Open Innovation in STEM Learning

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NEF
The Innovation Institute

December 2012

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A Research Report by NEF: The Innovation Institute

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ISBN 978-1-906970-13-0

We acknowledge and are grateful for the support of the Gatsby Foundation and to the many individuals and organisations who kindly provided information and views.

We would particularly like to extend our thanks to Arla Foods with Reaseheath College, BRUSH Electrical Machinery, EDF Energy, Jaguar Land Rover, MBDA Systems, National Grid and Rolls-Royce for providing in-depth case studies and site visits.

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Dr Rosie Bryson FIKE
Chair of the NEF Institute of Innovation and Knowledge Exchange, BASF PLC – The Chemical Company

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FOREWORD

Sir Richard Branson
Founder, Virgin Group

In times of fierce global competition businesses live or die by their innovation and canny re-invention. Are there better ways of working and should we be doing things completely differently? These are questions we're always asking ourselves at Virgin.

I'm not a fan of a desk or long board meetings and I don't believe that this is always the best way to get extraordinary ideas from people. At Virgin, we involve our staff at all levels of the business so they have ownership of their work. By allowing them to take responsibility and, within reason, to try their ideas, that's when I believe the inspiration for innovation begins.

We're acutely aware of the UK 'skills gap' – students lacking science and technology training, engineering and maths to support our industrial ambitions. There is no doubt we need to fill that gap urgently, whether to create greener aircraft engines or design better mobile phones.

We know that these technical skills are necessary but they alone can't lead to innovation. Without an understanding of business acumen these ideas cannot be put into practice or really take off.

It would be wonderful if students emerged, especially from vocational training, with technical know-how but also a good

appreciation of business skills and personal behaviours needed for success.

Some colleges will need to fundamentally rethink their approach and curriculum but I hope this report gives a wider understanding towards making these changes.

Never be afraid to try something new. You learn as much from your failures as your successes. And there is no better way to innovate than by just trying it. I hope you will be inspired to use a maxim widely known across Virgin: don't just play the game, change it for good.

EXECUTIVE SUMMARY

The aim of this investigative report is to shed light on the means through which high quality training impacts on improved performance in some of the country's highest achieving industries in science, engineering and technology (SET). What is innovative about their training approaches, and could these innovative training practices be transferred into FE colleges?

This report is the culmination of a research study which sought to identify **authentic innovative training and learning practices** used by SET industries that could inform and enrich teaching and learning of vocational Science, Technology, Engineering and Mathematics (STEM) in Further Education. The ultimate aim is to provide a basis that will:

- improve STEM learners' readiness to deal with real industrial situations;
- encourage contemporary and productive teaching and learning practices such as problem-solving and other forms of inquiry-based learning;
- underpin professional development of FE teachers.

The rationale for the project is that a number of research studies together with NEF's direct involvement with colleges in the development of their STEM strategies, highlighted a number of challenges that inhibit innovation and enrichment in STEM teaching and learning.

A major driver for this work is the determination to ensure that vocational education provides people with the skills and attributes that the economy needs. This is partly in response to the engineering and technical skills gaps coupled with the growth of new and emerging technologies. These two factors simultaneously inhibit and creates new UK industry. As a result there is a requirement to re-focus on STEM education.

The study involved activities including a review of current policy and recent reports, together with visits to companies to identify elements of effective and innovative training practice and several focus group events with industry and colleges that provided opportunities to seek views. These events included:

- A 'think tank' held in July 2012 included leaders from both industry and FE focused in clarifying the specifications from both industry and college perspectives. In addition, two further focus groups were held to validate the responses from the think - tank and seek further views.
- A series of meetings with NEF Panel members enabled deeper consultation with industry experts on criteria for innovative STEM education and training.
- A number of sessions were held within the NEF's Intelligent College Network in August 2012 which provided further contributions that helped to shape the outputs of this project, including the characteristics and attributes of a T-Shaped Technologist®.

The key outputs from these activities included:

1 **Criteria for innovative vocational STEM teaching and learning** based on contributions from participants at the

think tank, focus groups and other associated meetings, together with a literature review;

2 **Industrial case studies** based on company visits and insights into the practices of high performing SET companies;

3 **A "Toolkit" to support colleges** to transfer innovative practices as highlighted in the industrial case studies, including the adoption of the T-Shaped Technologist model and provide support to college leadership to develop a culture of innovation and continuous improvement.

The Criteria for Innovative STEM Education

Innovation happens all the time and is ever more increasingly a mandated requirement for industry, education and policy.

In education, at least some of the problems faced today, mirror those that were experienced in the past. But there are some specific trends. For example, the shift from teaching to learning. And, we can summarise the features of teaching and learning from what they were to what they could potentially be as in the table below.

TEACHING & LEARNING	"TRADITIONAL"	"NEW FACILITATING"	ENTREPRENEURIAL
Leadership Of Lessons	Teacher	Partnership	Learner
Focus Of Teacher	Covering Syllabus	Engaging Learners	Empowering Learners
Role Of Learner	Recipient	Participant	Determinant
Use Of IT	Didactic	Back-Up Resource	Experimental
Intention	Outputs	Development	Outcomes
Reason For Meeting	Timetable	Joint Working	Team Working
Role Of Homework	Testing	Reinforcing	Preparing
Role Of Assessment	Checking	Learning	Developing
Soft Skills	Chance Product	Bi-Product	Main Product
Economic Model	Conforming Employee	Intrapreneur	Entrepreneur
Approach	Instructional	Educating	Enterprising
Success Measure	Success Rate	Effectiveness	Impacts

Figure
The shift from 'old teaching' to 'new practice'.

These features can be used to identify "new practice" from "old teaching", but innovation remains a challenge. We look for characteristics of STEM education that enable innovation in STEM vocational teaching and learning to happen, and, where it does, will it be effective?

Four themes emerged and can be summarised thus:

a **There is an explicit and clear description of the desirable output from the teaching and learning experience**
It is a truism to say that innovation is not "innovation" if it is not effective. So, what exactly is innovative STEM vocational teaching and learning aiming to achieve? This report purports that there are certain attributes, skills and behaviours in the individual that are the desired output and they are modelled in the T-Shaped Technologist. These attributes are those that prepare learners for a future career in SET sectors.

b **The practice embeds a deep understanding of how learning happens**
This includes:

- ensuring that the rationale for learning, and its relevance, is clear;
- identifying the role of trust in teaching – learning relationships;
- exploiting ubiquitous learning – inside and outside the classroom, formal and informal;
- allowing learners to take ownership of their learning;
- taking advantage of technology; and
- aligning curriculum and assessment to the requirements of the output, and that of the real customer.

c **The provision is shaped by a collaborative effort and influenced by the real customer**
We look for an ecosystem or a community of learning that:

- involves all partners and connects to the wider community: learners, teachers, industry, employers, college leaders and policymakers;
- fosters open innovation and shared working;
- shares resources: people, experts, products and experiences;
- supports new frameworks, new delivery patterns;
- enables new pathways; and
- embraces new cross-curricular and multi-disciplinary teaching and learning.

d **There is a fundamental drive to find new and better ways of teaching and learning**
Education can be said to have succeeded when it inspires and enables. We propose in this report that where a culture for innovation is supported and valued, the result is likely to be inspiring. There is a drive to enhance quality of education, which should support innovation. However, what is not always understood is that failure is often a necessary part of innovation. And what is also clear is the need to identify barriers and enablers: both actual and those that are a product of the system. Processes that are in place to drive innovation will vary as colleges are at different points in their innovation maturity journey, but leadership, structures and support are essential if innovative STEM vocational education is to happen.

This report explores these themes and extends them further, particularly with reference to the issues of STEM learning and the value added to vocational education and training. The findings from the industrial case studies and other examples of good practice, add to the analysis of this criteria.

Case Studies from Industry

As part of the research study, the following organisations have provided the research team to observe first hand their authentic innovative practices which provided the basis for the development of the case studies:

- BRUSH is at the heavy end of high-skilled heavy manufacturing, producing turbines for the power industry across the globe. Apprenticeship training here is geared towards present and future needs, and includes easily transferrable elements of learner-directed and project-based learning.
- EDF Energy trains their people to work in nuclear power stations. The focus in this case study is on safety-training – and the lesson that innovation in training need not be "whizz-bang" – but is more about the commitment to the value of training and having a systematic approach.
- Jaguar Land Rover relies heavily on the continuous professional development of engineering staff to ensure the continued success of the company. An innovative model for a new postgraduate programme provides guidance around the need to better understand customer requirements as a driver for curriculum and delivery.
- MBDA Systems is a world leading missile and defence organisation which aims to recruit and retain staff for their full working life. Their work links schools and colleges, helping them to identify potential recruits that possess the right attributes. They place high value on understanding each learner and their drive for development focuses on setting targets for behaviours and attributes.
- National Grid trains many of their technicians at the Eakring Centre where the focus on providing realistic environments is very well established. But what is also obvious is that there a culture for innovation is embedded, with an appetite for risk in trying out new approaches and new technologies.
- Reaseheath College and Arla Foods formed a partnership with a group of leading dairy food companies to create a state-of-the-art training production facility. This study illustrates the role and strengths of collaboration between industry and education and the need for cross-disciplinary education.
- Rolls-Royce is a global provider of power systems and services for use on land, at sea and in the air and is renowned in the UK for its engineering apprenticeship programme. This programme has been redeveloped recently to incorporate lean-manufacturing concepts and to support personalised learning. The result is a now well-recognised, highly successful, innovative, learner-led programme, with many a lesson for educators and colleges on risk-taking, failure and learner-ownership.

Six main lessons arise from these case studies:

1 **Values and behaviours** really do matter in setting the compass for innovative training that is 'top-line' and is not about cutting costs nor about a quick return
2 Innovation is enhanced where people have the **confidence** and/or are encouraged to **challenge** the orthodoxy, and where **collaboration** and cross-disciplinary education is at the centre of the training model
3 Understanding what the aim of training is, is key to designing **a learning experience that is relevant** – the aim is often around attributes of the learner and not about a qualification
4 Training that sets out **ambitious targets** for attributes is challenging but rewarding
5 The **customer**, which in this context is SET industry, must be able to **decide** the **outcomes** needed from the training
6 At the cutting edge of Innovative practice, **learners are central** in determining their own learning success

Transferring the Lessons to Further Education

Whilst each lesson from these case studies is directly transferable into FE colleges, there are three important features of the FE context that need to be clear:

1 For a large part of their work, colleges deal with people whose career choice is not made, and for whom the pay-back for training is not always immediate. This contrasts with the case studies of training in industry, where the pay-back to the trainee and to the company can be much more immediate as career improvements are articulated.
2 Much of a college's STEM provision is dictated by qualifications and resources, both of which are directly related to funding. Industry is free to choose the form and content of their training in ways that are not always within the reach of colleges. Nevertheless, the case studies can serve to inspire new curriculum and new delivery techniques, and certainly can inform priorities and innovation practice at colleges.
3 Innovation happens all the time in FE colleges in ways ranging from very local and ad hoc to organisational. This report offers a toolkit which provides ways of thinking about how innovation can be encouraged successfully and supported by structures and processes. This report does not seek to prescribe the latter, but it highlights that successful innovation depends on leadership being open to creative thinking, new ideas and empowering learners and teachers.

