environment, human health and safety. Environmental standards for manufacturing processes and products. New and improved green production methods that eliminate or reduce hazardous substances/processes from the entire value chain of the products. ICT based techniques and services that prevent the footprint of hazardous processes, Eco-technologies preventing damages on the environment or human health.	No training action foreseen	low
RT1.26 – Lean Management for Service Industries	2	Holistic approaches for the management of service production, Target-oriented implementation approaches, Tools and methods for management of service production based on service-specific lean principles, Demonstrating for pure service providers, manufacturing service providers and service providing manufacturers. Methodologies for accuracy (zero-defect, zero waste), methodologies for high robustness to handle unexpected events, control and configurations systems.	For such problems learning by doing has proven quite effective. This is well handled by the concept of the teaching factory. A teaching factory should be set up covering management of services. A specific type of service has to be selected and these services have to be developed based on research to a showcase. This should be utilized to train other industries.	High

Table 3 Training and competence needs in Sustainable Manufacturing

Energy Efficient Manufacturing

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT2.01 - Energy-aware Manufacturing Processes – Measurement and Control	3	Energy management and control system in manufacturing , Energy Key Performance Indicator (KPIs), new sensors and visual systems for in-process measurement, ICT to measure and evaluate Energy-KPIs, energy control and optimization systems, Standard on Energy management Systems	Training and education is needed for in process measurement, new concepts considering EEM, KPI visualization, and benchmarking.	High

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT2.02 - Integrating Energy Efficiency in Production Information Systems	3	Energy efficiency with respect to production planning and control, Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), and Distributed Control Systems (DCS), Supply Chain Management (SCM), criteria to evaluate energy consumption and emissions for manufacturing activities, enterprise information systems standardization	Programmes on accelerated learning should be developed where all the processes from product design to assembly and packaging are reconfigured by a lean approach to achieve fewer, faster and more energy efficient solutions. Such programmes will maintain a continuous attention to the environmental concern of the production system.	High
RT2.03 - Using Energy Harvesting for Powering Electrical Sensors and Devices in Manufacturing Processes	2	Sensors' and controllers' energy storage devices, new technologies to recover energy from the environment, potentials of the energy sources, application of harvesting technologies to manufacturing processes	No training action foreseen	Low
RT2.04 - Energy Autonomous Factory	3	Factory-optimized on-site energy generation concepts, Energy saving techniques, Energy control and distribution for consumer/machine ("smart grid"), Alternative energy sources selection and management, Energy efficiency of the individual energy production, Technology for decentralized energy generation and distribution, Power storage in process integration.	Employees should be trained in "net-zero-energy-culture", and trained to save energy. They should develop knowledge about efficiencies when distributing energy in the factory.	High
RT2.05 - Intelligent Utilization of Waste Heat	3	Cross-plant analysis of waste heat recovery potentials, recovery technologies , optimized utilization of heat at various temperature levels including low temperature waste heat. key performance indicators for analysis methods on plant, advanced technology for medium and especially low temperature heat recovery, industrial collaboration in cross-plant networks	The concepts of Communities of practice should be exploited for this purpose. The applicability of the developed methodologies, technologies and co-operations should be demonstrated. Corresponding standards especially for the analytical methods are required.	High
RT2.06 - Framework for Collaboration in the Alternative Fuel and Raw Material Market	1	Methodologies and strategies for cross-industry and cross-sector collaboration. Co-processing of waste in industrial processes. Alternative fuels and raw materials (AFR). Synergies in the treatment of the waste materials, new efficient heating technologies, innovative compositions using alternative raw materials and waste, waste stream identification and potential reuse.	The cross-industry and cross-sector collaborative networks will exchange information and experience and thus contribute to the development of a learning community (community of practice). The application of alternative fuel and raw material represents a new approach that requires a mind shift and thus a radical new way of developing the necessary competence to effectively manage future manufacturing development.	High

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT2.07 - Technological Access to Wastes for Enhanced Utilization	1	Utilization of alternative fuels and raw materials, derived from waste. Technological advances in pre-treatment and upgrade options. Co-processing of waste as raw material, as a source of energy, or both to replace natural mineral resources (material recycling) and fossil fuels (energy recovery) in industrial processes. Development of production processes designed to cope with AFR. New efficient heating technologies, innovative compositions using alternative raw materials and waste, waste stream identification and potential reuse.	No training actions foreseen	Low
RT2.08 - Product Tags for Holistic Value Chain Improvement	2	Information system management, Standardized approaches for measurement and evaluation regarding energy consumption (and possibly data such as costs, quality or lead time) and data semantics, product Key performance indicator, Life Cycle Assessment (LCA), Life Cycle Costing, Total Cost of Ownership, Six Sigma.	The industrial partners in the project provide the manufacturing data required for the value chain information system and ensure practicability and industrial relevance. As neutral facilitator, academia provides the project approach, executes the data analyses and evaluation, and the software development.	Low
RT2.09 - Emission Reduction Technologies	1	New secondary emission abatement technologies (mainly focusing on CO2, NOx, SOx, dust and heavy metals) ,energy efficiency and thus less consumption of electrical or thermal energy input, cross-sector/industry approaches.	Cross sectorial education and competence sharing is necessary to attain the goals of this research topic. This may be attained by sustaining and expanding the communities established during the research and innovation effort. Competence development and education need to be done through Communities of Practice. Researchers and industry may investigate and solve problems, explore innovative solutions, and adapt them across sectors faster than in traditional learning. The set-up of virtual communities must be explored and state-of-the-art approaches to Communities of Practice adapted to engage in mutual learning not constrained by time and space. Tools and methods for sustaining such communities must be explored.	High
RT2.10 - Energy Efficient Particle Size Reduction	1	New grinding concepts and principles (e.g. pre-treatments, flexible grinding systems) New particle size reduction technologies. Product life cycle management, Pre-treatments, processing steps management, process simulation to adapt to varying requirements, flexible grinding systems.	No training actions foreseen	Low

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT2.11 - 'Green Manufacturing' for Future Vehicles	2	Research should therefore focus on the impact of new automobile architecture/design on manufacturing processes. The aim is to develop a framework that facilitates the green manufacturing of future vehicles. Energy related evaluation competence; energy waste awareness, and green manufacturing mindset. Manufacturing process planning and management, use of renewable energy sources, energy recovery, recycle and reuse of vehicle materials, use of recycled materials, use of "Carbon neutral" materials (priority on Biopolymers, Natural fibres), improvement / alternatives to energy intensive processes (priority on Painting), carbon footprint based selection of materials, optimization of logistics and sourcing.	Tools for sharing of knowledge (cross sectorial education) between car producers and other industries need to be developed for cooperation and identification of new ideas for greener manufacturing. Education and training of engineers and managers on holistic approaches.	High

Table 4 Training and competence needs in Energy Efficient Manufacturing

Key Technologies

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT3.01 – Modular Assembly Disassembly Production Systems	3	New systems for assembly/disassembly, new modular product architectures; modelling tools for the strategic planning of the systems evolution, intelligent cognitive elements to learn, real time diagnostic features for in-situ simulations, new configurable modular systems for assemblies; advanced automation and manufacturing control systems; models for adaptation of modular systems for assembly/disassembly, new assembly and disassembly systems for aging workers and disabled people; "efficient grinding" for disassembly, interoperability early standards; modularity with module language; standardization of environmental evaluation methods of manufacturing systems; design rules and guidelines for the integration of sustainable dimensions.	intelligent cognitive elements to learn actual situation of the systems in real time and develop in-situ simulations. Standardization of environmental evaluation methods of manufacturing systems; design rules and guidelines for the integration of sustainable dimensions.	Low
RT3.02 – Control for Adaptability of Manufacturing Processes	2	Integrated process models, analysis of machine signals, self-learning techniques, cognitive and adaptive control systems, plug-and-play interfaces, real-time control systems , Agent Control Technologies, Holonic Manufacturing systems, service-oriented control architectures, methods for representing high-complex production processes, adaptronic modules with embedded intelligence, multi-layer controls and model-based real-time compensation routines, wireless communication mechanisms, flexible system busses with integrated power supply , data analysis with respect to the different manufacturing processes and involved analysis algorithms. Integration of simulation systems at different level, Manufacturing Execution Systems (MES) , machine/process level control.	No training actions foreseen	Low
RT3.03 – Mutable Production Systems	3	Reconfigurable productive systems, tools for configuring production systems and performance simulation, intelligent and adaptronic modules equipped with standardized mechatronic interfaces and integrated power supply systems, self-learning capabilities in adaptronic modules, multi-layer controls and model-based real-time routines, wireless communication mechanisms, mechatronic modules integration into multi-functional productions systems that are capable of tackling any manufacturing process for mass customised manufactured products.	No training actions foreseen	Low
RT3.04 - New technologies and approaches for competitive sustainable businesses	1	Methods to improve the effectiveness of human tasks in manufacturing organisations, ICT Technologies for concurrent and distributed engineering activities within networks of companies and research centres, Effectiveness of manufacturing processes, machines/equipment and manufacturing systems. Energy management software at plant level.	Safety standards, energy labels. Demonstrators of the application of the above methodology in industrial sites Training for sustainability consciousness, engineers to adopt developed optimization frameworks.	Medium
RT3.05 - Interoperable Products and Production data exchange	2	Collaborative planning, management and optimisation of production and logistic resources, including the production planning and capacity management in non-hierarchical company networks, management and optimisation of production and logistic resources. Decentralised ICT systems for planning, scheduling and control based on distributed models and tools. Semantic of shared information and exchanged services. Information Technologies unifying the monitoring, operation and planning activities across a network and capable of providing the specific functionalities for the needs of a company; Cross-sectoral and multi-standard product and production field data ontologies.	ICT standards and involvement of supply chains in the projects. Education and training measures for new skills of production managers and engineers of different companies along the value chain to adopt common standards and mindset.	Medium

