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# Advanced manufacturing

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## Definition

Although there are clearly manufacturing sectors that are today classified as "advanced" (nano-technology, plastic electronics, etc), the concept of advanced Manufacturing is essentially both sector-free and time-dependent. The "advanced" nature of manufacturing does not depend upon what sector it is used in but on the state of development of the manufacturing approaches and techniques involved. It is also the case that what is "advanced" now will be mainstream in five years' time and "traditional" in 10–20 years.

The authors have located scientific papers that already speak, for example, of "traditional" approaches to thin-film polymer manufacture.

Advanced manufacturing does not relate only to brand-new, high-technology sectors. In many ways it might be better to see it, not as a unique and discrete industrial sector or collection of sectors, but as a set of technologies and techniques that have substantial and far-reaching import for all manufacturing, no matter how currently "traditional".

Notwithstanding this, of course, the development of the skills-base for these techniques and technologies will require specific education and training; not so much for "new" skills (because most of the main elements of advanced manufacturing are already in use in the UK to some extent) but towards the substantial enhancement and broadening of skills to enable these advanced techniques, and their advantages, to be quickly established in the mainstream of UK manufacturing.

The overlap of advanced manufacturing skills between what we would term "advanced manufacturing" and other manufacturing is clearly illustrated by skill areas such as systems engineering, modelling, materials engineering, characterisation, and so on. All these skill areas are already in use in manufacturing in fields as widely separated as motor vehicle production, advanced textiles and food production.

For further development of a national agenda to develop advanced engineering it will be necessary to identify, in detail, where and how existing education and training needs to be enhanced to permit advanced manufacturing techniques to grow across the whole span of the UK manufacturing industry.

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## Sectors

Any discussion of the sectors associated with advanced manufacturing is greatly hampered by the difficulty of predicting what production processes will be influenced most by the development of advanced manufacturing science and techniques. Factory-flow modelling and process control are examples of advanced manufacturing techniques that can be of value to almost all manufacturing, not merely that at the forefront of science and engineering.

Some sectors that currently make use of such techniques are listed below together, with the regions that specifically mentioned them as priorities for advanced manufacturing[1]:

- Advanced Engineering: North East; South East; South West; West Midlands; Yorkshire and Humber;
- Advanced Marine Engineering: South East;
- Aerospace: East Midlands; North West; South East;
- Automotive: East Midlands;
- Composites: East of England; South West;
- Industrial biotechnology: East of England; North East; South East; Yorkshire and Humber;
- Micro and nanotechnology: East of England; North East; South West; Yorkshire and Humber;
- Plastic electronics: East of England; North East;
- Rail manufacture: East Midlands.

In the sense that advanced manufacturing fundamentally represents the next step in the general manufacturing of goods, however, it is also clear that advanced manufacturing approaches and techniques are of central importance to all regions and will eventually be a feature of every manufacturing need from food and drink to household white goods.

## Skills themes

If the UK has weaknesses in advanced manufacturing they are focused not so much on the overall level of knowledge and skill of our engineers and scientists but on their relatively narrow, non-business education, and on the weaknesses in our approaches to venture capital and start-up support (although both have improved markedly over the last decade).

A further economic weakness is that the UK has lost all its indigenous engineering equipment manufacturers and machine tool manufacturers. Today, and for the

[1] LSIS (2010), *Skills for Economic Growth* p12–13

foreseeable future, all our advanced equipment will need to be imported from Germany, Japan and the United States.

Manufacturing is vital for the future prosperity of the UK and, in view of the fact that a huge proportion of traditional, labour-intensive manufacturing has now been moved offshore by the developed world, "advanced manufacturing" represents the primary avenue for achieving a dynamic and lucrative industrial base.

The underlying theme of all existing research into advanced manufacturing is that its further development in the UK will require a step-change in the level of knowledge and skill in the workforce and the further development of a solid cadre of well-educated technicians to match (and, if possible, exceed) the scientific and mathematical competences of employees at this level in countries such as Japan, Germany, Singapore, and so on.