Lessons and Recommendations

So what, then, is the value of the six key lessons from the case studies?

Lesson 1: Values and behaviours really do matter in setting the compass for innovative STEM education and for training that is 'top-line', and not about cutting costs nor about easy returns:

In each case, training has been accorded the highest priority in the company: the realisation of the idea that people make things happen and people are the key to success, no matter how automated the processes that they have to operate. This has the following connotations for colleges:

- How is innovation supported in the college?
- How is training 'sold' to employers – as part of the top-line drive for success linked to performance improvement (as with the companies in the outlined case studies) or, as a cost-saving bottom-line exercise?
- How well is staff training in colleges aligned with clear-cut college values and how well does the resulting staff operating culture reflect these values?

Lesson 2: Learning requires a learner and an understanding of his / her characteristics pays dividends:

It is standard practice in FE colleges to make great efforts to understand the characteristics of learners and to support their learning accordingly. In some ways, this is a lesson that industry may be slower to comprehend. However, the case studies here raise some interesting new approaches. Such approaches range from encouraging tutors to understand learning styles and applying this understanding to training; focusing learning on the individual's needs and moving away from convenient group teaching approaches of old. FE colleges could ask themselves:

- How well do our staff really understand the learning capacities and attributes of our students?
- Could differentiated learning approaches be used to provide effective alternatives to increase the personal value of learning for students rather than having students go through the same course at the same time, in the same place and at the same pace?

Lesson 3: Innovation is enhanced where people have the confidence and/or are encouraged to challenge the orthodoxy, and where collaboration and cross-disciplinary education is at the centre of the training model:

In each of the cases the essential nature of learning is understood: learning means discovering and discovering means challenging the accepted way of doing things. This often requires a pioneer or an organisational initiative to drive it, but the common currency is opening minds to opportunities and encouraging trainers to take measured risks in changing things for the better.

This is an indivisible truth about innovation: it cannot be imposed, it has to be made. And without collaboration, real innovation is not made. This goes to the heart of the value of this report:

- FE colleges can make best use of the case studies and these lessons by reflecting, adapting and challenging the way they do things.
- Colleges need to see themselves as part of an ecosystem for collaborative education. Collaboration across disciplines and with industry is expected to be at the centre of such an ecosystem.

The "toolkit" can only act as a prompt and a guide, and should not be followed blindly. College leaders should ask themselves: to what extent do our structures and processes allow people to challenge the orthodoxy?

Lesson 4: Training that sets out ambitious targets for attributes is challenging but rewarding:

It is telling that each of the case studies reveals the importance that companies attach to engaging their workforce with company values. What is equally revelatory is the deliberate way they then set about defining the attributes of the effective staff member and find ways to develop these attributes of character. This mirrors a major contemporary thrust in FE colleges, developing those desirable characteristics of tomorrow's workforce in today's students. In responding to the lesson from the case studies, colleges may ask:

- How well are we deliberately preparing our students for tomorrow's world of science, technology and engineering?
- Do we make clear the attributes and behaviours that are to be encouraged, developed and assessed through the T-shaped Technologist?
- What steps can be taken in our teaching, learning, curriculum and assessment to make sure we have the impacts we desire?

Lesson 5: The customer, which in this context is SET industry, must be able to decide the outcomes needed from the training:

The customer of the training in companies is the company itself, the benefit of transferable skills to the employee notwithstanding. In the company, therefore, the task of setting the goals of training is more straightforward than in the FE College. What is a more subtle lesson from the cases, however, is the progress that HR and training leaders have made in re-prioritising training and connecting its benefits with company strategic goals. In colleges, outside of employer-responsive training, the customer is not so well defined – but it is either employers (generally) or the individual. Herein lies the problem: how to provide the skills needed for tomorrow when people are free to choose their own career path and course of study?

The lesson from industry here is that FE colleges can ask themselves:

- Do we really address the requirements of the employers we provide for?
- How can we understand the future skills needs of industry and how can we adapt what we do to meet these needs better? and
- How can we work with the SME employer-base to help them understand their own future needs and to help provide people to meet these needs?

Lesson 6: At the cutting edge of Innovative practice, learners are central in determining their own learning success:

The remarkable thing about the training experience in these companies is the quest for better outcomes that drives new ways of learning: it is the quest for better outcomes that drives many of the innovations in learning. This manifests itself in many ways, from 'inverting' the training approach (by making it learner-led rather than teacher-directed) to the example of students setting out their own learning journeys. This idea is not completely new or unfamiliar to FE colleges. However, the way in which this approach is adopted using innovation as the driver is the real challenge highlighted in this lesson. Therefore, colleges may ask themselves:

- How much of our curriculum and our approach to teaching and learning is still

mainly teacher-led and how well does this achieve our aims?
- How could we move to a learner-led model and with what impacts? and
- How do we ensure that the learner experience leads to real opportunities beyond college, into industry?

There are also wider recommendations for policy and Government:

- **The STEM curriculum and qualifications offered by FE colleges** are the key to encouraging the success of many of these lessons from industry. Developing 'values-led' education to support a competitive economy requires linking training with desired outcomes, together with the required attributes of character, knowledge and understanding. We need curriculum that develops thinking capacity, encourages real learning, qualifications that demonstrate high-level skills, and a focus on the ability to apply knowledge.

  We have 'informationalised' the education of the young: for example, maths is often seen by learners, if not by lecturers, as a set of rules to learn rather than the means to acquire logical thinking and decision making skills. The former is useless for most people; the latter is indispensable for successful living. The knowledge that learners acquire when they leave from a college will not be sufficient for them to function effectively in 10 years' time. Theoretical underpinnings are crucial, but even more essential is "learning to learn" to be able to move with the current speed of developments in science, engineering and technology.

- **Effective and innovative STEM industry training** has happened where leaders have prioritised training and set outcomes as the metric: 'how well does training lead to the world we want' rather than 'how many people have been trained?' The logic is for Government to do the same. This means being bold in determining what it is we really want from our colleges of Further Education. What outcomes do we need to see flowing from organisations whose fundamental aim is to help generate socio-economic prosperity?

  The answer must have something to do with achieving social returns on investment, ensuring value for money and instilling a coherent ecosystem for STEM vocational education that supports colleges in their fundamental duty to address the needs of their communities and learners.

We need to get away from the perverse incentives of output measures and to search for new outcome metrics for colleges that encourage high quality STEM education and training that works. We need to stop tinkering with qualifications and look for a model that will drive real improvements in STEM education and training. The proposed T-Shaped Technologist® learning model addresses many of the required characteristics needed to create an innovative (effective) open learning environment in our vocational training system.

I hope that you enjoy reading this report and that it will precipitate stimulating debate.

Professor Sa'ad Medhat
PhD MPhil CEng FIET FCIM FCMI FRSA FIoD FIKE
Chief Executive, NEF: The Innovation Institute

1. INTRODUCTION

Innovation is being urged in education because education is changing. And education is changing the world over; governments are trying to make the connection between the potential of education and the needs of economic prosperity. Innovation is becoming the status quo.

Any new thinking about innovation in education has to accept that there is a lot of it about – but that there is an appetite for more. In the Further Education sector in England, the focus of innovation is on the curriculum, on teaching and learning, and on the means through which colleges and training organisations can best accelerate productive relationships with industries and employers to generate socioeconomic prosperity.

One place to look for new ideas is major SET industry employers who have had success re-engineering training to generate improved performance. What have they done, why have they done it, how has it worked and could it be transferred to colleges?

The key to the impact of this study is to accept that innovation in colleges is all about direction of travel – describing where the organisation is going, and not about destination – prescribing teaching and learning practice. Colleges are at different points on their journey and vary in many ways. Any guide or "toolkit" for innovation will only be useful if it understands this fact and therefore outlines possibilities rather than defines rigid processes. So, what would these possibilities deal with?

"The value of incremental innovation shouldn't be overlooked"

– Business Capability and Skills Manager, National Grid

The *T-shaped Technologist*® is an idea that captures the imagination of many. The construct is simple – a horizontal set of attributes that broaden a person's employability and ability to innovate and a vertical set of technical know-how and know-why. The case studies of STEM training in industry in this report highlight the value of the model: the companies featured are very deliberate about developing desirable attributes, not just in the vertical but also the horizontal. The key idea is to allow the horizontal to shape learning in the context of which the technical skills are learned and to ensure the vertical is based on relevancy and real applications. The future lies in this: no more soft skills by osmosis.

Does this transfer? One of the key distinctions of training in industry is that the pay-off to the trainee is immediate: skills for immediate use. With colleges, much of what is learned may come in useful, but ahead of career / job choices, the degree of usefulness is uncertain. The paradox is that this is precisely where the lessons from industry are so applicable. The horizontal of the T-shaped Technologist is a set of attributes used in all work environments; the capacity to imagine, think and learn – to recognise and use ingenuity – so valued in industry training is also essential to be able to adapt to a future working life as yet unknown.

Yet there is more: the case studies provide examples of highly successful companies enabling learners to learn what is new to them and independently rather than assuming everyone is at the same stage of attainment, equally ignorant / informed and needs to learn at a set pace with others. They deploy technology effectively and put the learning in to 'online learning'. The role of the teacher is

therefore to tutor and facilitate, and not to lead the teaching, and because they understand how learning happens they no longer act in a traditional teaching role.

Where this leads to is an inversion of the conventional teaching and learning model. Although this could in theory happen in any class or on any course, one of the big lessons from this study is that values count: if real learning is the highest priority in the organisation, then real innovation and real success are possible. If not, forget it.

A challenge for FE colleges is to how to create an innovative learning culture that aligns their aims in STEM education with the needs of their real customers. Beyond this, the other challenge is how to drive the development of a collaborative ecosystem of open innovation with partners outside the college.

1.1 Seeking Input from Industry and Colleges

This report is the culmination of a research study, which sought to identify **authentic innovative training and learning practices** used by SET industries that could inform and enrich teaching and learning of vocational STEM in Further Education. The ultimate aim is to provide a basis that will:

- improve STEM learners' readiness to deal with real industrial situations;
- encourage contemporary and productive teaching and learning practices such as problem-solving and other forms of inquiry-based learning;
- underpin professional development of FE teachers.

The rationale for the project is that a number of research studies together with NEF's direct involvement with colleges in the development of their STEM strategies, highlighted a number of challenges that inhibit innovation and enrichment in STEM teaching and learning.

A major risk in this endeavour is to assume things about the starting point for future innovation on the part of colleges; or, indeed, to assume that the traffic is all one way. Industry can also learn from the experience of colleges.

A 'think tank', arranged in June 2012, included leaders from both industry and education to understand the requirements of this innovation project, particularly from the FE perspective, with two guiding questions to address:

Q1: presuming that industry has to provide effective training to meet business needs, how can this potential effective and innovative practice be transferred to education?
Q2: how do colleges recognise innovative teaching and learning practices?

In addition to this think-tank, two further events were held which provided opportunities to seek views. An earlier NEF Panel meeting enabled consultation with industry experts on setting the criteria for innovative training, and a later Intelligent College Network meeting with senior college representatives validated the T-shaped Technologist® concept as the "output" of innovative education and training.