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT3.06 - Build-to-Order - New Production Planning and Control Models for Complex Individualized Products	3	Cooperation mechanism, sharing information, new production planning and control approaches able to coordinate the production activities in a highly customer-individualized market environment, robust production performance against external uncertain events , stochastic modelling of the uncertain events and risk concept tailored to the specific characteristic of production planning in non-hierarchical systems, cutting edge technology of combinatorial optimization.	Extensions of the existing standard can be proposed to support the developed approaches.	Low
RT3.07 - Efficient Use of Raw Materials	1	"Zero-waste" and "zero-defect" technology for manufacturing processes, resource efficiency and energy efficiency, accuracy of machines, new manufacturing methods, modelling and simulation tools and/or the integration of monitoring and control techniques. Information and Communication Technology (ICT) in combination with the manufacturing equipment. Near-net or finishing techniques. Application of materials with pertinent characteristics to improve manufacturing efficiency. Machining, assembly and shaping technologies that allow for making use of new high efficiency materials. Alternative raw materials with lower environmental impact.	No training actions foreseen	Low
RT3.08 - Model Based Engineering and Sustainability	2	Engineering of customised manufacturing systems. Integrated model-based, holistic engineering models supporting design engineers, dynamic networks for manufacturing value chain . information sharing and management, semantic models integrating product+service systems, customised machine-service systems.	Standardization of product field data / Interoperable & stand production network. The companies representing the manufacturing chains may have balanced relationships to facilitate cooperation and, with this, the project outcomes.	High
RT3.09 - Cooperative and Mobile Manufacturing Systems	1	Flexible production plants, mobile robots capable of cooperating among them and with human workers, modelling mobile robotic members and the interactions among them; technologies for coordinate, cooperate, communicate and interact among robotic elements, mobile and autonomous robots, autonomous mobile robots in production plants; collaborative robots in agile and flexible production plants. Standards for representing mobile robots within Virtual Reality environments; Standards for assuring secure and safe interaction among mobile robots and human workers.	Permanent testing facility where new robot technologies and human interaction capabilities can be tested in a real production environment. Standards for representing mobile robots within Virtual Reality environments; Standards for interaction among mobile robots and human workers	High
RT3.10 - High Performance (High Precision, High Speed, Zero Defect)	3	Technologies for high volume, high speed and new capabilities of processes, Process accuracy (zero-defect); Process robustness to handle unexpected events, Process adaptivity to changes in customer demands, control and configurations for improvements in process dynamics; optimization of machining cycles and process planning. efficient and productive outputs by high volume, high Speed and capability of processes; Cognitive systems, condition monitoring, diagnostics and prognostics to realise intelligent and self-optimising machines for "zero-defect" manufacturing; Key performance indicators to monitor productivity, cost savings and sustainability impacts; six Sigma methodology; lean Production paradigm.	No training actions foreseen	Low
RT3.11 - Model-Based Manufacturing	2	Virtual manufacturing environments for integrating knowledge in the manufacturing chain, virtual visualization and simulation of manufacturing processes, technologies and tools for rapid and cost effective modelling, simulation and virtual prototyping for optimization of the behaviour of machines, information sharing in the virtual manufacturing environment, design and life cycle analysis for holistic approaches.	Tools to enhance accessibility and sharing of the information generated in the virtual manufacturing environment in order to integrate it with design and life cycle analysis for holistic approaches.	High

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT3.12 - Mechanical MicroMachining Enhancement	1	Micro-manufacturing technologies at the industrial level, material removal mechanisms and of the micro structural behaviour of materials. Micro scale manufacturing technologies, miniaturized mechanical material removal processes, Material removal mechanisms; Micro structural behaviour of materials and its effects on machining forces, Deformations and quality on the work piece at micro level, Fixturing and handling systems for micro-parts, modular and multifunctional machine tools; process monitoring and control through accurate sensors and methods of data analysis; Manufacturing of 3D micro components, Micro drilling technologies. Manufacturing of complex micro 3D geometries for improved heat transfer interfaces. Assessment of micro machines and micro tools capabilities.	Major efforts should be dedicated to the dissemination of the state of micro manufacturing technologies in the industry. Education and training is needed to provide accurate and reliable information on capabilities and costs of micro manufacturing technologies.	Medium
RT3.13 - High Resolution Total Supply Chain Management	3	Planning and control methodology, A high resolution information infrastructure, intelligent objects and next generation IT systems, Collaborative manufacturing data exchange, Material flow management, Product life cycle management over multiple levels in a supply chain, Order status information , Equipment monitoring and maintenance, Integrated Maintenance Systems, Real-time monitoring for the production equipment, Planning and control of reverse logistics / recycling, Supply chain design with brownfield planning; Business models for design of sustainable supply chains; global supply chain management, product-service linkage and management of distributed manufacturing assets (virtual factories), securing of information and knowledge exchange and process synchronization. “semantic near” approach for describing products and product data to communicate cross company borders. Smart mobile components, networks integrating multiple wireless communication technologies, sensors for real-time network visibility.	Serious games may serve as a powerful instrument. Solutions are developed empirically by letting people play against each other using this virtual business environment. Training programs including all the actors of a supply chain are to be established. These programs provide support for the distribution and application of communication standards based on ICT technologies. International standards for intra- and inter-enterprise integration and networks oriented to large/SME, multi-product enterprises and supply-chains need to be developed.	High
RT 3.14 - High Accuracy Modelling	3	Planning and control (PPC) approaches, Integrated multiple optimization of production, ICT for the high resolution planning and forecasting of PPC processes, standardized inter-organizational ICT interfaces for communication, standards for the generation and visualization of high resolution models of worldwide operation production networks; inter-organizational standardized processes and data between interacting companies.	No training actions foreseen	Low

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT3.15 - Semantic Business Processes	1	Inter- and intra-organizational business workflows and process execution, Semantically defined objects, processes and interfaces, dynamic business, automated information flows, integration of different IT-Systems, interfaces for simplified collaboration, common business models, Knowledge sharing, semantically supported inter- and intra-organizational workflows, standardization of adequate semantic models for process engineering and workflow management, Business Process modelling, semantic modelling language.	"Communities of practice" to identify common models, processes and framework is necessary. Methodology and tools for bringing tacit knowledge to explicit knowledge need to be developed. The standardization of adequate semantic models for process engineering and workflow management. Companies and users need to be informed and trained in how to use Business Process modelling.	High
RT3.16 - Professional Virtual Collaboration Platforms for Regional Clusters Optimization	2	Dynamic and flexible representation of business processes and technology, virtual collaboration among regional clusters, professional virtual collaboration platforms, competences-based multilayer collaboration networks, knowledge management, dynamic business networks, knowledge resource sharing, process and service standards, Integrative training and governance.	Integrative training and governance The optimal point of a professional virtual platform is to be able to conduct research on new product and service innovation based on knowledge resource sharing. Cluster, communities, expert groups - should be integrated in the virtual collaborative governance and maintenance.	High
RT3.17 - Ontology Based Engineering Asset Management	2	Engineering Asset Management (EAM), closed loop Product Lifecycle Management (PLM), maintenance resources management	Need for new educational programs. Cross sectoral education related to understanding of societal and cultural trends, identification of consumers and market opportunities, exploitation of new global business paradigms. Safety and well being of future workers also demand new cross sectoral education actions.	High
RT3.18 - Semantic Based Engineering	3	Life Cycle Data management, Semantics through ontologies, semantic based engineering, interoperability environment, Collaborative engineering.	There is the need for cooperation and exchange of knowledge between different companies and stakeholders. "Communities of practice" to identify common models, processes and framework might be valuable. Methodology and tools for bringing tacit knowledge to explicit knowledge need to be developed.	High

Research topic	Topic Relevance Indicator	Key competences needed	Specific related training needs	Relevance of training
RT3.19 - Forthcoming "Brown Fields" Re-engineering	1	New business model to increase the effectiveness of brown field production, "plug and interoperate" devices, interfaces for fast interoperability, fast simulations and re-programming tools, methods to improve the plant control, new business models of plans usage and re-modernization, production plan design methodology to increase the effectiveness of "brown field" re-engineering and re-use. Control the plan while under improvement / taking into account different machines ages. Fast plant assembly / disassembly strategies and methodologies. Management of hazardous wastes. Soil contamination.	No training actions foreseen	Low
RT3.20 - Advanced Automation for Demanding Process Conditions	1	Energy efficiency, intelligent automation and control systems, advanced process control systems, intelligent control systems able to connect different independent subsystems, machine auto-diagnosis, operational efficiency, modelling for flow .	Promising concept standardization activities have to be adopted to guarantee the transferability of the B2C-community building processes. All the persons involved in the building process have to be trained in the different methods and in the use of the relevant tools. Guideline development.	Medium
RT3.21 - Business Concept B2C-Communities	1	Integrating the customers into the development process of new products and services.	No training actions foreseen. Standardization activities have to be adopted to guarantee the transferability of the B2C-community building processes. Methods have to be designed that lead to customers' participation in such communities.	Low
RT3.22 - Knowledge Embedded Products	3	Smart materials, sensors, RFID, product intelligence, embedded information and knowledge, Business strategies for intelligent products, knowledge embedded products and new intelligent functionalities	Companies would be educated into new market thoughts that would generate revenue for the companies. Case studies of best practice and state- of-the art within knowledge embedded products.	Low
RT3.23 - Dealing with Unpredictability	3	Contextual and strategic risk management, risk scenarios from simulating behaviour patterns in a technical, business and social context. Semantic web technology combined with serious games. Scenario engine.	Semantic web technology combined with serious games.	High

Table 5 Training and competence needs in Key Technologies

5.3.3 Exploitation of advanced knowledge transfer mechanisms

In this section the potential exploitation of the different advanced knowledge mechanisms defined in the IMS2020 roadmap for the different training needs are highlighted, as reported in the radar diagram shown in Figure 15, and in the following description for each key technology area.

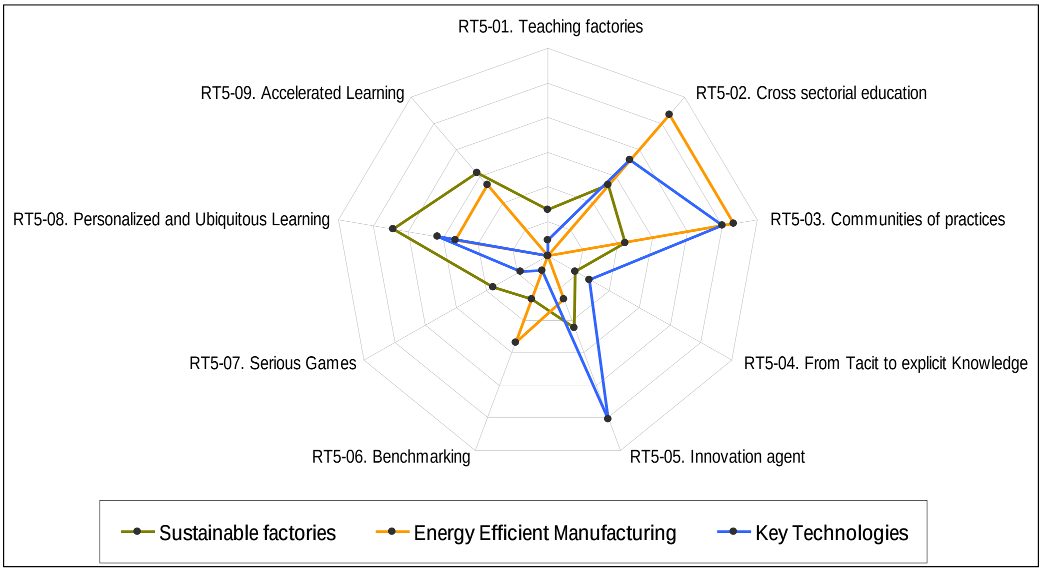


Figure 15 Potential of knowledge transfer mechanisms

Sustainable Factories

Training mechanisms for enabling the Sustainable Factories paradigm are substantially based on new tools to implement new knowledge areas in manufacturing routines.