*Advanced manufacturing in the UK requires a flexible workforce with strong specialist skills in the areas of science, technology, engineering and mathematics and design.*[2]

This has to be understood in the additional context that advanced manufacturing will require fewer, but much more highly trained, employees. The actual numbers required by a UK manufacturing sector moving fast towards an advanced manufacturing-based future are unclear but they will certainly be only a fraction (possibly 10%–20%) of the workforce required to operate equivalent traditional manufactories.

In terms of the skills required for advanced manufacturing some key themes emerge from the existing literature:

### 1. Multi-disciplinary

In contrast to the situation perhaps a few decades ago, there are no longer clear delineations between industrial "sectors" in terms of the ranges of skills they require and this greatly influences their needs as to both professional and technician-level staff.

Most companies require multi-disciplined people, capable of seeing and using the links between disciplines such as chemistry, biology, and physics and with a holistic understanding of the links between disciplines and sectors.

[2] BIS (2009); *Growth Review Framework,* p.5

### 2. Well-rounded skills

It is clear from the literature that the development of entrepreneurial and dynamic advanced manufacturing will require people who have not only very high-level professional and technical skills but are skilled in a wide range of business skills.

### 3. Careers

Although skills are of vital importance to the development of advanced manufacturing in the UK it is arguable that it is equally important and urgent for teachers and careers staff to understand not only the importance of manufacturing but the way in which modern manufacturing works and the attractiveness of careers in the field.

There is much work going on in this direction but, up to now, this has been largely directed at attracting young people into science and engineering careers in general. There may be a case for expanding the effort to highlight the exciting and challenging careers available in the more advanced manufacturing sectors.

In what follows we have attempted to focus on skill themes specifically related to advanced manufacturing needs but it is evident that many (if not all) skills, will be required across the whole manufacturing sector as it moves towards more advanced techniques.

## Design

Designers will need to understand the capabilities of advanced manufacturing techniques so that they can design components, equipment and products that will make full use of the significant advantages offered by them.

The field – although centred on computer-aided design (CAD), assembly line or production robotics, CNC machine operation and computer-aided engineering (CAE) – also now overlaps, to a large extent, with fields such as systems engineering and virtual engineering.

Designers also need to be aware of the potential for additive manufacturing, unmanned systems and the use and application of robotics.

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## STEM (Science, Technology, Engineering and Maths)

Advanced manufacturing depends on the UK having a body of highly educated and trained engineers and scientists capable not only of making best use of existing advanced manufacturing approaches but of developing those techniques further and creating new ones.

The remit of this paper is post-16 but it is evident that young people's interest and expertise in advanced manufacturing must be fostered prior to that age and must be developed through advanced science and mathematics and by teachers who are knowledgeable about the application and uses of science and maths in advanced manufacturing.

This process will be vital to create not only a body of highly knowledgeable and skilled scientists and engineers but an even larger number of highly numerate and scientifically aware technicians.

The significant development of STEM subjects at school and college, and their promotion and development in engineering and science at university level, is therefore vital.

*OECD evidence shows that almost 25% of employees in manufacturing have a first degree in science or engineering. This is lower than China (over 45%) but ahead of the United States (around 15%).*[3]

Even at the most basic level, employers have highlighted the lack of laboratory skills and of multi-disciplinary skills in current A-level students and the need to expand and reinforce the teaching of advanced multi-disciplinary science to A-level (and equivalent) students. Examples of such needs might include biology, biochemistry and biological nanotechnology (with genetics and molecular biology), chemistry, colloidal chemistry, and polymer chemistry, and physics (especially quantum mechanics as related to nano-materials and devices, and to the use of advanced polymers and materials in space science).

[3] op cit Bis (2009)

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## Science/engineering skills

At the highest and most important level it is clear that universities and colleges need to ensure that their top-level science and engineering courses keep up with the science and technology at the forefront of advanced manufacturing. For example:

- nanotechnology;
- advanced materials science;
- advanced metrology;
- additive techniques (for both electronics and component manufacturing);
- microbiology and genetics;
- lithography;
- production and process techniques.

There is also clearly a need for the higher-level students to understand manufacturing techniques and product and process development, including the latest ideas of factory design and process flow.