"Innovation is not about spending lots of money to achieve a result or inventing something new, it's about using what we have available at our disposal and creating new ways of solving problems or improving how we run our business"

– Campus Chancellor,
EDF Energy

2. INNOVATION IN STEM EDUCATION AND TRAINING

In a way, there's nothing new about innovation. The process of innovation happens all the time. In education, at least some of the problems faced today mirror those faced by civilisations ancient through to modern. There's many a pithy quote from an ancient Greek that applies as well today as it did all those millennia ago.

It is not surprising. The wealth of nations depends on every rising generation to develop, enhance and progress and the specific demands on education change all the time. The challenges inherent in the transfer of skills, ideas, knowledge and behaviours from one person to another, from one generation to another are complex and varied. And at the heart of the process, teaching and learning requires teachers and learners, whose objectives and attitudes often differ vastly. It is little wonder that the search for new and better ways of doing things is continual.

Within this general direction there are some specific trends. In the more recent past in England, for example, a key trend in innovation in teaching and learning has been the shift in emphasis from teaching to learning. That is, to understand what effective teaching is, means to understand better how people learn. To measure success, we need to know what has been learned, and not just what has been taught.

This trend has its origins in a variety of places. In STEM, some of the practical sources would include initiatives from the 1960s and 1970s such as the Nuffield Science Teaching Project[1]

and the School Mathematics Project[2] in the UK. These examples drew 'discovery-based' learning to the fore and encouraged learning through experiment and experience.

At around the same time, in the broader context, a combination of concerns with 'the secret garden of the curriculum'[3], the consequences of the failure of 'technical education' as the third strand of tripartite system of education brought in by the reforms of the 1944 Education Act; growing dissatisfaction with education as a 'national system locally administered' gave rise to a new way of doing things. It was time for a more central approach.

Nationalising the curriculum at the very time when almost everything else was being privatised, Kenneth Baker's Great Education Reform Act 1988 also ushered in GCSEs, national inspection via Ofsted and the first break with Local Authority controls – via Grant Maintained Schools and through the transfer of over 150 powers from local to central government. Part of the wider consensus across western democracies became known as 'new public management', and these reforms remain largely in place today.

It may come as a surprise to know that at this time of centralising of powers came some significant innovation in vocational education. Specifically, the Technical and Vocational Education Initiative (TVEI) sought (largely unsuccessfully) to redress part of the academic / vocational divide[4] and new local management arrangements paved the way for colleges to be freed from Local Authority control in the eventual 1992 Further and Higher Education Act.

These changes encouraged much innovation in education. There were some obvious causes. In the early years of GCSE, the new all-ability qualification had caused a re-think on how to teach and learn in schools. Group-work and 'child-centred' learning became far more mainstream. And more people did better, changing the nature of intake into colleges, causing an over-supply of applicants to A-level courses (as the academic / vocational divide took even greater root), and leading to the perpetual increases in enrolments in colleges that continue. albeit more slowly. to this day, and which are about to be enforced formally, as the participation age rises to 18.

A more negative rationale for innovation in recent decades has been the accompanying squeeze on resources. Even when funding has increased, either efficiencies were expected or labour costs were rising (or both). And in harder times new ways of doing things have to be found.

At the same time, two other major trends have driven innovation in teaching and learning in vocational education. On the one hand, there is technology. The rapid advent of the internet, the revolution in communications, the near-ubiquity of reliable hardware and the everyday use of IT by the young, have all shaped an entirely new set of teaching and learning contexts and possibilities.

The other major shift has been the determination to link vocational education far more closely to economic need, and to ensure such education provides people with the skills and attributes the economy needs. This is partly a reflection of the growing understanding that in a globalised economy, technical professionals

1 For a short history, see "*I do and I understand": Half a Century of Curriculum Development*, www.nuffieldfoundation.org
2 Refer to the Collaborative Group for Research in Mathematics Education, Southampton University www.crme.soton.ac.uk
3 For an outline of the impact of James Callaghan's Ruskin Speech in 1972, see: (Wilby, 2006)
4 An easily accessible description of the TVEI can be found in (Evans, 2011).

*"Rarely does an idea emerge as a fully formed concept . . . it needs to be **shaped and modified**"*

– The Innovator's Solution (2003)

are the make or break for an advanced high quality-of-life society. In part, it is a response to the scientific, engineering and technical skills gaps in parallel to the growth of new and emerging technologies that squeeze and pull the growth of UK industry (CBI, 2011) (UKCES, 2011a) (HM Treasury and BIS, 2010). In addition, there is the call to get rid of the "bright red line" between education and work (OECD, 2012) and so to reduce the problems that seem to arise when education is not aligned to opportunities in work and industry (Harrington 2012). This has led to a re-focussing on STEM education in Further Education and with this, the emerging realisation that there are challenges to be addressed (Green & Fletcher, 2012).

It is not surprising that these trends and policies have driven innovation in teaching, tending more and more towards an emphasis on understanding learning. This has been reflected in the work of national agencies such as the Quality Improvement Agency (QIA) and its successor the Learning and Skills Improvement Service (LSIS), but the impact of such agencies is very limited to encouraging and to enabling the willing. The real work on innovation happens in the colleges. And there have been some outstanding examples of innovation in teaching and learning in colleges: from virtualising the entire college's curriculum[5] to inverting the 'teaching – learning' model[6]; from highly effective innovation for economically-valuable skills to the new and far-reaching ideas for entrepreneurial education. There is exciting new ground being broken in the way people learn, and the success they then have in using their new skills, understanding and knowledge.

5 Examples of *virtualising* initiatives can be found at the STEM Assured® South West College www.swc.ac.uk, and the Worcester College of Technology.

Yet innovation remains a challenge. Partly this is because of latent conservatism of organisations; partly it is about the drivers for Further Education. The new freedoms for colleges are so far more apparently connected with structures and governance, whilst news on the new curriculum and funding arrangements following the Wolf Review (Wolf, 2011) are awaited. At the same time as Ofsted's new focus on teaching and learning is to be welcomed, there is a genuine question about the extent to which Ofsted still helps drive a compliance culture. People are afraid to innovate if they think they might be penalised by the inspectorate. And they will be penalised if innovation "fails". And to compound the effect on STEM, inspection and accountability have no impact on the delivery of STEM (Green & Fletcher, 2012). Whilst Ofsted is in fact only too keen to find new examples of effective innovation. The constraints of funding, audit and accountability remain as blockers to innovation.

And yet innovation happens and it works. The Gazelle initiative and the NEF Intelligent College Network (ICN)[7] are to be applauded for the courage it requires of college leaders to collaborate in making step-changes around STEM offers. If we want enterprising people to run our economy and skilled technologists to grow our industry, we have to help produce them. This means radical new ways of teaching and learning. The ICN and Gazelle colleges are not alone, but they are acting collectively in the greater interest of the people they serve and perpetual innovation is their key.

In spite of all the well-understood theories of effective teaching and learning, there is still much work to support better STEM education. There remains the ancient challenge: the art of teaching being to get people to want to learn and the science is to ensure that the learning is fit-for-purpose. But at the heart of the organisation is the appetite for risk, the intelligence to understand the need for better and the competence to lead change. These facts are part of the life of most organisations. No organisation is so good that it has no need to innovate. In fact it is quite the opposite: the best organisations are best at innovating.

What, then does all this tell us? That colleges have an appetite for innovation, certainly; that colleges are good at innovating, of this there is considerable evidence; that there are big barriers, real or perceived, absolutely – particularly in STEM education. But that there is other learning to be had: that colleges need to understand the requirements of industry.

Our fundamental questions are then:

Q: What is the role of innovation in STEM teaching and learning?

- What identifies teaching and learning as innovative?
- What makes it effective?

Q: How can FE Colleges lead innovative STEM vocational education?

- What can colleges learn from training in industry?
- And how can college leaders initiate innovation for STEM education?

6 *Inverted instruction*, or *flip* teaching, relies on technology to allow teachers to focus on supporting deep learning rather than on the transfer of knowledge (Lage, Platt, & Treglia, 2000).

7 The Intelligent College Network is comprised of the STEM Assured colleges who aim to help drive economic growth by increasing their STEM capability for the benefit of learners, industry and the FE sector itself, based on the ideals in the NEF report, *The Intelligent College* (NEF, 2011).

MYTH	REALITY
Flash of insight	Comes from immersion
Brilliant, successful idea	Fail early but often
Individualistic	Collaborative
New knowledge	Admitting ignorance
Invention	Mostly development
Leader-led	Supported by leaders, grown by individuals
Originality	Borrowing
Look to the future	Look sideways and backwards
Internal R & D	Networked, open innovation
Product pipeline	Consumers as innovators
All about learning	Unlearning just as vital
Everyone loves innovation	"Better" is not always recognised
Sources: (Leadbeater, 2006a) (Berkun, 2010)	

Figure 1
The Myths of Innovation

2.1 So what is meant by "innovation"?

There is no set definition for "innovation" but all definitions refer to it as the successful implementation of a creative idea or an adaptation of a process, work methods, or product that is novel in the current environment (Reiter-Palmon, Herman & Yurkovich, 2006) (Amabile, 1996).

Innovation in teaching may refer to any commitment to create new content, implement new methods, and processes to support learners to take an active role in their own learning. This may include new approaches to curriculum development, assessment, delivery and use of new technologies. There are hugely inspirational stories of innovative education that catch the eye and the headlines, such as Bloodhound SSC in the UK, the Khan Academy, or those examples as might be documented by World Innovation Summit for Education (WISE)[8].

But many of these inspiring stories can also add to the "myths" of innovation – that for something to be innovative it needs a huge leap in new thinking, resources and a whole new way of doing things. And there is the biggest myth that all innovation will succeed, instantly and brilliantly.

Innovation is rarely the result of exceptional acumen and sudden insight, on the contrary, it is

8 Information on these can be found at: www.bloodhoundssc.com, www.khanacademy.org, www.wise-qatar.org respectively.

usually about 'adopt and adapt' and this should be excellent news for FE leaders and college managers. The key to the idea embedded in this report is that, just maybe, there are excellent examples from industry training, which could be adopted and adapted to deliver direct innovation value to FE colleges in the UK. But there are also lessons in this list which will be explored later.

2.2 Where does innovation in teaching and learning happen?

There is an easily identifiable general trend in education to shift from teaching to learning. We can summarise the features of teaching and learning from what they were to what they could potentially be as in Figure 2 below.

These features can be used to identify 'new practice', but we need to look a little more deeply beyond teaching practice to holistic criteria that will support educators to identify innovative practice in STEM and to foster the right conditions to develop further new practice that is effective and relevant.