Improved cross sectoral approaches are expected to increase the general set of competence of new workers. At the same time personalized training methods and tools should revitalize competences for development of vertical technologies.

A secondary impact is attributed to acceleration of learning practises within industry due to the problem solving oriented to sustainability. Adoption of new training methodologies (teaching factories, serious games etc.) is seen quite interesting in this view.

Soft actions have been related to facultative sharing of knowledge trough communities of practices. Adoptions of new standards in industrial routines indirectly produce new training needs coming from compulsory innovation activities.

Energy Efficient Manufacturing

Training needs are mainly related to technological improvements with respect to energy consuming industrial routines. Industry oriented training approaches like training for innovation dedicated tools, accelerated learning practices and benchmarking are suitable for this purpose. General broadening of traditional scientific curricula also represents a priority push action. Innovative training methodologies are seen as less significant compared to rearrangement and diffusion of technical contents.

Key technologies

Training needs related to key technologies are mainly related to systematization and clarification of competences based on innovative technological applications. Standardization of competences and performances is a valid mean for innovation and sharing of information. Clarification of key competences is also based on methods to make tacit competences explicit.

A basic role is represented by improvement of cross sectoral education. Contribution of traditional training centres, like universities and research centres is important for a variety of applications and problems in key technology implementation. Such variety involves both general preparation and specific experience based on vertical applications. Both these aspects require amplification of traditional scientific curricula. New personalized and ubiquitous tools are instead considered strategic within industries for continuous learning on recent technological developments.

5.3.4 Conclusions and recommendations

Human resource development is an area of increasing interest for policy action. The requested improved linking between education and industry skills induces a renewed focus on training of vocational and technical personnel. Particularly relevant is the skill development related to hard competences in manufacturing processes.

The IMS 2020 research topics have been analysed. Key competences coming from new technological demand have been identified for each topic; moreover, proper knowledge transfer mechanisms have been analysed for each technological area.

A general high impact of training activities has been highlighted. Particularly, training activities provide support in following ways:

- supply of preliminary knowledge necessary to supplement research activities within product chains;
- reinforcement in fallout and spreading of research results;
- adequate standardization and transfer of new knowledge resulting from research activities.

Major problems are referred to development of standard sets of new competences related to complex technological aims. As a matter of fact a relevant number of competences are application driven, so their complexities increase with the complexity of related applications.

New knowledge transfer mechanisms such as teaching factories and serious games are promising future opportunities. A general broadening of their usage should be deepened with reference to technological and knowledge areas. Traditional training mechanisms oriented to industrial implementation of competences or to the general providing of scientific skills today still represent the bulk of knowledge transfer. Coordination of extensive training actions involving different stakeholders has to be deepened in terms of complementarities and interfaces between training suppliers and industrial users.

5.4 Research on innovation processes

5.4.1 Motivation

In the global market, with the emergent economies, European enterprises have serious difficulties in surviving, let alone excelling, unless they are capable to leverage successfully their capacity to innovate. Enterprises in almost all sectors are forced to develop innovative products in shorter cycles due to market constraints. In this context, Wang and Ahmed (2003) describe the market situation as dominated by hyper-dynamics, uncertainty and chaos.

The innovation statistics carried out with European enterprises demonstrates a paradox in Europe of having good research activities, but with poor impact concerning innovation and global competitiveness (EIS, 2009). This raises significant challenges concerning the implementation of the Lisbon strategy to transform the EU into the "most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and great social cohesion" (EurActiv, 2000) where innovation plays a fundamental role. The problem is not necessarily lack of funding, with the EU RTD program totaling 229 billion Euros in 2007, neither is it lack of engagement of enterprises in innovation[1], with 41.2% in industry and 36% in services (Parvan, 2009). However, the reality demonstrates that a total 85% of product development resources are wasted on products and services that never reach the market, which is compounded by the fact that only 18% of those products reaching the market actually prove successful (Bauer, 2005; INA, 2005). In addition, the distribution of innovation across Europe is uneven, with Sweden, Finland, Germany, Denmark and the UK considered as innovation leaders in the European Innovation Scoreboard (EIS) in 2008 (EIS, 2009).

In response to the pressure resulting from competing in a global market, enterprises follow two major trends:

- **Open Innovation.** The limitations of the internally focused innovation are summarily captured in the simple simulation of *Red Queen Effect* (Bayless, 2009) applied to product development. The simulation indicates that a 10% decrease in product life cycle would require a company to double the introduction of new sustainable products each year, which implies significant increases in innovation funding just to maintain for the company to keep its market position. This is a simple simulation based on shrinkage of the product lifecycle. If one considers the globalization phenomenon, then it is unthinkable to keep the closed innovation model. Consequently, organizations have been compelled to reach out beyond their boundaries to engage with others in the attempt of maximizing the efficiency of their innovation processes by collaborating with others. The realization that the world no longer allows for companies functioning in isolation has led to the establishment of a networked fabric composed of enterprises collaborating with one another based on a platform of trust – Collaborative Networked Organizations (Camarinha-Matos, 2008).

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[1] With exception of France

- **Extended Products.** Facilitated by the paradigm of sustainable development, enterprises have realized that their customers are more interested in solutions to a need, rather than a packaged product. This introduces the concept of extended products, where a product is enriched with services and the business model is focused on what needs are addressed by the combined solution (e.g. Jansson & Thoben, 2005). So for example, one may consider that car manufacturers are moving away from providing a simple car towards providing a solution for mobility.

These trends have a significant impact on the way innovation has been traditionally viewed and dealt with by enterprises, which no longer consider it viable to harness alone the necessary creativity power within their corporate boundaries to excel. Consequently, the barriers of closed innovation have been torn down and the new paradigm of open innovation (Chesbrough, 2003) has been adopted, where multiple parties are engaged thus increasing the creativity potential. Initially the paradigm of open innovation was applied solely to the enterprises, but the open innovation movement has gone even further than organizational boundaries reaching out towards individuals, realizing that the global connectivity provided by the Internet has created a **Global Brain**. This has led to the notions of crowd sourcing and the existence of a global brain, but there are multiple challenges towards harnessing successfully the power of the masses and the success cases are more anecdotal rather than systematic. A harsh reality concerning innovation is the low success rate of transforming ideas into sustainable business models, and in response, the Living Lab paradigm (Schumacher & Niitamo, 2008) has emerged where the creation process is not only open involving multiple innovators, but places the customer at the center of the innovation process, actively taking part of the creation of products and services at every step. However, the novelty of Living Labs implies that there are serious challenges for individuals and organizations to adopt the paradigm to produce successful outcomes.

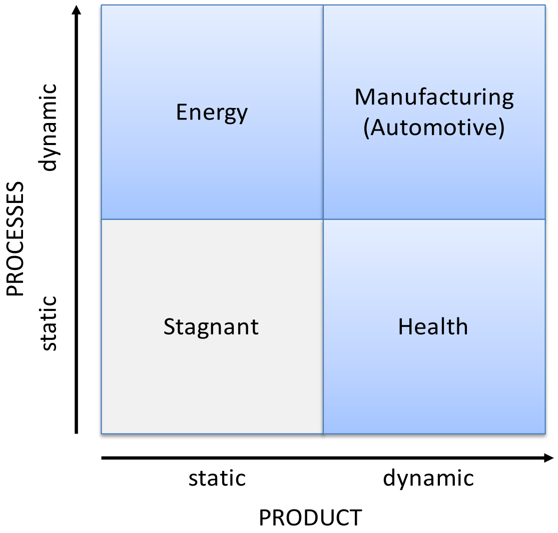

Figure 16 Characterization of Industrial Sectors in Terms of Dynamicity of Processes and Products

In this new innovation landscape, learning plays a pivotal role in achieving systematic success. The learning needs to take place at organizational level and also at the level of each of the individuals.

The industrial sectors illustrated in the diagram of Figure 16 are of particular interest to innovation due to their strategic interest to the European economy, as reflected by the European Union research funding for moving industries from static to dynamic products/processes. A strong direction in manufacturing is sustainability, which can also be applied to innovation (Nidumolu, Prahalad, & Rangaswami, 2009). Adopting an innovation strategy driven by sustainability implies a radical individual and organizational behaviour that require learning to ensure that the stakeholders develop the necessary competences. The quadrants reflect the dynamicity of both products and processes:

- Health. In this case, the products are dynamic, with the pharmaceutical companies competing to explore new solutions for various health problems. However, from the perspective of processes, these are established gradually over time and once in place, are slow to change due to the inherent implications on health safety and the governing legal framework that safeguards society’s wellbeing.
- Energy. The situation with this industrial sector is that products do not change, being mainly variants of energy albeit from different sources. From the perspective of the market, the differences are noticeable in the way energy is packaged as different products. However, the processes of collating and distributing energy are highly dynamic as the sector is going through radical change as it aims to attain sustainability and avoid the adverse effects of climate change. So one may consider the case of smart-grids where the traditional supply-demand model is being changed as the boundaries of the consumer blend with the role of supplier.
- Manufacturing (Automotive). In this case, the aim is to go beyond mass customization to highly personalized extended products. The automotive industry is well established, but the market forces are imposing the need to have ever changing products, which require new processes

5.4.2 Innovation

Innovation in public understanding is often seen as the invention of something groundbreaking new. Industrial innovation isn`t solely concerned with the generation of new ideas but also with making an economical effort out of them. Innovation encompasses the entire process from the generation of an idea – the invention or the combination of known objects – to the penetration of the market with an economically successful implementation of the idea – as much for products as for processes or services (Baldwin & Hanel, 2003).