Although all these subjects (and production engineering) are highly specialised in their purest forms, it is essential that students across all science and engineering disciplines gain a solid understanding of the way in which they affect the transition of new ideas and concepts into marketable products/services.

*Employers need people who can combine qualifications in science, technology, engineering and mathematics (STEM) with a wider set of skills, such as team-working and communication abilities, which enable them to work flexibly across a range of activities within companies.*[4]

Similarly there is a need for the education and training of higher-level students to be broader and to include skill areas that have, traditionally, not been generally considered as essential for engineers and scientists:

*The innovations in technology which characterise the sector [Advanced Manufacturing] are created from cross-disciplinary fertilisation. This gives rise to the need for individuals with an understanding of multiple scientific disciplines, and the different target markets and supply chains that the innovations can supply. Management and leadership, new product development and commercialisation skills are important and will become more so as the sector develops,*[5]

The rapid advances in materials science require design engineers who understand materials modelling, the capabilities and limitations of advanced composites and

[4] BERR (2009), *New Industry New Jobs*, p.29
[5] UKCES (2010), *Skills for Jobs Today and Tomorrow: vol 2,* p.25

plastics and the means of translating them into components and products in sectors such as aerospace, transport, building and general engineering.

Some of the main concepts and disciplines required for advanced manufacturing are as follows:

- nano devices and materials (still largely at R&D stage – requiring post-doctoral scientists – but quickly moving into potential new manufacturing areas);
- catalyzed nano-wire growth;
- metrology;
- bottom-up and top-down fabrication (self-assembly);
- additive manufacturing (as the main engineering target of the above);
- optical, e-beam, and ion beam lithography (and block co-polymer techniques);
- sol-gel techniques;
- polymer chemistry and advanced thin-film techniques;
- liquid phase deposition;
- characterisation skills (eg using advanced microscopy);
- process engineers – process improvement techniques;
- food scientists and technologists;
- biofermentation;
- energy specialists – solar cell technology, advanced batteries;
- plastics, paints and pharmaceuticals;
- genetic and associated products;
- micro-biology;
- chemical engineering (including microbial chemistry);
- colloidal chemistry;
- anaerobic digestion technologies.

# Marketing

*... our country has in the past suffered a notorious weakness in its ability to bring creative inventions (the product of creative technical skills and ingenuity) to market.*[6]

Many activities that make the best use of advanced manufacturing techniques at present are at the forefront of science and engineering and so tend to be developed by small, entrepreneurial companies based on one or two highly skilled engineers or scientists, or in a small, start-up unit in a university science park.

The entrepreneurial nature of this activity means that any deficiency of marketing understanding or support can mean market failure, however fundamentally sound the science and engineering may be.

It is clearly essential, therefore, that any advanced manufacturing activity should have access to skilled marketing assistance and that during their studies scientists and engineers receive – as a matter of course – a basic introduction to marketing and business finance. This should clearly be very practical rather than the more theoretical traditional "business studies" module.

# Management skills

Associated closely with the above, the need for enhanced management skills in the field of advanced manufacturing is certain but difficult to define from the present research. In many ways the skills required are already present and being developed in advanced manufacturing sectors such as aerospace, biotechnology (especially pharmaceuticals), electronics, plastics, and certain of the transport sub sectors (electric cars, for example).

One key skill mentioned during this research was financial awareness. It might perhaps not be the first key skill considered for advanced manufacturing, but there is no doubt that the location and negotiation of suitable tranches of venture and working capital for advanced manufacturing developments and for start-ups is of the utmost importance. Subsequent careful management of the finance and the need to accurately predict and negotiate good rates for working overdrafts is almost as important for the success of advanced manufacturing start-ups as the science and engineering behind them (as many failed ventures will testify).

"Package schemes" – offering young engineers and scientists access to start-up finance and general personnel, finance and marketing support – such as those

[6] SEMTA (2009); *Skills and the future of Advanced Manufacturing: A Summary Skills Assessment for the SSC Advanced Manufacturing Cluster;* p., 4

sometimes offered by universities in their science parks are often the difference between success and failure.