Innovation can happen at many other levels in education:

- Culture and teachers – the education system, including management and the people involved in leading education
- Curriculum and assessment – the content of the teaching, and the way in which learning is measured

TEACHING & LEARNING	"TRADITIONAL"	"NEW FACILITATING"	ENTREPRENEURIAL
Leadership Of Lessons	Teacher	Partnership	Learner
Focus Of Teacher	Covering Syllabus	Engaging Learners	Empowering Learners
Role Of Learner	Recipient	Participant	Determinant
Use Of IT	Didactic	Back-Up Resource	Experimental
Intention	Outputs	Development	Outcomes
Reason For Meeting	Timetable	Joint Working	Team Working
Role Of Homework	Testing	Reinforcing	Preparing
Role Of Assessment	Checking	Learning	Developing
Soft Skills	Chance Product	Bi-Product	Main Product
Economic Model	Conforming Employee	Intrapreneur	Entrepreneur
Approach	Instructional	Educating	Enterprising
Success Measure	Success Rate	Effectiveness	Impacts

Figure 2
The shift from 'old teaching' to 'new practice'

- Teaching and learning environment – the format for delivery of education and training
- Technology and tools – the resources employed in delivery and management
- Individual skills and learners – the ability of individuals to be innovative in everyday activities

But it is delivery that takes the lion share of research interest, where moves away from didactic, chalk-and-talk teaching towards student-centric, personalised, activity- or problem-solving learning are analysed. And so much of the work to encourage innovative teaching focuses on the role of teachers and practice within the classroom. And much of the research indicates that practice in the classroom lags behind "the rhetoric of change" and is not student-centred (Shear, Novais, & Moorthy, 2010).

Researchers leave the larger questions on new models of education to support the conditions for new and more effective teaching and learning largely unexplored, particularly in vocational technical education. While in parallel, successive governments implement radical changes to qualification structures with seemingly little understanding of the research on education and training and even, at times, with little reference to the real requirements of industry. And back at colleges and schools, lecturers and teachers are exhorted to be innovative in the classroom. But there are several reasons why we must look beyond merely asking lecturers and teachers to do new and "better" teaching.

Individual lecturers cannot be expected to be innovative in their approach to teaching without adequate guidance, support and training (Ferrari, Cachia & Punie, 2009). The support and guidance derives largely from the structures in place: from the physical environment (size of classroom, availability of equipment) to the culture and management system (is collaboration embedded and the norm? are timetables and schedules flexible? Is there clarity of purpose?). And change is sought when there is a "failure" or problem to solve but real innovation brings with it the possibility of further failure.

We can consider a list of functions or activities that appear to characterise innovative teaching, such as the use of methods to ensure success in all pupils, learners appear engaged, learner feedback is encouraged – for example (Microsoft, 2007).

But by focusing on innovation on only one level or characteristic at a time, the interconnectedness of authentic innovation in teaching and learning is lost. Colleges (and indeed education as a whole) need to take a strategic approach and adopt innovation at all levels. Such a recommendation was endorsed by government and academia – for example in the Innovation Nation report (DIUS, 2008), also (Simplicio, 2000).

Instead, we will consider the criteria that define innovative teaching and learning in STEM. By understanding the pre-requisites for innovation, it is possible to then support the transfer and development of innovative practice.

2.3 The Criteria for Innovative STEM Education

So how do we identify innovative teaching and learning in STEM? We recognise authentic innovative STEM teaching and learning by considering if it meets the following criteria or themes:

1. There is an explicit and clear description of the desirable output from the teaching and learning experience:

- Understanding attributes of value beyond the education and training
- Setting out to develop those attributes,deliberately and systematically
- Encouraging learners to understand the value of STEM
- Looking to address future needs, through horizon-scanning

2. The practice embeds a deep understanding of how learning happens

- Addressing the question: Why am I learning this?
- Moving the model from teaching to learning
- Aligning assessment with real learning
- Focussing on real, deep learning of STEM fundamentals

3. The provision is shaped by a collaborative effort and influenced by the real customer

- Devolving responsibility to the learner in a model of cooperative learning
- Exploiting technology to support new ways of teaching and learning
- Embracing cross-curricular and multi-disciplinary teaching
- Collaborating with industry to meet shared goals and exploit opportunities

4. There is a fundamental drive to find new and better ways of teaching and learning

- Fostering an innovative community of learning
- Assuring quality through deliberate action
- Displaying coherent civic leadership

CRITERION 1

There is an explicit and clear description of the desirable output from the teaching and learning experience

The general characteristics of work-readiness are well-known: adaptability, initiative, endeavour, trainability, teamwork and so on. The ability to innovate, think creatively, use ingenuity are also becoming sought after cross-sectoral skills. But these desirable attributes are not always well defined, neither within education in the UK, nor in industry – although the lack of these are uppermost in employers' minds (UKCES, 2011b). And the problem is exacerbated by the tendency to see all young people as 'employees' – and not a range of alternatives including self-employed and start-up entrepreneur, with different attributes of value.

Another major problem is that where some of these attributes have been defined, such as those Personal, Learning and Thinking Skills (PLTS) in UK secondary education[9], that osmosis still predominates as the means by which the rising generation acquires these skills: they are usually supposed to arise rather than being taught. And where they are taught, there is no measure of attainment that is made clear to those on the outside of education.

The requirements for the output are clear: provide a more capable, numerate, literate and technologically-knowledgeable population and

9 These have been defined as 6 characteristics (independent enquirers, creative thinkers, reflective learners, team workers, self-managers, effective participators) in the National Curriculum for secondary and primary education in the UK, and are also addressed by the Specification of Apprenticeship Standards for England (SASE) (BIS & DFE, 2011)

one with the attributes of character that contribute to work-and life-readiness, with cross-sectoral and higher level skills, such as business awareness – those T-shaped skills mentioned earlier. There are also notable examples of defined sets of attributes from education in the US that the UK can learn from: *engineering habits of mind* and *21st Century skills* (NAE &NRC, 2009) (P21, 2009).

These attributes plus those that add value to individuals working in SET industries, those that provide the ability to make links between technologies, solutions and problems, are a key part of what is known as "T-shaped skills for STEM", and which we have extended and made more explicit in the T-shaped Technologist®, described later in this report.

Beyond this, educators in the UK need to stop presuming that employment is the end–game: self-employment and enterprise offer other routes, preparation for which FE colleges can and should do more.

There are two further changes: a curriculum that more readily responds to the future needs of industry at a more local level; and leadership that prioritises deliberate efforts to inculcate desirable attributes in young people. Where they have worked, sector skills councils have helped at least develop the co-operative mentality necessary to drive this. But what is really needed for colleges to contribute successfully is the freedom to create more value at the local level for local industry. And where it is now working, the drive to make education provide work-ready people is proving successful in changing not just what is learned, but how, for the better.

The 'future needs' of industry are often seen in terms of the immediate needs for skilled workers with work-ready attributes. This has two consequences: making sure that colleges do indeed help meet this demand; and changing the demand.

The more immediate demands centre on work-readiness and the remedy lies in curriculum, leadership and relationship management at the local level.

The intermediate needs have a different and less familiar remedy. Horizon-scanning is essential: How can colleges help SMEs understand better how tomorrow is shaping up in their sector? How can colleges provide learners with the right

Engineering habits of mind – Vex Robotics Competitions

There are many student STEM competitions that are employed to promote STEM and engage young learners. One example is the Vex Robotics Competition (VRC) programme – a global series of events that uses the VEX Robotics Design System as a platform to encourage STEM design and problem solving.

An evaluation of VRC reported that not only did learners who had taken part in the VRC show an increased likelihood to take up STEM courses and careers (as would be expected), but that the teachers and adults leading the teams of learners reported that those learners had also developed better **engineering habits of mind** together with skills such as goal setting, handling feedback, managing time, leadership qualities and so on.

guidance to take up STEM courses for the future? These are not questions typically in the top ten questions colleges ask of themselves, and yet it could, and should, be so. Colleges have reach into their local employers and their community. In addition, they have resources for some horizon-scanning and the capacity to develop mutually valuable relationships with industry based on meeting needs in order to provide learners with future opportunities.

CRITERION 2
The practice embeds a deep understanding of how learning happens

Seventeen year-olds show a great capacity to learn to drive; they often show less obvious drive to learn. They are not unique: learning is just one aspect of life and for human beings life is a complexity of choice. And when we make choices we tend to try to do things that are good for us. The bit that is good about learning is not always easy to see – so kids drive, adults watch TV and the *X Factor* trumps *Horizon* many times over.

A significant challenge for learning is making it 'relevant'. Relevance is relative: relevant to what? The answer is likely to be idiosyncratic, but will reflect an individual's need for satisfying natural needs – physiological, emotional, intellectual, moral. In practice, training in industry has a natural advantage since the starting point is about enabling people to work better. This represents an immediate and easily identifiable benefit that eludes much of the curriculum in formal education in schools and colleges.

One answer is to adopt and apply: make the curriculum more relevant to the work. Ensure it is up to date, that it responds to the demands of industry and society, and avoids the repetition that still characterises individual journeys through formal learning. This is one way to enable learners to

An airplane for engagement – FlyBe

FlyBe created the "Future Engineers" programme in the South West of England to inspire young people to enter engineering. For the launch event, FlyBe employed an aircraft to engage learners and to link the engineering teaching at the local college and university.

Many companies now use the end result of engineering, an "end-product" – a vehicle, structure, something very concrete – to make the links in learners' minds and STEM teaching, so connecting the real world to theory.

A real submarine for training – EDF Energy

There are elements of the nuclear engineering apprenticeship programme at EDF Energy that pushes the boundaries of training. Apprentices are trained on maintenance operations on a live project: a 50 year-old nuclear submarine, and not in a lab situation nor in a simulated environment. The result is highly engaging and effective training, where safety and real practice become embedded in the learners.

Thinking Skills in Science – Harrow College

Harrow College has been trialling in their ICT provision **Cognitive Acceleration in Science Education**, an approach where students are encouraged to develop thinking skills applied to learning in science.[10] The teacher is a facilitator only and does not dictate the "truth". At the college, they are implementing a modified approach: the teacher can guide and the discussion happens through 'type as you talk', where learners and teachers comment via messaging on the VLE (Virtual Learning Environment) while someone is presenting or talking. This has resulted in improved self-study using the transcripts of the sessions. It has proved useful in identifying teaching points being misinterpreted. There is a proposal to apply the same approach to the college's engineering provision.

understand the importance and the benefits of learning and to address a key question for them: why am I learning this?

This is particularly important for the STEM disciplines. STEM is considered to be "hard". The STEM subjects tend to suffer from lower intake and lower retention. But given the importance of STEM education and training for industry in the UK, it is vitally important that learners understand the relevance, and moreover, how what they are learning will contribute to exciting new technologies, solutions to global problems and even more tangible are those "end-products" that grab attention: the supercars, the submarines, the massive structures. This issue of relevance is now well-recognised in activities to promote science and engineering. There are now numerous examples of industry collaborating to provide "end products", such as an aircraft, or submarine, both as a learning and promotional tool where learners are engaged by highlighting the relevance of the STEM curriculum to the real world.

However, providing relevance is not the only answer. An appetite for learning is invaluable for successful training and the key lies in stimulating the individual's desire to learn. If the benefit is not so immediate, in terms of practical application, then it can still be felt – by appealing to the creative capacities and learning styles of the individual.

There is a drive in education to move the emphasis from teaching to learning. This is based on appreciating how people learn and on recognising that what is learned is not easily understood from knowing what is taught. For example, we have 'informationalised' the education of the young. Maths, a case in point, is often seen by learners, if not by lecturers, as a set of rules to learn rather than the means to acquire logical thinking and decision making skills. But the former is useless for most people; the latter is indispensable for successful living.