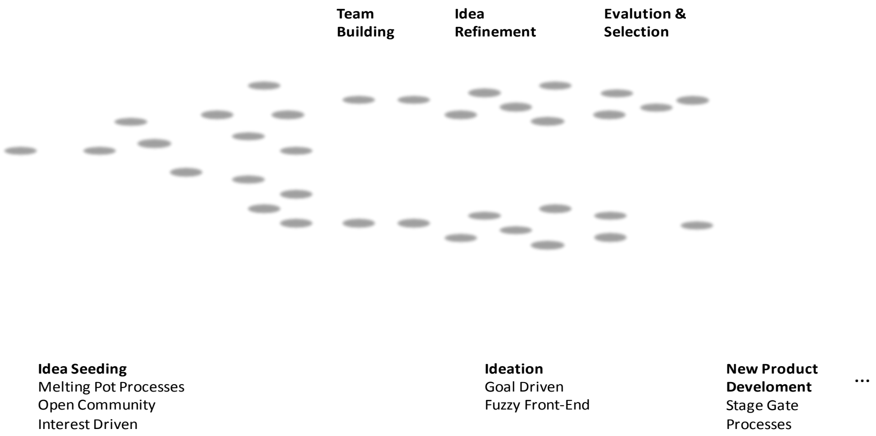

Figure 17 – Innovation process from seeding, ideation and new product development

The innovation process therefore represents all phases from idea generation to marketing and sales. Figure 17 reflects the innovation from seeding of the idea until the new product /process development, which then leads to the operations.

To develop successful innovations companies use several methods to determine the customers' demands. The integration of end users and other stakeholders into innovation projects has proved to reduce business risks such as the invention and acceptance of products, services and applications. However, the integration of the end-users remains a difficult task. Marketing and focus groups are relatively well known sources of information.

A new concept in the literature is introduced by Henry Chesbrough (2003): Open Innovation. The central idea of Open Innovation is that in a world consisting of widely distributed knowledge, organizations like enterprises cannot afford to rely entirely on their own research. Instead they should buy or license processes or inventions (e.g. patents) from other companies. In addition, internal inventions which are not used in business could be taken outside the enterprise (e.g. by licensing or joint ventures). In contrast, closed innovation refers to processes that limit the use of internal knowledge within a company and make little or no use of external knowledge. To assure the future potential for innovation companies profit from collaborating with external experts and integrating them to their innovation process within the product development. Thus the companies' profits of the partners know how and get access to complementary resources. On the other hand collaboration in the critical phase of product innovation conducts the reduction of the in-house production depth and leads to the dependency of external partners. Another critical element is the use of intellectual property rights (IPR). Within a study in Germany and Switzerland the problem with IPR is mentioned to be less important than the dependency on a partner (Capgemini, 2009). The open innovation approach is well known in the field of software development.

A concept in the literature enhancing the open innovation idea is the concept of European Living Labs. These offer a unique opportunity for organizations to include end-users and other stakeholders in new product development or other innovation processes. This enables the user to be a co-creator in the innovation process (Schumacher et al., 2008).

These approaches have the early stage of innovation in focus. The early stage of innovation is characterized by high uncertainties and the constant generation of new and relevant knowledge (Klünder, 2006). The knowledge is generated and immedialty used in non-linear work steps. The complexity of these work processes cannot be described appropriately in a quantifyable model (Akin, 1979). This is taken into account as today's attempts do not have the pretence to describe the early stage processes in a whole within methods or best practise examples (Bauer, 2006).

Cross states that the theory of cognition to support early stage innovation processes should be based on the intuitive processes of innovators (Cross, 1984). The intuitive processes can be seen as routines.

Cooper describes the early stage in innovation processes as the phases which separates the winners from the loosers (Cooper, 1988). This statement is underlined by studies in Germany and Japan which show the coherence between the planning in the early stages and the success of the products (Verworn, 2006; Verworn, Herstatt, & Nagahira, 2008).

Within the early stage of innovation up to 70 % of all follow-up costs are determined (Gebhard, 2000). Taken into account the high development cost in the automotive sector the understanding and the successful support of the early stage of innovation becomes indispensible for econimical success.

Most of these innovation principles have been exploited by the "Platforms"initiatives at multilevel (global EU, country, region, project). These Platforms drive the early stages of research and innovation initiatives by prioritising and supporting pre-competitive technology development addressing multisectoral needs. They generalise the technology development for new solutions and competence development and introduce the life-cycle orientation to the overall technology development for new product/processes.

Ideation

Ideation is a concept that is generally not well understood in depth. In many organizations ideation is viewed similar to creating ideas. However, creating ideas is only the very initial seed for the ideation process. Recent empirical studies have revealed that the process of generating ideas is not considered as a problem in industrial organizations – the perceived problem is the continuing idea development process – the ideation process (Bessant & Stamm, 2007).

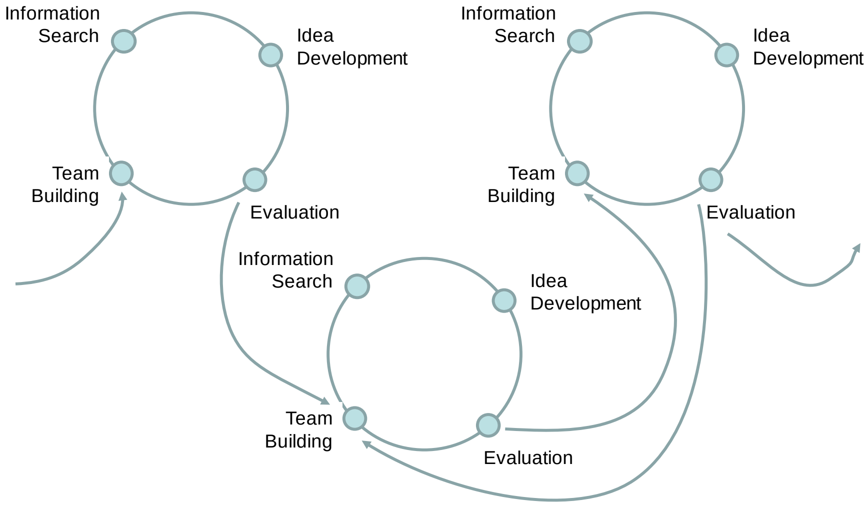

Figure 18 - Ideation process

Ideation is basically a circular process (as shown in Figure 18, see also (Duin, Jaskov, Hesmer, & Thoben, 2008b)) that differs significantly from the sequential process approach that most people are trained in (Leifer, 2000). Furthermore, ideation is an inter-disciplinary and cross-organizational process that requires a certain degree of common language. Due to the inter-disciplinary nature the common language additionally has to be neutral (Hansen, Mabogunje, & Moeller Haase, 2009).

Traditionally, problems have been seen as complicated challenges that should be solved through breaking them down into smaller and smaller chunks. However, most modern problems – and ideation problems in particular – are complex rather than complicated. Complex problems are messier and more ambiguous in nature; they are more connected to other and often very different problems; more likely to react in unpredictable non-linear ways; and more likely to produce unintended consequences. A typology of problems can be seen in Figure 19.

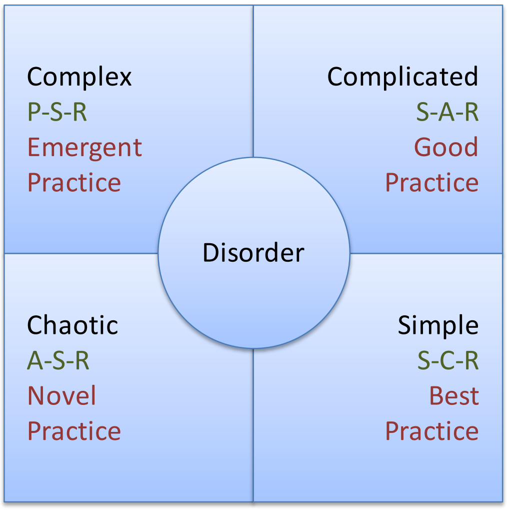

Figure 19 Typology of problems (after Snowden & Boone, 2007)

The perception and response to complex issues are dependent on the nature of the sense-making process. The sense-making process, on the other hand, is dependent on the perceived nature of the problem.

The typology framework proposes an association between the nature of context of problems and appropriate responses. The framework consists of five domains (Figure 19).

- **Simple**, in which the relationship between cause and effect is obvious and the appropriate approach is Sense – Categorize – Respond
- **Complicated**, in which the relationship between cause and effect requires analysis or some other form of investigation and/or the application of expert knowledge, and the appropriate approach is Sense – Analyze – Respond
- **Complex**, in which the relationship between cause and effect can only be perceived in retrospect, but not in advance, and the appropriate approach is Probe – Sense – Respond
- **Chaotic**, in which there is no relationship between cause and effect at systems level, and the appropriate approach is Act – Sense – Respond
- **Disorder** – in which it is unclear what type of causality exists. Disorder is in the center of the graphical model. Here people will revert to their own comfort zone and choose the approach related hereto.

Connectivity

The advent of Web 2.0 (O'Reilly, 2005) concepts and technologies not only fostered users' active participation to content creation, and therefore transforming knowledge consumers into 'prosumers', but also boosted the collective creation of knowledge and made users keep active control on the kind of knowledge and information produced and diffused and on its quantity and quality too (e.g. Wikipedia). This new perspective (Sigala, 2007) brought new life to innovation and, of course, to its creative component, as Web 2.0 clearly supported the so called 'knowledge fusion' process that characterizes the knowledge creation emerging from combining, adapting and improving different knowledge components developed in different contexts as now commonly happens in diverse and dispersed professional environments (Fliaster, 2004; Fliaster & Spiess, 2008). The emerging paradigm of Open Innovation (Chesbrough, 2003) pushed further the need of sustaining the concept of co-creation by developing new collaborative tools which link together actors that go beyond organization natural boundaries, as like as suppliers, customers and, in some cases, even competitors (Manyika, Roberts, & Sprague, 2007; O'Reilly, 2005).

McAfee (2006) translated the Web 2.0 into the SLATES paradigm in order to bring it into the corporate (and more in general, organizational) environment by labeling it as ENTERPRISE 2.0. Therefore, by introducing ENTERPRISE 2.0-inspired tools in the work routine knowledge workers find in their organization the Web 2.0 social and collaborative tools they are already accustomed to. Moreover, in the Open Innovation perspective, the emergence of workers belonging to virtual communities not only within the organization itself, but also, extended beyond or, even completely external to it, can be not only tolerated, but even encouraged. A key point, as (Angehrn, Maxwell, & Sereno, 2008) pointed out, is related to the fact that in the cooperative creation process people like to ask for advice to, and receiving it from, their peers or the ones who are reputed being experts in some domains of knowledge. The explanation relies on the "emotional, psychological and social needs of individuals" that have to be fulfilled (Angehrn & Maxwell, 2008). Therefore, it becomes apparent how sharing content and being part of virtual communities in blogs or in online video sharing websites or contributing to wiki projects and the use of any other Web 2.0 tool increase people feelings of self-recognition, of reputation in the community, of being connected to other people which is one of the basic needs of individuals experience (Maslow, 1987) as well as of trust in other people (Tung, Tan, Chia, & Koh, 2001).