It is important, too, that young people – whatever their main subject of study – understand vital aspects of modern business management, such as competitive advantage, business-modelling, supply chain management, cash-flow and balancing revenue streams, intellectual property rights, data security management, quality control systems, lean manufacturing techniques and supply chain management.

Many sources stress the fundamental need in advanced manufacturing for research skills at both technician and professional level and from what would traditionally be regarded as research facilities (eg universities and research laboratories) to the operational areas of an advanced manufacturing unit. Perhaps more so than in traditional manufacturing, all staff in advanced facilities will need to work in collaboration with research organisations/higher education institutions; researchers will need to be able to work effectively with technicians and engineers.

The line between research and production is very blurred in advanced manufacturing, with significant and continuing crossover between the contributions made by ‘researchers’, 'engineers' and ‘technicians’.

## Technical skills

The manufacturing enterprise of the future will require many fewer employees at the operative and craft levels and a much higher proportion of higher technicians and professional staff.

At the technician level it is important that schools are producing highly educated young people for the colleges and universities to develop into advanced technicians for sectors such as biotechnology, advanced materials (plastics and composites), aerospace (with an emphasis on both syllables), medical equipment manufacturers, and so on.

In our opinion the development of advanced manufacturing in the UK will need to begin with the education of teachers about the potential of these technologies and the superb careers available for young people in advanced manufacturing. Much work is already under way in this area for STEM and the science subjects at GCSE level/ but it may be that non-science teachers, careers staff and parents are still relatively unaware of the immense potential for careers in advanced manufacturing.

There is clearly a great deal of potential for these developments through the new GCSEs in science subjects (especially the inter-disciplinary sort), through new Apprenticeship frameworks, and through closer links between schools and local companies.

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There are national requirements for technical people and technical apprentices in roles such as:

- electricians (mainly those who understand advanced solid state electronics and printed electronics processes);
- radio frequency technicians;
- IT technicians (particularly for integrated control systems);
- surface mount technicians;
- composite technicians (eg knowledgeable and skilled laminators and infusion technicians);
- systems management technicians;
- tooling and jigging technicians.

In the foreseeable future we will also need technicians capable of managing and maintaining robotic production lines and mobile, autonomous robots.

*We require technicians with skills in the installation and maintenance of complex capital equipment. These skills include programmable control, pneumatics, robotics, vacuum, RF equipment, and process control, for example. Both the graduate-level and technician-level skills are applicable across a wide range of industries.*

*Many industries require the same generic skills for their technicians. These are frequently referred to collectively as **mechatronics**, and include the electronics, mechanical and programming skills required to install, operate and maintain complex, high value capital equipment.*[7]

[7] Dyson, C. (2001), A learning network for the semiconductor industry; in *International Journal of Electronic Engineering Education* (2001) p.4

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## Conclusions

1. It is not feasible or possible to prioritise any of the skills presented in this paper. This is mainly owing to the aims and basis of the existing secondary research on which this paper has been largely drawn.

   Very little of it attempted to provide a timeframe or sense of which or where the most urgent skill needs are – most of the reports tend to be satisfied with identifying broad skills and knowledge needs within the context of advanced manufacturing.

   The existing research also does not prioritise the themes or sectors except to identify the main "sectors" and skills groups involved, which in many ways runs counter to the potentially extremely profound impact of advanced manufacturing techniques on all manufacturing sectors.

   However, interviews with a selection of industry experts and providers have highlighted some examples of sectors where the funding is such that the pull effect could act as a catalyst encouraging facilities for training in the required future skills (see below).

   These following examples are drawn from in-depth interviews:

   The Nuclear sector is an area of rapid growth with the potential to attract very significant funding. Through to 2025 there are plans to create six new-build nuclear centres at a cost of £6 billion each. Meeting the skills needs to make this happen will rely on attracting new people and new skills into the industry because the new plants will be designed and operated at the cutting edge of both engineering and nuclear capabilities. Most urgently, the industry will require people with scientific skills and qualifications from Entry level upwards. It is widely felt that there is a pressing need to attract more female entrants to Advanced Manufacturing sectors and greater numbers of school leavers to enter the industries via vocational routes.