Moving from teaching to learning shapes a different interaction between teachers and learners, manifesting itself in teamwork, problem-solving, student feedback for improvement and so on. These approaches develop thinking skills of all kinds. In so doing, it requires teaching to move from orchestrating to facilitating; and for teachers to constantly ask, what is the purpose of today's learning? And where else can learning happen? The

10 Adey (1999) provides a thorough explanation of CASE and related research.

Virtual reality to engage – AWFTE

The Association for Welding, Fabrication, Training and Education (AWFTE) use a wide range of teaching tools including virtual reality (VR). And they report VR is effective in engaging students before going into workshops. There are three aspects to its use: it provides a cost saving, allows independent learning off-site, and most interestingly VR provides a safe environment to simulate risks and failures, so embodying safety aspects of the course. Trials at colleges have indicated that learners engaged with VR successfully. It is innovative and effective in that it supports the learner and the teacher, and allows learners to progress at their own pace.

Khan Academy is a vivid example of the effectiveness of learning supported outside formal environments. But it is also about learning through doing, learning through applying, learning through cross disciplines and functions.

A closely related question is that of assessment: **how to know what has actually been learnt.** Traditional approaches, written exams, online tests, etc can provide a measure of achievement, although it is not always clear from these that the deep or 'higher order', learning has been achieved (Looney, 2009). Exams and tests are after all a hugely artificial construct that are not necessarily related to how an individual will apply the lessons learnt in real life. The recent policy push in the UK to move towards single high stake exams is also recognised to reduce innovative teaching as the incentives to "teach to the test" are increased. And in parallel there are approaches beyond written tests that are about the application of knowledge and skills.

It is often said that what makes STEM difficult is that these disciplines can be compared to creating a high-rise building: each level of building blocks needs to be firmly in place before the next level can be added. So it follows that exams should assess how well all the important building blocks are embedded. Kahn (notably of The Kahn Academy) comments that if all that is in an exam is important then it is important that learners be expected to achieve 100% scores (Kahn, 2012).But this is in fact not the case: there are very few instances in mainstream STEM education where close to 100% is expected.

Assessment is another area where high quality industry training has an advantage, since it is easier to carry out on-the-job assessments of attainment. The case studies in this report make it clear that exams and tests are not the primary form of assessment – testing and exams clearly exist, but it is the learning experience that is valued by the companies, and it is the long-term application that is assessed through evaluation.

There is a need to step beyond the constraints of the educational environment and connect to the wider community, service and business sectors (Hannon, 2011). This wider view of the world can support education and training for STEM in subtle but effective ways: it can bring with it an appreciation of the environment, ethics, legislation, society that adds depth to technical knowledge. This aspect was very clear in the training programme at MBDA Systems. And if colleges are to provide learning outside the classroom, collaboration will be key.

CRITERION 3

The provision is shaped by a collaborative effort and influenced by the real customer

The idea of innovation in STEM Education often leads us to focus on the paradigms of traditional classroom and teaching idealisms, when in reality a call for the re-definition of the roles of teachers and learners is required before it is possible to understand the necessary innovative practices. Teachers should be seen as enablers, motivators, mentors and coaches of learning processes; processes that are owned and controlled by the learners (Ferrari et al, 2009).

This then demands – and nurtures – independent learning skills. This is the key to innovative learning. The idea is that devolving responsibility for learning enhances the capacity for learning. The key to innovation in teaching and learning is to maximise the contribution of learners, who are customers of education, to the process.

This is not just about an additive effect, i.e. there are more minds at work this way – but it is also about addressing the 'drive to learn' question. Enabling people to determine the pace, nature and scope of learning and being clear about the aims of learning experiences increases the learning and the extent to which the aims are achieved.

It has been documented that schools that harness the power of learner-ownership to transform their approach to teaching and learning are likely to feature more project or enquiry-based learning, a greater and more meaningful student voice and peer-to-peer teaching and mentoring (Hannon, 2011). And this is noted in the industry training featured here. By its nature, training in industry more often than not is closely linked to the tasks as part of the job role. This puts industry at an advantage: they need not look for constructed situations.

Ownership of a real project – BRUSH Electrical Machines

At BRUSH, they have trialled **project-based Health and Safety training for their apprentices** "Think Safe, Work Safe, Home Safe". The intention was to instil a good understanding of the reasons for safe working. The apprentices were provided with a budget and made responsible for the training and delivery of the programme to the rest of the company. The apprentices not only "stepped up to the challenge" but delivered very good training and materials for the company. They "taught" their tutors and managers in safe working. The project instilled a sense of responsibility, fostered self-training, and developed key desirable behaviours in terms of team work and collaboration.

Facilitating ownership of learning requires a cooperative and collaborative approach and this once again is evident more so in industry than education. Innovation happens on many levels and key evidence has shown that in industry, cooperative work and learning not only creates new opportunities, but fosters an innovative creative environment. Learners are committed and enthused and feel ownership of their learning experience, and develop a sense of belonging and responsibility to the organisation.

Online Project Collaboration – Open University

The Open University (OU) has embraced technology as the way to support self-paced learning. They have built the learning experience around the student, in full awareness that learners today are sophisticated users of technology, and of social media. The OU seeks to push the potential of technology to its limits, understanding that their students will engage appropriately to support their learning. The challenge is to change the teaching model and to provide a more collaborative and interactive paradigm.

For instance, the student team project required as part of any accredited engineering programme which supposes teamwork and collaboration – but OU students are typically dispersed and study part-time so teams cannot easily meet. The solution is to create a few and highly structured opportunities for the student teams to meet, in this case the programme includes two face-to-face project weekends, but to support the main development through **online project collaboration**.

Much of this is being supported by appropriate use of technologies. A key area for innovative practice in education is the advancement of technology. The arrival and enhancement of technology has provided a platform for collaboration and sharing of resources and skills, which in turn, have resulted in innovative technologies and teaching methods. Although the development of new technology provides an opportunity to cultivate innovative practices, they can only succeed if the teachers are aware of such technologies and how they can be utilised.

Technology then plays an important part in creative and innovative practice and should be utilised as a platform for delivering teaching and learning in an innovative way. The availability of technological resources addresses a need for teachers and learners to be flexible, and adaptable to changes within curriculum development and delivery methods. This adaptability should be transferrable within organisations and across sectors.

There is a role here for industry to collaborate with education, and a role for government to provide the incentives for industry to support education, to meet those longer-term requirements for the survival and success of UK industry.

Where collaboration really works is when it does more than inform or allow more effective use of resources. Collaboration can be a driver to mobilise resources other approaches would miss, to revive and enrich, and to provide a whole new different way to teach and learn (Leadbeater, 2006b). And this was evident in the case of the partnership between Arla Foods and Reaseheath College, where the participation of industry was key to creating an authentically innovative training environment and has provided opportunities beyond for other learners.

And it is not just about collaboration between colleges and employers, it is also about the drive by the college to collaborate within, and to look for continuous improvement.

CRITERION 4

There is a fundamental drive to find new and better ways of teaching and learning

Education can be said to have succeeded when it inspires and enables. There is a drive to improve, and enable inspirational teaching, that occupies the minds of educators. The 'stick' that compels this is the inspection regime; the 'carrot' is the reward for doing a good job. The one is external, the other intrinsic. There is a balance, one inevitably left to individuals to strike: the 'stick' can all too easily be a targets and norms driven force for compliance, mediocrity, orthodoxy and risk-aversion. The latter can be a path to incoherent strategies, variable quality and unfulfilled potential.

In the world of innovation, risk-aversion and the 'safe' route are major impediments. Improving quality requires innovation: it is usually about changing what or how things are done – and why.

Learning Walks to share good practice – College of North West London

Staff at College of North West London have this year started to go on Learning Walks, where they go to different classrooms to see and discover how others have been teaching and learning. This can help inspire learning and ideas. It is also a simple support mechanism that fosters collaboration.

This demands both individual and corporate leadership. At the organisation level, what is needed is an approach that constantly challenges the way institutional self-interests can militate against providing better. At the individual level, there is a need both for communities of learning that support the innovator and for deliberacy in assuring high quality of activity.

CHARACTERISTIC	MEANING
Challenging	Highly skilled enthusiastic teachers who inspire a culture of learning
Understanding	Probing questions used skilfully: students display understanding
Expecting	Learners are fully involved in evaluating and reflecting on their own learning
Evaluating	Teachers are reflective and keen to improve their practice
Creating	Lively and imaginative teaching and lesson planning that meets learners' needs
Supporting	Learners needing additional help are identified early, and supported promptly

Figure 3
Characteristics of Outstanding Teaching[11]

11 This is a summary from p97 of (Ofsted, 2011)

Inspired by a better way to teach – ARM Holdings

ARM Holdings, a leading technology company that designs processors for mobile computing, has developed a novel rapid prototyping platform to simulate electronics called *mbed*. This tool allows engineers who are not experts in electronics, but understand what features and functions they require for their product, to create "quick and easy" prototypes of the features they require of the electronics subsystem before final design and manufacture.

It is of significance that *mbed* was inspired by education: the creators spotted teaching tools for electronics that, although laudable in their aims, did not work. The creators of *mbed* decided to create a better and innovative teaching tool based on real electronics. As development started, it was clear that this tool was of value to customers as a prototyping tool that reduces the time to development from a month or more to just a few days. What is even more interesting is how *mbed* is now being used in STEM promotional activities and in teaching.

And what is also clear is that innovative practice may happen where barriers are identified. Those that are just a product of the current system, that are arbitrary, can then, if identified, be removed. As happened at Jaguar Land Rover.

In relation to the quality of education, Ofsted has of course an important impact by setting out what is in scope for college inspection. The recent shift of emphasis to teaching, learning and assessment makes Ofsted in effect a campaigner for 'good' (or better) teaching. A recent scan of what Ofsted sees as outstanding teaching and learning reveals expected characteristics that should surprise nobody.

The essence of this is that doing well in inspections will depend more and more on doing right by learners. As the new regime kicks in, the perverse incentive to manipulate data / the curriculum in pursuit of success rates are being kicked out.

This is associated with the drive for achieving better outcomes (qualifications and developing attributes that help people progress in education, get on in work, contribute to socio-economic prosperity) and the gradual, if not yet consistent, retreat from the adverse consequences of the pursuit of rising outputs (success rates that ring hollow and seem to suggest certificates in number but not impact).

So innovative education cannot be just about the college and employers: it is about an ecosystem comprising other colleges, schools, universities, industry bodies, the community. The drive to develop an innovative learning community, form external relationships and display leadership is key to NEF Intelligent Colleges.[12] And lessons can be learnt from other countries that policy needs to support ecosystems for education: provide the freedoms for innovation by simplifying the system,

12 The Intelligent College Paradigm and the features are explained in more detail in a report of the NEF following a Think Tank in June 2011 (NEF 2011).

maximizing participation, providing systems to sustain top-down and bottom-up innovations (CERI, 2009); and recognise that failures will happen where innovation is allowed to flourish (Hannon, 2011) – but where innovation is successful the potential payback is very high.