All of these aspects are very important from the motivational point of view too, as people do not like to participate in or provide their contribution if they do not perceive any personal usefulness, advantage in doing it. Motivation is strictly related to incentives to contribute (McAfee, 2006). (Angehrn, Luccini, & Maxwell, 2009) makes clear that "a game designed to engage employees in the innovation process can become a strategic asset and not only a productive tool (Ahn & Dabbish, 2004). In addition, if the game can extend its audience outside the organization, connecting employees to outsiders and providing a source of weak ties and 'idea brokers' (Fliaster et al., 2008) this can bring further benefit to the organization. Having fun is one of the most successful ways to increase self-motivation. This is particularly relevant in the domain of innovation where creativity should be stimulated. (Angehrn et al., 2009) reports also how Web 2.0 concepts and tools can have a positive impact on innovation in general, and in particular on new product development by detailing the experience matured in the deployment of InnoTube, one of the Web 2.0-oriented tools designed and developed in the framework of the FP6 Laboranova project, in different contexts of use, from New Product Design & Development (NPD) to team building and ideation. Such experience has allowed to verify their usefulness and to point out some of the strategic drivers for innovators community, starting from (1) the use of rich media for exchanging and sharing ideas, to (2) network visualization for displaying connectivity among people, between people and knowledge assets, and the value in reconnecting oneself to own competences, to (3) rich profiling for reconnecting to oneself or for being exposed to the community, and to (4) gaming dynamics that can foster connection value creation (Angehrn et al., 2009).

Finally, the impact and the value of interactions and connections in knowledge workers daily activities has been made apparent in a McKinsey Quarterly Report (Manyika et al., 2007) where it was highlighted that (1) almost half of the US knowledge workers activities will involve tacit interactions (such as, "negotiations and conversations, knowledge, judgment, and ad hoc collaborations"), (2) "Technology tools that promote tacit interactions, such as wikis, virtual team environments, and videoconferencing, may become no less ubiquitous than computers are now", (3) companies using such tools "will develop managerial innovations – smarter and faster ways for individuals and teams to create value through interactions" and gain substantial competitive advantage with respect rivals, (4) there is an emerging need "to couple investments in technologies with the right combination of incentives and organizational values to drive their adoption and use by employees". Therefore, given an increasing impact of interactions on ordinary daily activities, the sooner a company will be able to adopt the proper tools to handle them, the more it will gain competitive advantage, even in the short term.

Evaluation

Evaluation is a general technique, which is applied in several domains, but in the particular domain of innovation, it has been mostly applied to product development where each process is completed by running evaluations against the objectives of the phase (Kerzner, 2009). These objectives shift from phase to phase, for example form the completeness of requirements in the requirement phase, to feasibility in the design phase, or functioning in the implementation phase. In any case these evaluations are focused on technical criteria (Kahn, 2006), which are categorized in groups of overall aims, such as manufacturability, assembly, ecology, maintenance, safety and others as design-for-X sets of constraints. Such evaluations are typically undertaken by test engineers in the development departments. It is recognized that such technical approach often leads to good but expensive solutions, which is overcome by adding a separate value analysis evaluation with cost/benefit measurements, often through a separate department and initially in a late design phase.

Evaluation draws on another source of quality management, risk management and project management, where the focus is more on identifying the potential impact of events on the development, production and delivery process. A well-known example is the Fish-bone diagram (Brussee, 2004), which relates possible product failures to its consequences, so that corrective actions can be taken already in the early design phases. Such evaluations are typically undertaken by dedicated risk / project / quality management departments following their own standard operation procedures.

A third evaluation perspective is a more recent, advanced-state-of-the-art financial and entrepreneurial perspective that is implemented in business idea competitions and business plan competitions (Hitt, Ireland, & Hoskisson, 2007). Rather than an internal perspective on the product or the organization of its development, the focus of this evaluation is on its outside validity with questions like: will there be enough financial, personal and knowledge resources to complete the project? Will the result be acceptable to its users, and who are the users (Exner, 2002)? How likely is it that the idea under consideration will prevail over its contenders? Such evaluations are organizationally not yet well placed and are undertaken by associations and (ad hoc) board within the innovation ecosystem.

These perspectives have been retained in engineering production management techniques for Impact assessment and monitoring activities. They deal with the early appraisal of market knowledge regarding enabling technologies for new product/processes. Impact Assessment provides estimation of actors/stakeholders expectations and support policy-makers before research and innovation entering the competition stage

5.4.3 Competences

In a meta-analysis on the effectiveness of diverse creativity trainings, Scott et al. (2004) showed that creativity can be trained and that cognitive oriented programs that provide users with specific strategies or heuristics for working with information are most effective for the development of creative problem solving competencies. DeHaan (2009) pointed out that cognitive skills, such as divergent thinking (including ideational fluency to visualize and accept ideas), convergent thinking (to focus and evaluate ideas), and analogical thinking (to use familiar ideas for understanding novel ones) are essential for the development of creativity. Thus, a successful innovation environment requires not only optimal situational conditions (such as freedom, autonomy, encouragement, lack of criticism, and so on; see (Runco, 2004)) but also optimal learning conditions. Electronic group based techniques or so-called group support systems proved to be powerful devices in fostering creative processes. Looking for example at brainstorming techniques, DeRosa et al. (2007) found, that large electronic brainstorming (EBS) groups are more productive, more satisfied with the interaction, and outperform large face-to-face (FTF) groups. The advantage over FTF is that barriers such as social apprehension, social loafing, or production blockades can easily be overcome by e.g. writing up the ideas (brain-writing or mind-mapping) independent of time and location or by introducing positive reinforcements for generated ideas. Finally, individual differences (such as personal view of competition or need of resources for stimulating creativity) and the different phases in innovation processes have to be taken into account when searching for the optimal ideation environment (Scott, Leritz, & Mumford, 2004). Feedback or knowledge application, for example, inhibit creativity in the idea generation phase, but are beneficial for the product generation phase.

There are some examples of recent initiatives that seek a new approach to education for capability development and high skilled jobs. They are carried on at national level (Germany, Great Britain and Italy) and at international level (USA). These experiences are best practices and models for new interdisciplinary approach to competence development.

5.4.4 Living labs overview

The initiative of Living Labs came up in the early nineties and the term Living Lab was firstly proposed by Lasher, Ives and Jarvenpaa (1991) to the academic community. In Europe, Living labs gained more attention during the European test bed discussion from 2000 to 2004. Living Labs can be viewed as a method in the innovation process to integrate users. Simplified, Living Labs reverse the idea of product development to some extent. In this concept, consumers are involved in the innovation process from the inception of ideas thus they can directly influence the innovation process instead of being just customers of a pre-developed product. Living labs can be analyzed by using different perspectives. One of them is the organizational view used to show the difference between a Living Lab and a traditional R&D Lab. Over time the idea of Living Labs evolved from a rather technical testing perspective to an evaluation environment for new ICT solutions. Strongly connected to this view of evaluating rather innovative and new ICT solutions at an early development phase is the perspective of involving Living Labs users actively in co-creation processes. This involvement is supposed to minimize the risk of neglecting the customers' expectations through active involvement in the Research and Development (R&D) phase. These possible achievements are supposed to justify the resource intensity of co-creational Living Labs and the need for special competences of persons in charge. There is a common agreement in the available literature of Living Labs, that a certain degree of contextual knowledge of the reviewed ICT solution among the participants is necessary to get plausible responses and usable results of the experiment.

Concerning the surroundings and the concept of Living Labs, there are generally two possible different configurations. On the one hand, Living Labs can be designed to utilize context simulations. The conditions in these Living Labs are used for the specific research goal. On the other hand, so called real world Living Labs allow users in the "real" world to experience and experiment with ICT solutions. These real world Living Labs can vary strongly in terms of size and geographical distribution. The decision for one of the two concepts depends on variables like available resources and the parameters of the ICT solution to be tested.

Furthermore, a rather medium- and long-term time frame for conducted Living Lab studies is stated by common literature on Living Labs. In terms of the number of participants in Living Lab studies, there seems to be a slight change over the last years. Whereas at the beginning of Living Lab studies, the number of participants involved was rather small (Abowd et al., 2000), nowadays the possibility of big user groups in Living Lab environments is rising (Eriksson, Niitamo, Kulkki, & Hribernik, 2006). Similar to the decision for or against real world Living Labs, the chosen number of participants depends on pragmatic considerations, like how many participants are necessary to achieve a certain quality of the results. Eriksson et al. (2006) poses that the bigger the number of participants the better the foundation for innovations. That is an interesting field for further research with the question of the optimal size of Living Labs and in which cases simulations or real world Living Labs are appropriate.

As bottom line Folstad (2008, p 116) defines Living Labs as follows: "Living Labs are environments for innovation and development where users are exposed to new ICT solutions in (semi)realistic contexts, as part of medium- and long-term studies targeting evaluation of new ICT solutions and discovery of innovation opportunities".

Several initiatives were established in the last years. One very promising is the European Network of Living Labs (ENoLL) (www.openlivinglabs.eu) initiative, started with the first wave of 19 Living Labs across Europe in 2006. Today, after additional waves, the network has resulted in 128[2] Living Labs of different levels of maturity inside and outside Europe. The idea behind this network is to have the ability to support all parts of the Innovation Lifecycle and to offer services for all actors involved, from industry to academia with an open community of independent Living Labs for all purposes.

All these principles are retained in the initiatives such as a competence centers that in various countries and in Europe form the networks of excellence in the respective fields of knowledge and industrial interest.

5.4.5 Research directions – topics on innovation

The key challenge with innovation is to understand that it is more than the act of inventing something new, in fact, the processes supporting innovation are quite complex and change as an idea is seeded until it reaches the market as a product or service. However, the aim of organizations is how to harness innovation to gain a competitive edge in the global market

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[2] According to www.openlivinglabs.eu/networkk.html, the total number is 128

whilst keeping the costs low in order to maximize the Return On Investment (ROI). Of particular interest is the paradigm of living labs that combines open innovation with the centralized role of the consumer, thus leading to co-creation process involving all stakeholders of the innovation of a product/service. Throughout the competence development process, in order to develop new open minded engineers it is necessary to have the right combination of high added value competences, global awareness and market competitiveness.