   Within engineering the Marine sector was mentioned as being of particular importance, particularly in terms of developing new materials. We learned that at present there are apprentices specialising in materials development within hydraulics working to develop non-corrosive components to cope with the different combined corrosive effects of oil and water.

2. However, this paper poses a number of questions and highlights key points for providers to consider:

i. Multi-disciplinary skills:

As was noted earlier in this paper, most companies state a requirement for multi-disciplined people, capable of seeing and using the links between disciplines such as chemistry, biology, and physics and with an holistic understanding of the commonalities in both theory and practice between disciplines and sectors. Two examples of this are provided here but they do not attempt to describe the extent and depth of any multi-disciplinary requirement for any particular sector or activity.

Example 1: Additive Manufacturing

In this field it appears that engineering companies are, for example, looking for skilled engineers who understand the chemistry of materials' deposition and 3D design techniques: that is, not merely the traditional mechanical engineering competences, but substantial additional knowledge and skills of the molecular-level chemistry of materials. In some cases this can also include biological knowledge because some compounds are organic.

Example 2: F1 Motor Engineering

Some pieces of research report that the UK-based F1 motor companies – those at the forefront of advanced engineering – state a need for more rounded engineers (as above perhaps) with an understanding not only of mechanical and electrical engineering and aerodynamics but of nanotechnology (involving quantum physics as well as the biology of organic compounds) and "micro-machines" (eg artificial cells involved in the production of new lubricants and chemicals). They also need the wide knowledge and competences involved with additive manufacturing as above.

Acquiring more rounded engineers and technicians is probably the single most common thread or theme running through all the reports studied for this research. The boundaries between the "pure sciences" are now considerably blurred. For example, nano-machines can be constructed at the molecular level, requiring considerable expertise in chemistry, biology and physics.

Questions

Thinking about Technical Apprenticeships – how broad and deep do the current Apprenticeships need to be to provide the necessary multi-disciplinary skills?

Can providers identify how well the current fit is and if employers believe the current Apprenticeship frameworks will produce such a well-rounded technician?

How will these future skills and knowledge elements be developed and delivered by Apprenticeships?

How can they encourage more apprentices to enter industry at Apprenticeship level – eg to what extent can existing courses such as the Engineering Diploma be enhanced to meet the need?

## ii. Well-rounded skills

The development of entrepreneurial and dynamic advanced manufacturing will require people who not only have very high level professional and technical knowledge and skills but also possess a wide range of business skills including management of finance, marketing and entrepreneurial management skills.

### Questions

How and in what ways can providers support employers on business/ management skills?

What will be required to support teaching staff in delivering highly focused and advanced financial and marketing skills in appropriate qualifications?

Again, how will the sector include these future skills needs in Apprenticeships?

What are the barriers to Higher level Apprenticeship delivery?

## iii. Skills of careers staff

The urgent need for our teachers and careers staff to gain a deep understanding not only of the importance of manufacturing but of the way in which modern manufacturing works and the attractiveness of careers in the field was further highlighted in the recent promotion of Ministers' visits to manufacturing sites. A “factory doors open week” was suggested to help young people (and hopefully those in liaison with young people) gain a better appreciation of how exciting and challenging cutting-edge advanced manufacturing can be.

It is vital that providers look forward to the leading-edge aspects of advanced manufacturing and anticipate the knowledge and skills of future technicians. To achieve this some staff may need to be given experience of a range of uses of advanced manufacturing techniques and environments – and particularly of the way in which entrepreneurial skills can be harnessed alongside high-level

technical and professional skills to create world-beating companies, products and services.

Questions

How can providers help and encourage employers to get involved and to undertake talks and invite young people and teachers/lecturers into their manufacturing plants/sites?

What would be the best way of significantly enhancing the knowledge and awareness of teachers and lecturers (as well as careers staff) of advanced manufacturing?

General question relating to all such themes:

Provider intelligence

- How do providers identify future skills and knowledge needs?
- Who do they partner with to do this?
- How do they engage with sector stakeholders?
- How do they enhance and maintain their own knowledge, skills and awareness of developments?
- What do they need to help them with this?