2.4 So what does this really mean?

We can propose a toolkit for colleges that supports development of teaching and learning that meets these criteria.

But there is a recognition that innovating is not easy and is thwarted by a variety of factors, internal and external...

... and we look to identify education that will inform new teaching and learning for STEM education, support innovation in colleges and address future needs for industry and learners.

There is, nonetheless, much that is being done to improve the quality of teaching and learning…

...and there is much that can be learned by seeing how training in industry can succeed.

3 CASE STUDIES

*"Innovation must be **repeatable**, procedural and algorithmic . . . it requires much **more than inspiration**"*

– Howard Smith (2005)

The case studies presented in this report represent a snapshot of current effective and innovative training practices in companies in SET industries around the UK.

These are not presented with the intention to provide blueprints for success and innovation to be transferred wholesale into colleges – far from it. They do however provide discussion points; they often provide teaching points; and sometimes they even inspire.

In addition to the case studies, there are of course, very many other examples of innovation in education. In this report a selection of small and large examples are outlined to serve as illustrations of the immense potential to improve the effectiveness of teaching and learning in STEM.

3.1 Jaguar Land Rover

The success of Jaguar Land Rover (JLR) relies on the continuous professional development (CPD) of engineering and technical staff to ensure that the latest technologies are incorporated into their products and processes effectively and efficiently.

One recent issue was the upskilling of JLR graduate engineering staff in specific technical areas to support future product strategy and low-carbon technologies. This needed to happen when the individual was ready and when the time was right for the project.

Training at these levels usually involves either short CPD courses or through masters degrees.

The former provide a very mixed and unrecognised level of training; recognition of new skills, however, is very important to the company and to their staff. But the traditional part-time master degree programme model also brings its own problems. One is that contextualisation of teaching matter – for example translating text-book terminology and processes to "JLR-speak" and JLR procedures – is essential to maximise learning and efficiency.

Another problem is related to the choices made by individuals. Committing to a restricted menu of modules for the next two or more years for a part-time masters degree is a big step; particularly if there is a high chance that your role and your projects will change within the lifetime of the degree. How galling to realise that the training that would be of most use to you over the next year is not at your university but can be found at another?

Jaguar Land Rover worked with seven top universities; Warwick, Loughborough, Cranfield, Coventry followed by Bradford, Southampton and York Universities; to deliver a coordinated but highly flexible programme for engineers. Close to 50 modules, many highly specialist such as Powertrain Design, Hybrids, Computer Simulation, Electronics, others more cross-cutting across disciplines, e.g. Sustainable Product Design, Quality Tools, Project Management, can be taken separately or combined to form a qualification, such as an MSc. Some of these modules are only offered to JLR staff; but most are open to students on other programmes or indeed on the same programme but at different companies. The mantra employed is: "Best courses from the Best sources".

The added benefits are that employees can "toe-dip" at the early stages before committing to a qualification. In addition, getting to know the different universities allows both the provider

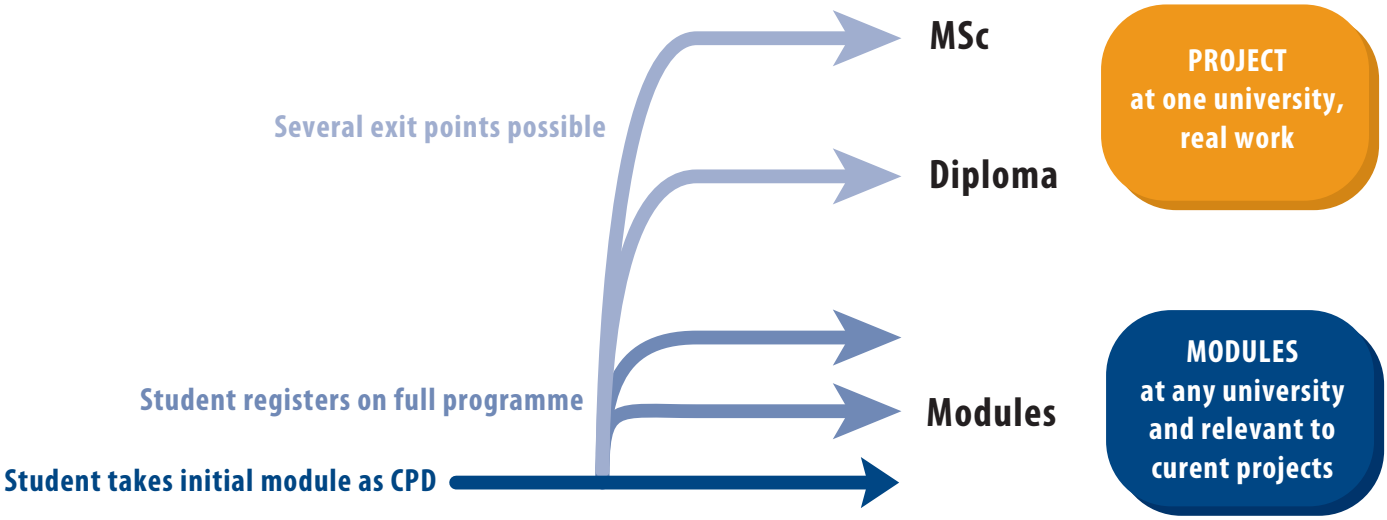


Figure 4
A collaborative and flexible programme (based on the TAS ©Jaguar Land Rover 2012)

and the student to find best matches for project work so improving both the outcomes for the work of the lecturer and the experience of the learner. A further aspect of this model was that JLR have noted the benefits of getting people from different sectors to share learning. Through this model, members of staff can then select and benefit from the latest knowledge and acquire a prestigious qualification, whilst undertaking company sponsored training.

What next? Jaguar Land Rover is looking for a similar model of collaboration of FE colleges to provide the training element for their apprentices and to up skill their supply chain.

What are the characteristics of the training approach? The key elements are:

- **Flexibility to accommodate the needs of the 'customer'** – both from the perspective of the individual and their workplace. This is based on understanding of what are the real constraints on the quality of STEM education.
- **Collaborative working** adds value to the learner, to the employer, to the college offer. (And a lesson to the provider includes recognising that no one provider can be the best for all training.)
- And **contextualisation**: the learning embeds the terminology, case studies and equipment in common use in the industry. This provides a dimension of authenticity and supports learning and understanding in the learner.

3.2 Rolls-Royce

As leaders in a growing and global industry with a doubling of their order book, Rolls-Royce is under pressure to grow their talent. As part of the efforts to ensure a pipeline of new talent, the company is active in STEM promotion to influence education and outreach activities to increase diversity in their engineering workforce. The supply chain is also trained by Rolls-Royce to ensure quality and efficiency.

The engineering apprenticeship programme at Rolls-Royce is renowned, and for good reason. The ranks of the senior and director level staff at Rolls-Royce and other major companies include many engineers who undertook an apprenticeship at Rolls-Royce – you could call it "the Rolls-Royce of apprenticeships".

But there was a long-standing issue of engagement and enabling recruits, who came from a wide range of backgrounds and different attainment levels, to progress at different rates during their apprenticeship programme. The challenge was how to set up personalised learning within a group – one of the holy grails of teaching. The company was also keen to foster team working and other valued attributes: self-discipline, communication skills and leadership. And there was a push to embed lean manufacturing and BIT (Business Improvement Techniques) into the culture.

The solution the company came up with seems so simple in concept. But teachers and lecturers will recognise the work and determination required. The tutors set up a team-based management system based on the work station idea of lean manufacturing. Each team has a base to which they report their collective performance: from turning up on time to progression on the programme. Learners can progress at their own rate, sometimes faster and sometimes slower, managed by a "flight deck" to control and self-monitor progress against parts of the programme.

> *"We don't count on serendipity . . . it's too fundamental to how we work"*
>
> – Chief Technology Officer, P&G[13]

What were the challenges? It was not easy at first: tutors were not comfortable handing over responsibility for learning, apprentices were not always sure how to manage the reporting, teams did not always "gel" and at times it was not clear that this was an improvement.

A few months on and as the system bedded down and as the apprentices became accustomed to the new system and the tutors became accustomed to their new roles of coach and facilitators, the result is now a programme that is highly effective with engaged apprentices who are directing their own training. The surprises have been the rapidity with which the learners settled into teams and roles, the number and sophistication of the improvements suggested by the learners, the unexpected consequences of competition to "beat the other team" combined with the pull to work together – including outside the confines of the work/learning environment – where team members encourage and support each other. The outcome is technical staff with a culture of lean manufacturing and BIT, and embedded skills in teamwork, communication and leadership.

So what are the characteristics of the training approach? The key elements are:

- The **application of methodologies from the industry**, in this case business improvement techniques, to manage the teaching and learning of the team of learners
- **Personalised learning within a team**: the "flight deck" provides the means to manage individual progress and for learners to self-monitor

13 Refer to web article in Business Courier, *P&G says its increasingly global footprint won't shrink Cincinnati's critical R&D role*, June 2011. From www.bizjournals.com accessed April 2012

- **Trust and facilitation**: learners can direct their own training; the teachers are now coaches and facilitators

3.3 EDF Energy

"Why talk to us about innovation in training and education?" was the initial response from EDF Energy when requesting a chance to interview the company about its approach to training. The training of people for work in a nuclear power station is so closely associated with operational safety that, at first glance, the question is well put. What safety requires is compliance – not lots of good new ideas every day on how to carry out procedures!

And yet, on closer inspection, here is an employer capable of offering a good many lessons on the power of innovation in training and its pay-off in improved performance. Transforming training from a cost-centre prone to cost-cutting to the means through which performance is enhanced is a success story of the past decade.

EDF Energy sets out clear company values which are translated into behaviours reinforced by training. People who operate the nuclear plants and the supporting functions are trained to operate the plants in a safe and efficient manner. If a nuclear plant is shut down, there is a significant commercial penalty because of the lost electricity production. So improving both the technical and behavioural performance of the operating staff is a key driver for training, supporting both safe plant operation and improving the commercial viability of the plants.

EDF Energy is committed to the use of the Systematic Approach to Training (SAT)[14] model that inverts the traditional model of teaching. SAT starts by determining the exact outcomes necessary and then creates the training inputs and measures their impact – rather than providing everything for everyone at the same pace in a time-honoured way in the hope some of it sticks.

Drawn from global nuclear experience and from industries where high reliability of personnel performance is essential (for example, in aviation and military services including the US Navy), 'peer-checking' is now standard practice in the UK nuclear industry. It is an essential part of human performance tools, incorporated into training programmes for operational staff to ensure safe and reliable operation. It is routine but it has to be learned – this innovation means people being checked by colleagues is an expectation, an element of a positive open working culture, where the routine is never viewed as dispensable.

The main facet of this success story lies in a 'top-line' values-driven approach to working; the complete commitment of managers to the value of training.