In particular, the following 6 research topics are relevant. They contribute to the innovation capability development in specific areas of character/culture innovation for industrial manufacturing under three headings: fundamental trends, orientation, in context competence development.

Fundamental trends	orientation	in-context competences
• Global brain • Learn to innovate • Go green	• Living labs • Risk management	• Sustainable new apprentiship

1. **Global Brain.** The ultimate instantiation of the open innovation model is captured with the imagery of the global brain, where *it is necessary to research technology and processes that enable manufacturing enterprises to engage with the collective intelligence of all individuals within the global reach of the internet and across cultural barriers.*

   Open collaborative networks where:

   - industry bring their innovation demands to the market
   - researchers offer their competence
   - framework agreements regulate rights and ownership to results

2. **Learn to Innovate.** The ability to create has long been regarded as an innate attribute of an individual, but it is a cognitive ability and consequently it is feasible for individuals to improve. However, the development of innovation capability also applies to organizations as they distil best practice and mature their processes**.** *It is necessary to research new approaches to competence development that target the associated competences in ever smaller time-to-competence time slots.*

   Establishment of:

   - arenas for brainstorming and exchange of ideas
   - Techniques for systematic identification of innovation demands and solution requirements
   - Mindsets and culture for innovation

3. **Go Green.** Rather than regarding sustainability as an impending hurdle with legal and regularity entanglements, enterprises can embrace it as an opportunity for change and become first movers into new markets. *The challenge is to research new frameworks that address the challenges of manufacturing enterprises to adopt sustainability as a means to become competitive.*

Such frameworks must include modules and methodologies for:

- Building of sustainability mindsets
- Identification of potential improvements
- Probable outcomes of improvements
- Implications internally and throughout the supply chain
- Initiation of innovation processes

4. **Living Labs**. The potential of involving the consumer in the innovation process from its inception holds enticing promises, from achieving higher success in innovation outcomes to creating a market ready to consume the resulting invention. *The living labs movement is relatively new, requiring further research into facilitating the implementing and transferring knowledge concerning living labs paradigm to manufacturing enterprises.*
    - Conceptual to a teaching factory where the users can influence the development of new solutions based on real environment experience and requirements.

5. **Risk Management**. The complexity of reality with its multi-faceted social dependencies makes randomness difficult to predict with a model, thus it *is necessary to research new ways of coping and attenuating risks of low probability but with high impact.*
    - The importance of the ability to deal with unpredictability in innovation processes as been highlighted earlier in the IMS2020 work as it was described as a research topic (RT3.23) (see *D2.3a Action Roadmap on KAT1-KAT3*.

6. **Sustainable new apprenticeships.** Research and development aims to educate both new researchers and industrial engineers towards sustainable production systems. New approaches should re-create *Apprenticeship* to enable young students and workers to forefront variable and challenging context with new learning. *This new approach to education, training and learning must sustain the development of mindset capable to frame the complexity into a logical developmental order with variables.*
    - Expert engineers should act as personal coaches for students and workers in the location, explaining how to frame in a logical development the multiple inputs (from science, technology and business).
    - The “tour” of laboratories, associations and enterprises should highlight the scope of new apprenticeship in terms of products, processes and businesses.
    - The field experiences should be transferred into intangible professional and emotional knowledge to ensure a follow-on and a long lasting imprinting.
    - The new apprenticeship should be designed to be disseminated into science&society events and into social networks with continuous reporting of feelings, ideas and perceptions.

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6 The roadmapping process and work structure

This chapter presents the methodology used to develop the IMS2020 KAT5 Roadmap. The approach has been designed to ensure the highest relevance to input coming from the industrial community as well as to ensure the international (IMS Regions) relevance to the results. Moreover, the work has kept into high consideration the work already and recently done both at European and International level on proposing roadmap in the field of manufacturing.

Most of the development has been done through collaborative tools shared with all the Roadmapping Support Group, a growing community that, at the moment, counts 254 participants from 108 mainly industrial organizations.

Development of the Roadmap has been done in close cooperation with the other Roadmaps (see Figure 20)

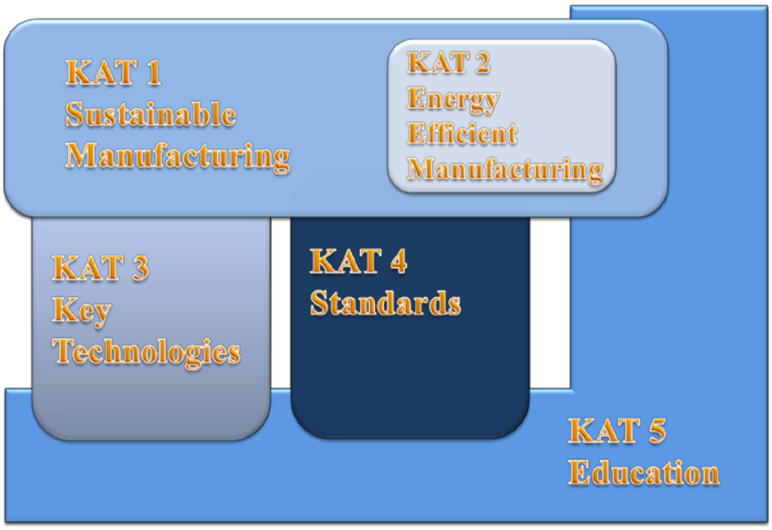


Figure 20 Relations between the IMS Key Area Topics

Starting from the mapping of the existing roadmaps and ongoing researches, an open online survey, two brainstorming workshops and 106 interviews, the IMS2020 team has developed some possible future scenarios for the 2020 manufacturing and approximately 70 research topics to be proposed to the European Commission and the IMS (see Figure 21).

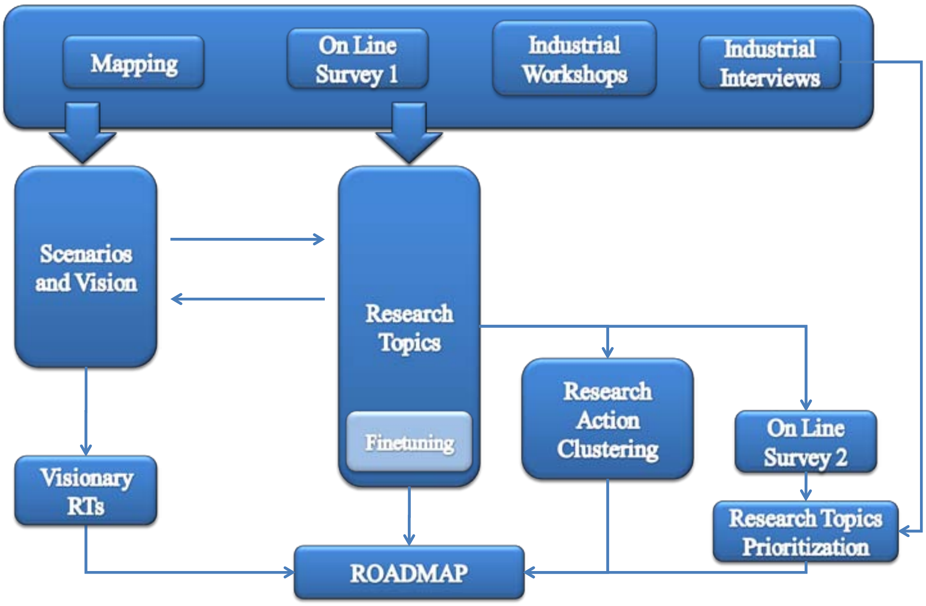


Figure 21 IMS2020 Roadmapping workstructure

6.1 Mapping of past and ongoing research activities and mapping of roadmaps

The objective of this work is to define a detailed and effective state-of-the-art of initiatives involved in the five IMS Key Areas (Sustainable manufacturing, Energy efficient manufacturing, Key technologies, Standards, Innovation, competence development and education). This mapping exercise focuses especially on Research Activities, Standards, Regulations, Laws, Roadmaps and the assessment of present IMS collaboration between IMS regions.

The methodology followed for the state-of-the-art mapping activity is implemented in the form of mapping tables – one per KAT - realised in Excel, clustering the past and ongoing researches as well as existing roadmaps into the identified main characteristics of each Key Area.

The work analyzed a total of 754 Research Issues coming from:

20 Roadmaps

- FUTMAN (EU)
- MANVIS (EU)
- MANUFUTURE (EU)
- ARTEMIS (EU)
- CLEANPROD (EU)
- EUMECHA-PRO (EU)
- INEMI (EU)
- I*PROMS (EU)
- ITEA (EU)

- MANTYS (EU)
- UCIM (EU)
- WiSeNts Roadmap (EU)
- Artist Roadmap (EU)
- Once-cs Roadmap(EU)
- Hipeac Roadmap (EU)
- Manufacturing Panel 2020 (EU-UK)
- The Ministry of Economy, Trade and Industry (METI) Roadmap: (Japan)
- NIST Symposium (US)
- Canada 2020 (Canada)
- Koreas Long Term Plan for Science and Technology – 2025 (Korea)

13 Past and ongoing projects

- AssemblyNet - Precision Assembly Technologies for Mini and Micro Products (Rete Tematica VFP) – Growth;
- EUPASS - Evolvable Ultra-Precision Assembly Systems (VIFP – NMP/IST);
- IRMA - A configurable virtual reality system for Multi-purpose Industrial Manufacturing Applications (IMS);
- KOBAS Knowledge Based Services provided by a network of High Tech SMEs (VIFP – NMP);
- LicoPro - Lifecycle Design for Global Collaborative Production (IMS – VFP);
- NEXT - Next Generation of Machines (VIFP – NMP);
- ProdChain - Development of a decision support methodology to improve logistics performance in production Networks (IMS – VFP);
- Prominence - Promoting Inter-European Networks of Collaborating Extended Enterprises (VFP – Growth);
- Promise - Product Lifecycle Management and Information Tracking using Smart Embedded Systems (IMS – VIFP – IST);
- RIMACS VI FP;
- SMERobot - The European Robot Initiative for Strengthening the Competitiveness of SMEs in Manufacturing (IFP – NMP);
- Symphony - A dynamic management methodology with modular and integrated methods and tools for knowledge based, adaptive SMEs (IMS – VFP);
- VRL-KCIP EMIRACLE VI FP-NMP

Moreover, a total of nearly 1000 standards and regulations have been considered.

The results of the mapping activity are presented in the form of a summary, summarizing the key findings of the corresponding mapping activity. For a detailed description of the Mapping work, please refer to the following deliverables:

- Mapping of Past and Ongoing Research Activities;
- Mapping of Standards, Regulation &Laws.