So what are the characteristics of the training approach? The key elements are:

- **The value of peer-working in learning**: Peer-checking is just one of the error prevention tools that through which learning and innovating can happen.
- **The deliberate connection between values**

14 Standard textbook references to the *Systematic Approach to Training include* Kirkpatrick, D. (1959) Evaluating Training Programs, Second Edition., Berrett Koehler, San Francisco Warr, P., Bird, M. & Rackham, N. (1970), *Evaluation of Management Training*, Goer, Aldershot

and behaviour and learning: There is a culture of safety and pride in the company that has been well supported by the renewed emphasis on training in the past decade: training programmes are owned by managers who believe in improvement and the benefits of training.

- **The deliberate connection between the training programme and desired impact:** The company is committed to using the Systematic Approach to Training to identify the required output from training, followed by an assessment beyond.
- **How to turn a compliance culture into a continuous improvement culture**: On the surface, EDF Energy is all about compliance: safe and reliable operation of the plants with no surprises. However, the truth is more complex: only by setting such high standards for safety is training taken so seriously; and through this comes all sorts of innovation in culture, in improving safety; in training itself; and in managing training.

3.4 Arla Foods

In 2012 a cutting-edge Food Innovation Centre focussed on dairy processing was recently opened at Reaseheath College in Cheshire. The multi million pound Centre was developed in consultation with companies such as Arla Foods, to ensure that the facilities reflected the latest thinking in industry. The aim was to provide learners and trainees with a realistic environment that represents state-of-the-art technology in industry, to produce dairy products from milk and butter to cheese and yoghurts. The result was a centre that is recognised as one of the best immersive and realistic teaching facilities for food in Europe with an international reputation within the food and drink manufacturing sector. The college is now the Network Champion for Dairy within the National Skills Academy for Food and Drink, and the partner to Arla Foods for all their training across the UK.

Through this new facility, the College and its partner employer group EDEN (Euro Diary Education Network), which includes the largest dairy producers in the UK, Robert Wiseman, Muller, Dairy Crest, First Milk, Cotteswold Dairies, as well as Arla Foods, are tackling the issues in the training of food technologists and engineers:

- For engineers: inculcate through the environment the behaviours and culture of food production, which are "different" compared to other engineering environments
- For technologists: train in the technology, processes and science through the availability of high-tech equipment

One of the key lessons leant by the college was to bring in industry as early as possible. When the college presented industry representatives with the initial completed plans, the experts "ripped them up", and started again. The experts highlighted the gap between the textbooks and the real world. Best practices were imported from around the world, including Denmark, where dairy is a major industry and has a dairy education that complements that industry. To keep up to date with recent sector developments, there are already plans to update the Centre's offer and resources in the immediate future.

In a bid to maintain the Centre's relevancy, the college intends to hire out the facilities and staff

to local food producers to support investigation of processes and equipment, market research, or product development. This provides further opportunities to link employers with the college, thereby ensuring that curriculum remains industry relevant.

Of course the Centre is open to other learners; for example, approximately half of the students in the Food Technology department are following A Level courses, and these learners will be able to take part in activities inside the Centre.

So what are the characteristics of the training approach? The key elements are:

- **Industry drives the design of the training offer**: For example, many of the participating dairies have placed additional members of staff to help with the structure and delivery. Arla Foods has placed a member of staff to train the college staff on their equipment and processes, and to understand their business requirements; Muller helped with the curriculum for engineering, automation and presentation skills, and Robert Wiseman assisted with lean manufacturing and continuous improvement skills.
- **A new model of collaboration with industry has been instilled**. There is now an active relationship with industry, where staff take part in industry activities.
- In addition, the college is now seeking further niche training opportunities for industry, with a heightened awareness of the importance of **behaviours related to culture, branding and identity** and the need to indoctrinate trainees in the values of their company.

3.5 BRUSH Electrical Machinery

BRUSH is a real British success story. At the very heart of high-skilled heavy manufacturing, the company produces generators, transformers, switchgear and related control systems for the power industry across the globe. At a time when the economy is in a precarious state and manufacturing is the key to recovery, it is heartening to know that BRUSH has seen virtually no recession: their order book is increasingly full.

But the 'demographic deficit' brought about by the age-profile of skilled workers is beginning to impact on availability of the skills and people in this industry.

There are many reasons for the success of the company but a significant one is the very deliberate connection made by the company between high quality training and high quality for both production and customer service; and the awareness that innovation in training leads to improved performance.

Training is geared to industry needs of the present and of the future. This builds confidence in apprentices in the value of the learning process. It also means making challenging demands of students to understand and be able to apply theories and principles.

There is a deliberate approach which is particularly innovative, to educate and train managers so that they can understand better the learning styles of the apprentices, and in turn, they can manage expectations by knowing what the students are learning and, thus, align the training and industry needs accordingly.

A further deliberate and critical ingredient to training is the path taken to instil corporate values in the behaviours of all staff at BRUSH. These values drive the behaviours expected in the company and help to shape the way training is valued and apprentices are treated on their way through the programme. The programme is based on a simple compelling idea: 'Our Next Generation': developing recruits to become the skilled workforce of the future.

Demography has focused attention on the next generation and the fact that the skills needed for the future are in their hands and minds. The overarching focus of clear-sighted management and leadership has provided the support for renewed emphasis on training to overcome this issue of demography.

Trainees work to achieve not only the knowledge and skills but the attributes of the "excellent BRUSH employee". Through managers understanding and adopting different learning styles, trainees are able to learn in ways best suited to them, ensuring that the vital mix of knowledge, skills and attributes is always achieved.

So what are the characteristics of the training approach? The key elements are:

- **A clear connection between recruitment, training and outcomes needed for the company**: Recruitment is conducted to ensure a good match between student capabilities, training and eventual employment with BRUSH.
- **The support of managers including training them to bring the best out of their trainees**: All managers participate in training, enabling them clarity on trainee learning styles, so that they can manage training expectations and match train and industry needs better.
- **The central place of company values in determining behaviours and developing attributes**: The company is run on the basis of a set of corporate values that are explicit, easy to understand and prominent. These values are intrinsic in driving the behaviours and shaping the attributes of all staff in BRUSH.
- **A clear focus on the way learning styles can be used to maximise impacts of training**: BRUSH sets great store by the way different learning styles are understood and valued by line managers in the workplace.

3.6 MBDA Systems

One of the key aims of the MBDA recruitment process is to identify people for a life-time career within the organisation. It is absolutely vital to the organisation that the right people with the right attributes, with the potential to add value over a future 30 to 40 years, are taken on – retention is critical, and so is diversity. The development process beyond is also key to ensure that the right skills and right behaviours are fostered.

The recruitment process is key and pretty novel. No advertising takes place. Instead the company fosters a close relationship with schools in their area. Teachers are mentored to support them in teaching; the company invests time and energy in school projects, both to support the pipeline of learners into technical careers, but also, less altruistically, as an informal recruitment programme, the

Figure 5
A pipeline for technical talent development

company gets to develop a relationship with potential recruits.

What do they look for in terms of their recruitment? Attitude: the will to take part, staying power. Mentoring and coaching begins quite informally before recruitment. School pupils with those identified attributes are encouraged to apply to the MBDA Scheme. When asked how the company achieved the very high rates of female apprentices, the apprenticeship manager replied "There is no silver bullet: it comes down to working very closely with schools and ensuring they and their pupils see the opportunities." He paused and added: "And I tell mixed schools that their project teams must be mixed too – I do not accept the excuse that only boys are interested." And the outcome? In the current cohort of MBDA apprentices 50% are female, as compared to the national rate which is below 3%.

And what about development during the apprenticeship programme? The programme in itself is fairly standard. But the emphasis on personal development is not: the apprentices are encouraged to reflect and self-assess – very large log books record their progress, thoughts, plans for the future. They undertake personalised programmes to develop self-confidence, presentation and communication skills, leadership and responsibility, teamwork and collaboration. The activities to support development of these soft skills are various and diverse: from STEM promotion, volunteer work, formal courses and programmes, World Skills teams and in-house training. And they can be self-driven, which is encouraged, or suggested and supported by the company. Immersion and learning at all times are key.

And the impact? Loyal and highly productive learners that take those behaviours so deliberately fostered back to their classrooms. And the technical learning then takes care of itself.

So what are the characteristics of the training approach? The key elements are:

- Ensuring a robust pipeline of learners into the organisation through **collaboration and close engagement with partners in**

education, identifying potential recruits over a period of time, by getting to know them

- Diversity and engagement achieved by emphasising the **role of people and the desired behaviours**, not the technical skills nor prior knowledge and academic attainment
- **Outstanding technical skills follow on from behaviours**: the required technical skills and knowledge are developed after recruitment and are not found to be an issue – as long as the required behaviours have already been instilled
- **Emphasis on teamwork, independent tasks, volunteer work** to follow through on developing those attributes that are so important to the organisation.

3.7 National Grid

The energy market is undergoing huge changes and new challenges. There is the development of a super grid across Europe; in parallel, there is a move to diversify and bring energy production from the national to the local level. Both scenarios bring new technologies and business processes. In the words of the manager of National Grid's Eakring Training Centre, "The skills map is changing". National Grid view training & development as key to keeping ahead of these changes and challenges.

When we visited the National Grid Eakring Training Centre, the plan was to investigate the 3-D virtual reality environment employed at the centre for training of operatives and maintenance engineers.

What became clear was that this was just part of a planned approach to training making use a blended approach encouraging a mix of approaches and diversity in teaching & learning: from tutor-led classroom instruction, work based learning, e-learning, self-directed learning, to the use of the expensive real physical simulated and real technology intensive 3D simulation environment. The 3D virtual reality system provides training on equipment that is expensive to bring into the training centre, or too remote and so expensive to reach. While there is variety in teaching & learning, assessment remains highly consistent.

The focus is on best use of time, given expected outcomes, with tools that are fit-for-purpose. The outcomes are set according to the training needs defined at the business level. This is part of a **Training Cycle**:

- **Training needs** are identified by the business, based on key performance indicators (KPIs) for safety and productivity, and the required competencies for the job role. Specifications provide targets and outcomes.
- A decision made if there is to be an intervention or **new learning programme**. If an intervention, then updating is carried out on the job. If a Learning Programme, then this will be carried out off-site, usually at the Eakring Centre.
- The **design of a learning programme**, is carried out by training experts at the Centre, and trialled and piloted before implementing fully.
- **Evaluation and review of the programme** includes feedback from the business provides feedback: Are targets and outcomes from the Training Needs Analysis

met? i.e. has there been an impact on KPIs? Over the longer term, does training impact on staff? And over time, review and re-evaluations may require new re-assessments of training needs as well as changes to the Learning Programme.

How do they know their impact is positive? The Training Cycle embeds the need to measure effectiveness of training very closely to productivity, safety and competency. But does this translate to longer term added-value? The company tracks staff very closely in the first five years, from recruitment to progression to middle management, to assess how they progress and develop their talent. And there is high retention and high levels of progression, over and above national averages for the industry.

The 3D virtual environment that originally attracted us to National Grid Training Centre, although innovative in its own right, is by no means the end of the story.

What was also clear is that there are many elements of practice at the centre that leads to effective teaching & learning and that this tool is primarily an indication of the level of investment by the company on training. There is a clear focus on training staff development and support, with investment in opportunities for sharing of good practice and the chance to propose new tools and new ideas, such as a week-long internal conference. As the visit was drawing to a close, one of the training staff commented: "It is about trust by senior management: we are allowed to try things out, think things through and take risks in a safe and controlled manner."