6.2 First step of the survey

The main objective of IMS2020 is the identification of the most important trends for future manufacturing systems. Therefore, the creation of roadmaps highlighting the main milestones of the innovation activities, were of crucial importance. In order to do this, the relevant research topics and supporting actions, which shape the future of manufacturing through international cooperation, had to be identified. As one of several tools to generate ideas used as inputs for the research topic generation, an anonymous survey was set up. Subsequently, this section will briefly describe the structure of this survey.

After a short introduction, which gave information about the background of the IMS2020 project, the participants were invited to provide basic information about their organisations (sector/ number of employees). Afterwards, they were asked to name and to elaborate their personnel innovation idea. These innovative ideas had to be related to one or more specific key areas. Furthermore, relevant changes in the business environment, which have a significant impact on the success or the failure of the defined innovative processes, had to be described. In order to collect as many innovative approaches as possible the participants had the possibility to deliver multiple ideas. In order to motivate a high number of experts, especially form industry, to participate in the survey, each project partner of IMS2020 sent out invitations to his relevant contacts. The results of this first step of the survey served as a profound basis for the creation of the applied research topics in the specific key area of IMS. The results from the on line survey is shown in Figure 22.

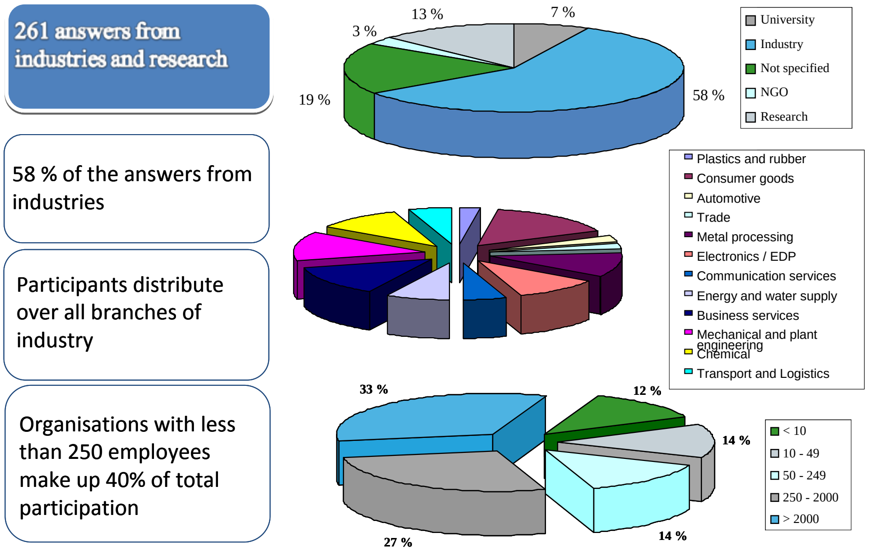


Figure 22 Results from the on line survey

6.3 Expert interviews

With the purpose to provide a sound industrial background to the IMS2020 roadmap, 106 face to face interviews to industrial world-wide experts have been performed. In particular:

- 61 from Europe
- 10 from Japan
- 16 from Korea
- 18 from US
- 1 from Australia

In order to provide comparable results, a detailed interview guideline has been prepared. The following part, will describe the structure of these expert interviews.

In chapter (A) a short explanation of the content of the IMS2020 project was given as well as a description of the project background and the advantages of the IMS Community. Chapter (B) contained general questions that should lead to an identification of the expectations and the main interests of each participant related to the five Key Areas. The third part of the guideline, respectively chapter (C), was divided into five subchapters. Each subchapter was related to one of the Key Areas and gave each Key Area the chance to implement specific questions regarding the relevant key area topics. Additionally, this structure gave the interview partners the chance to select the key area(s), in which they could provide high quality input based on their specific experience and knowledge. In order to define the interdependencies between Key Areas, the experts have been asked to describe the links between standards/education and the other key areas. Based on this information, each Key Areas was able to point out trends for the future manufacturing system in their specific area.

In the last chapter of the guideline, chapter (D), the participants were asked to name and to evaluate their personal innovation ideas. These innovative ideas had to be related to one or more specific key areas. Furthermore, relevant changes in the business environment, which directly influenced the success or the failure of the defined innovative processes needed to be defined. Finally, the expert interviews enabled the participants to describe further ideas that might have been relevant for the context of IMS2020.

As said, in addition to the information taken from the online survey, the results of the expert interviews were used as input for further defining possible scenarios for the future and consequently the roadmap of IMS2020.

6.4 Industrial workshops

It is important that the process of identifying research topics is as wide and open as possible. The topics to be included should reflect the needs of the industry and at the same time advance the state of the art in manufacturing.

One of the tools to collect ideas for research topics is the workshops. A workshop is a forum where invited representatives are encouraged to bring ideas for discussion and then, through an interactive process, develop research topics. This gives two approaches to obtain new ideas:

- Research topics presented and brought to the workshop by the participants.

- Research topics created at the workshop based on discussions and other forms of interaction.

There have been two workshops. The first was held in Brussels on April 23, 2009. The second was held in Zurich on May 26, 2009.

The first workshop in Brussels covered all five Key Areas. The scope was to identify future research topics or actions in each of the five Key Areas. The research topics should indicate the industrial needs for the manufacturing industry towards 2020 and beyond. They should be based on collaborative research across geographical regions and cultures and be eligible for public funding. There were 22 invited persons from industry attending the workshop. In addition 17 persons from the consortium were present.

The workshop was split in two sessions. The first one was a plenary session where all attendees were invited to present important problem areas or research ideas. They were given five minutes to present a problem description, potential research topics and a justification for the idea. After each presentation there were allocated time for questions and discussion. In total, there were 18 presentations from different industries. These included a total of 45 proposals for research topics.

The second session was based on group work. Four groups were formed to develop new ideas for research topics. During the plenary session, each participant was encouraged to write down ideas inspired from the presentations and discussions from the other attendees. These ideas served as input for the group work sessions. Each group were moderated by an IMS 2020 member. A rapporteur was appointed to produce a report summarising the discussions in each group. The four groups generated a total of 26 proposals for research topics.

The second workshop was dedicated to the current Key Area. The workshop was included as a half day session at a working conference of a special interest group of the IFIP (International Federation for Information Processing) working group WG5.7. The special interest group works with experimental interactive learning in industrial management. It contains mainly members with an academic background.

After an introduction to intelligent manufacturing systems (IMS) and IMS2020, the workshop objectives were explained and the organisation discussed. Existing research topics and ideas for research in education were presented to the participants as a basis for the discussion. In the plenum, brainstorming was conducted to generate new ideas and to complement existing ones. There were 20 participants. A total 16 ideas for research topics were developed in smaller group works. They were presented in a plenary session and enriched through discussions and clustering.

The ideas obtained at the two workshops were at different level and partly overlapping. They have through later processes been refined and clustered and merged with ideas from other approaches used to collect ideas.

For a detailed description of the workshops, please refer to www.ims2020.net.

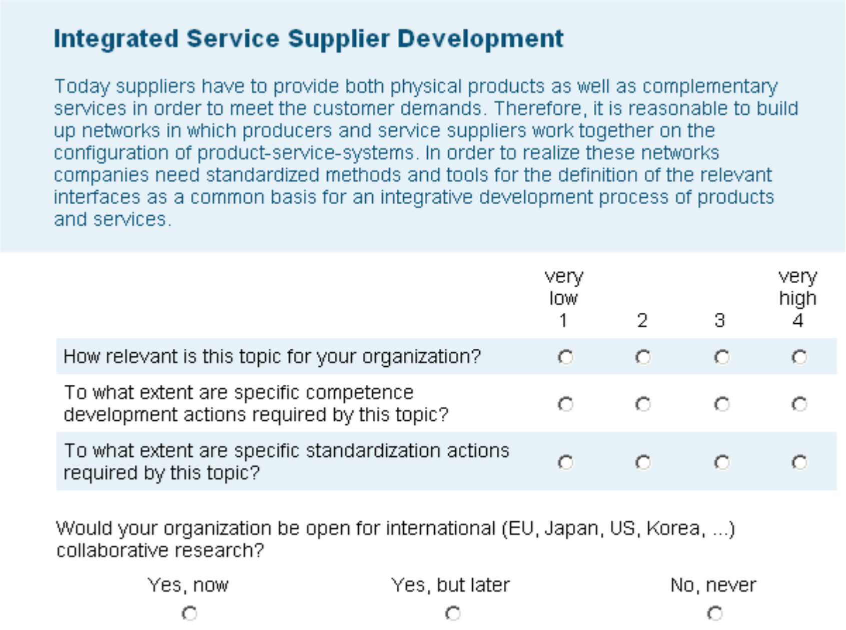
6.5 Second step of the survey

Based on the aggregated ideas for future research collected with the several tools, the IMS2020 team proposed nearly 90 research topics. In order to have these proposed research topics assessed by a maximum number of experts from industry and research organizations a second online survey was set up. The main objective of this survey was to get an indication of the topics' relevance and the willingness to participate in global, cooperative research on the topics. Based on the gained information the topics were prioritized and the suitability for research on IMS-level was pointed out. Therefore the survey was promoted to experts all over the whole world.

360 persons from 43 different countries participated in the survey.

Design of the survey

On the initial page of the survey statistical data like the number of employees in the participant's organization, the sector the organization belongs to and the country the participant is from are requested. On the following pages the research topics are presented as short abstracts. Based on the abstracts the participants are asked to assess the relevance for their organization, to evaluate the importance of standardization and competence development actions as well as to indicate their willingness to participate in international collaborative research. Compare the example given in Figure 23 for the design of the survey, the measured attributes and the applied units.



Integrated Service Supplier Development

Today suppliers have to provide both physical products as well as complementary services in order to meet the customer demands. Therefore, it is reasonable to build up networks in which producers and service suppliers work together on the configuration of product-service-systems. In order to realize these networks companies need standardized methods and tools for the definition of the relevant interfaces as a common basis for an integrative development process of products and services.

	very low 1	2	3	very high 4
How relevant is this topic for your organization?	○	○	○	○
To what extent are specific competence development actions required by this topic?	○	○	○	○
To what extent are specific standardization actions required by this topic?	○	○	○	○

Would your organization be open for international (EU, Japan, US, Korea, ...) collaborative research?

Yes, now	Yes, but later	No, never
○	○	○

Figure 23 Example for the design of the second online survey

Analysis of the survey and assessment of research topics

As stated above, the main objective of the survey was to assess the research topics regarding their relevance for different stakeholders and their suitability for research on IMS level. Therefore two concise indicators visualizing these attributes have been designed.

The topic relevance is visualized by a system of green lights (see Figure 25). Three green lights indicate that the respective research topic is among the third of topics with the highest relevance within the Key Areas. Two out of three green lights symbolize that the topic is among the second third and one green light expresses that the topic is among the last third according to the relevance.

To indicate the interest of the different IMS regions in doing research on the proposed topics a bar chart was designed. The graph is showing the percentage of participants per IMS region, which are either now or later open for collaborative research on a specific topic, compared to the percentage of participants not open for that kind of research on that topic (see Figure 25). A quick look on the described bar chart gives a good impression of the suitability of the topic for research on IMS level.

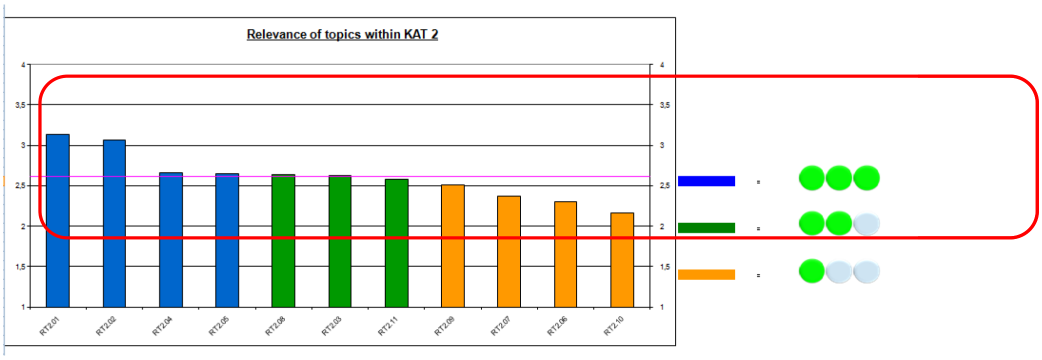


Figure 24 Relevance (ranking) of Research Topics

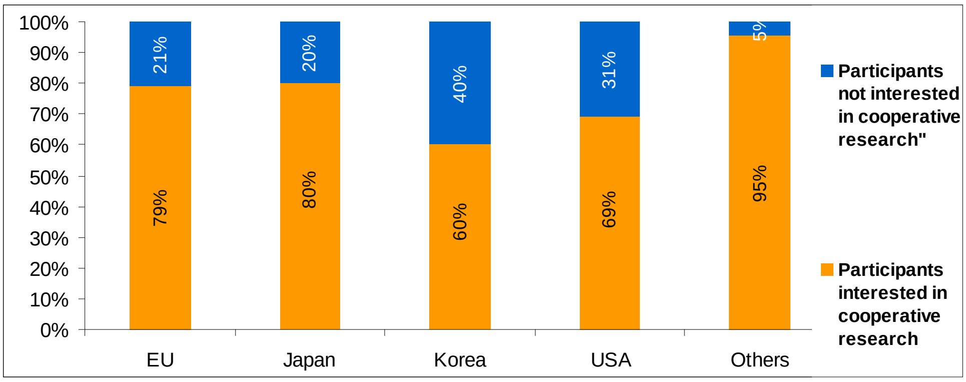


Figure 25 Example for bar chart visualising suitability for research on IMS level

6.6 Wiki

A wiki is a website that allows the easy creation and editing of any number of interlinked Web pages, using a simplified mark-up language or a text editor, within the browser. Wikis are used to create collaborative websites, to power community websites, for personal note taking, in corporate intranets, and in knowledge management systems. The IMS2020 wiki (http://ims2020net.wik.is) is meant to support a collaborative development and improvement of the topics suggested by the interviews, the first step of the online survey and the workshops the IMS2020 project did. As most wikis the IMS2020 wiki serves a specific purpose, and off topic material is promptly removed by the project team.

The purpose of the IMS2020 wiki is to evolve and to specify new fields in manufacturing research. The research topics should gain accuracy and relevance from the experience, knowledge and know-how of industrials and researchers from all over the world. For that reason the research topics are made accessible to a broad community in the state developed so far. The IMS2020 wiki has been announced among all qualified industry and research contacts of the IMS2020 core project partners to achieve the contribution of these experts.

For every visitor of the webpage the access to read a research topic is open, while they have to register (providing just their name and email address) to be able to comment. They can navigate through the wiki by looking for the Key Areas which seems most interesting for them. After choosing a KAT list of all assigned research topic abstracts appears. By hitting the link of the most promising topics the visitor can read the whole description and, if registered, of course comment. To offer an incentive all visitors are informed that if they contribute they can become a part of the Roadmapping Support Group and gain full access to the final results of the IMS2020 project. By taking the comments of experts from the field into consideration not only the relevance of each topic is proofed but the topics can also be improved due to the real requirements. Figure 26 gives a hint on how the wiki looks like.

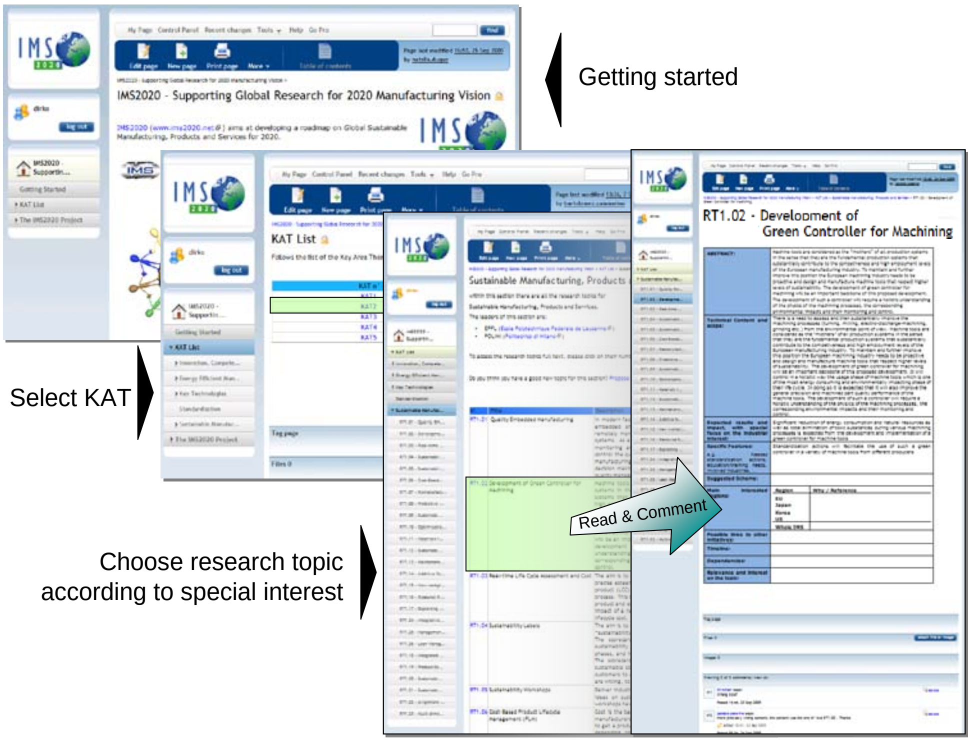


Figure 26 The IMS2020 Wiki

7 Annex 1 Innovation, competences development and education research topics - overview

Table 6 gives an overview (abstract) of all Research Topics developed.

Research Topic	Title and abstract
RT5.01	**Teaching Factories** Teaching factories are real production facilities developed for education and training purposes for students and workers, which will significantly reduce the gap between academia preparation and industrial needs, and improve the life long learning effectiveness of skilled workers.
RT5.02	**Cross Sectoral Education** The manufacturing industry is in constant need for updating their competence across many disciplines as new enabling technologies and global (cultural and societal) development constantly provide new opportunities and challenges. There is a serious need for research to understand how professionals and enterprises can most efficiently acquire such cross sectoral competence on a continuous basis, particularly in SMEs where individuals often need to stay up-to-date in many disciplines.
RT5.03	**Communities of Practice** The understanding of the important processes in which individuals develop, use and communicate innovative and dynamic knowledge, outside of the traditional knowledge management systems, is immature. Communities of practice can provide more structure to these knowledge exchange processes within and across organizations, there is a need to better understand how these processes and methods may be established and maintained to make exchange of best practice efficient and sustainable.
RT5.04	**From tacit to explicit knowledge** Individuals' tacit knowledge is a crucial component of the enterprises' knowledge base, however, traditional knowledge management systems are not suitable for capturing and externalizing tacit knowledge, a problem particularly critical to SMEs which are vulnerable to loss of core competence when individuals leave the company. Research into how emerging technologies (unstructured tagging, weblogs, wikis, etc.) may help capture tacit knowledge, in conjunction with understanding how this knowledge may be socialized, e.g., through communities of practice, may help companies to better utilize tacit knowledge.
RT5.05	**Innovation Agents** Global innovation agents represent actions in finding and developing innovation and ideas globally, and implementing the new ideas to the manufacturing industry, making sure that innovation and research in the

	manufacturing industry represent the latest and most innovative areas. Research within this area needs to focus on innovation agents as a concept for learning, and how this may be implemented in the manufacturing industry, e.g., through the identification of state-of-the-art and empirical evidence.
RT5.06	**Benchmarking** Benchmarking as a tool is well established, but still lacks refinement to present a powerful mechanism for learning, however, benchmarking has a clear potential as a systematic learning methodology. The proposed research will investigate how benchmarking can be converted into a systematic approach for learning, identify the necessary infrastructure to attain this, as well as undertake pilot implementations to evaluate the effects.
RT5.07	**Serious Games** In the knowledge society, human capital has become of strategic importance for enterprises and there is a need for more effective technologies and methodologies to support rapid competence development, knowledge externalization and knowledge transfer. The use of serious games for game-based learning empowers enterprises with greater agility in responding to market pressures and needs.
RT5.08	**Personalized and ubiquitous Learning** Flexible and targeted training of individuals, permitting individuals to choose when and where to learn, is preferable when individuals are required to stay up-to-date in their fields when faced with tight schedules and high workload. Digitalized course module repositories for manufacturing, supported by tutoring systems can be developed and adapted to mobile technology to allow tailored and individualized learning paths, made available through the use of, e.g., mobile technology.
RT5.09	**Accelerated Learning** Systematic learning from experiences and from exploring new ideas, through Problem Based Learning, has a great potential for enabling faster and better take-up of new technology, products and services in the manufacturing industry. Research needs to focus on two parallel activities, i.e., the development of a problem based learning approach enabling training of employees, experience exchange and cooperation within and between organizations, and the development of inter-company exchange programs for stimulating collaborative learning.

Table 6 Research Topics – overview

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