What are the characteristics of the training approach? The key elements are:

- Education and training is part of a **planned approach, based on business needs and takes into account the long-term impact on staff**. Impact and KPIs are a focus in assessing the value of training and learning programmes. On-going evaluation and reviews as part of the Training Cycle ensure learning programmes remain relevant. The impact on the learners, the staff undertaking the training, is assessed over the long-term.
- **Training staff are empowered** to try out new ways of teaching, **allowed to take risks**, propose new ideas and try out new tools. There is investment and trust in training staff, who, as a consequence are enthusiastic, active in finding novel approaches, collaborative in their approach to sharing ideas, and feel valued by senior management.
- **A mix of training approaches is encouraged**. The outcome of this is an engaging curriculum and imaginative use of resources: from the very **high-tech 3D virtual** simulation system that attracted us to visit the Centre, the real physical simulated environments that are a major part of the Centre, to a range of tools that would not be out of place in any school or college.

3.8 Six Lessons from the Case Studies

There are six lessons that are directly transferable to FE colleges which can be summarised as:

1 **Values and behaviours** really do matter in setting the compass for innovative education and training that is 'top-line' and is not about cutting costs nor about quick returns

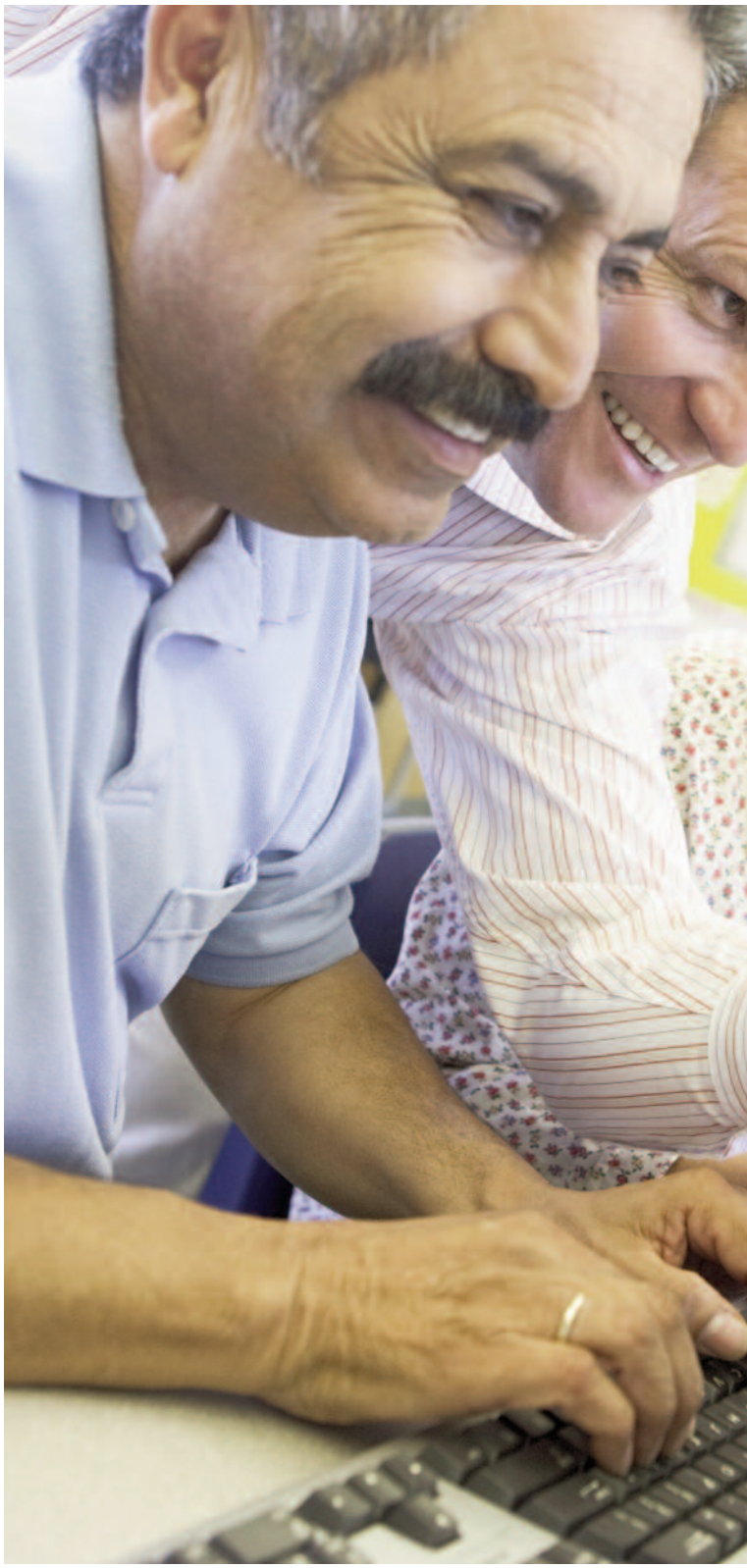
2 Innovation is enhanced where people have the confidence and/or are encouraged to challenge the orthodoxy, and where **collaboration and cross-disciplinary education** is at the centre of the training model

3 Understanding what the aim of training is, is key to designing **a learning experience that is relevant** – the aim is often around attributes of the learner and not about a qualification

4 **Ambitious targets** should be set for training that is challenging but rewarding

5 The customer, which in this context is **SET industry**, must be able to **decide the outcomes** needed from the training

6 At the cutting edge of Innovative practice, **learners are central** in determining their own learning success



4. MAKING IT HAPPEN – A "TOOLKIT"

So how do we make authentic innovation in teaching and learning in STEM happen? It is not about taking a cookie cutter approach – but nor do we ignore what has worked for others. We recall that innovation cannot come from one source, nor is it possible to systemise– but it is possible however to provide a fertile ground for innovation (Berkun, 2010).

We provide here a toolkit to be treated as a scaffold to aid college leaders and managers to start.

So how can colleges transfer the lessons from the case studies? We describe in more detail those six lessons and how they can be transferred to FE colleges.

We have noted in particular the need for educators to have an "output" from STEM education and training in mind. So what are those attributes, characteristics that innovative STEM education should be developing? We describe concepts here behind the T-Shaped Technologist® to help in defining the attributes that STEM education should develop, based on those attributes that are both valued by industry and that provide learners with real opportunities.

But beyond these lessons and looking ahead to new and better ways of teaching and learning for the future: what can colleges do to encourage authentic innovative STEM

education? We suggest here a scaffold to support the development of innovation within criteria that define innovative practice in colleges and implement the understanding of new effective practices used in industry, coupled with those best examples from education.

4.1 Transferring Lessons to Colleges

There are three important features of the FE context that need to be clear:

1 For a large part of their work, colleges deal with people whose career choice is not made, and for whom the pay-back for training is not always immediate. This contrasts with the case studies of training in industry, where the pay-back to the trainee and to the company can be much more immediate and career improvements are articulated.

2 Much of a college's STEM provision is dictated by qualifications and resources which are directly related to funding. Industry is free to choose the form and content of their training in ways that are not always within the reach of colleges. Nevertheless, the case studies can serve to inspire new curriculum and new delivery techniques, and certainly can inform priorities and innovation practice at colleges.

3 Innovation happens all the time in FE colleges in ways ranging from very local and ad hoc to organisational. A toolkit can provide ways of thinking about how open-innovation can be encouraged successfully and supported by structures and processes.

So what, then, is the value of the six key lessons from the case studies?

Lesson 1: Values and behaviours really do matter, in setting the compass for innovative STEM education and for training that is 'top-line', and not about cutting costs nor about easy returns:
In each case, training has been accorded the highest priority in the company: the realisation of the idea that people make things happen and people are the key to success, no matter how automated the processes that they have to operate. This has the following connotations for colleges:

- How is innovation supported in the college?
- How is training 'sold' to employers – as part of the top-line drive for success linked to performance improvement (as with the companies in the outlined case studies) or, as a cost-saving bottom-line exercise?
- How well is staff training in colleges aligned with clear-cut college values and how well does the resulting staff operating culture reflect these values?

Lesson 2: Learning requires a learner and an understanding of his / her characteristics pays dividends:

It is standard practice in FE colleges to make great efforts to understand the characteristics of learners and to support their learning accordingly. In some ways, this is a lesson that industry may be slower to comprehend. However, the case studies here raise some interesting new approaches. Such approaches range from encouraging tutors to understand learning styles and applying this understanding to training; focusing learning on the individual's needs and moving away from convenient group teaching approaches of old. FE colleges could ask themselves:

"Training is not just for work, it is about the whole picture"

– Training Manager, BRUSH Electrical Machinery

- How well do our staff really understand the learning capacities and attributes of our students?
- Could differentiated learning approaches be used to provide effective alternatives to increase the personal value of learning for students rather than having students go through the same course at the same time, in the same place and at the same pace?

Lesson 3: Innovation is enhanced where people have the confidence and/or are encouraged to challenge the orthodoxy, and where collaboration and cross-disciplinary education is at the centre of the training model:

In each of the cases the essential nature of learning is understood: learning means discovering and discovering means challenging the accepted way of doing things. This often requires a pioneer or an organisational initiative to drive it, but the common currency is opening minds to opportunities and encouraging trainers to take measured risks in changing things for the better.

This is an indivisible truth about innovation: it cannot be imposed, it has to be made. And without collaboration, real innovation is not made. This goes to the heart of the value of this report:

- FE colleges can make best use of the case studies and these lessons by reflecting, adapting and challenging the way they do things.
- Colleges need to see themselves as part of an ecosystem for collaborative education. Collaboration across disciplines and with industry is expected to be at the centre of such an ecosystem.

The "toolkit" can only act as a prompt and a guide, and should not be followed blindly. College leaders should ask themselves: to what extent do our structures and processes allow people to challenge the orthodoxy?

Lesson 4: Training that sets out ambitious targets for attributes is challenging but rewarding:

It is telling that each of the case studies reveals the importance that companies attach to engaging their workforce with company values. What is equally revelatory is the deliberate way they then set about defining the attributes of the effective staff member and find ways to develop these attributes of character. This mirrors a major contemporary thrust in FE colleges, developing those desirable characteristics of tomorrow's workforce in today's students. In responding to the lesson from the case studies, colleges may ask:

- How well are we deliberately preparing our students for tomorrow's world of science, technology and engineering?
- Do we make clear the attributes and behaviours that are to be encouraged, developed and assessed through the T-shaped Technologist?
- What steps can be taken in our teaching, learning, curriculum and assessment to make sure we have the impacts we desire?

Lesson 5: The customer, which in this context is SET industry, must be able to decide the outcomes needed from the training:

The customer of the training in companies is the company itself, the benefit of transferable skills to the employee notwithstanding. In the company, therefore, the task of setting the goals of training is more straightforward than in the FE College. What is a more subtle lesson from the cases, however, is the progress that HR and training leaders have made in re-prioritising training and connecting its benefits with company strategic goals. In colleges, outside of employer-responsive training, the customer is not so well defined – but it is either employers (generally) or the individual. Herein lies the problem: how to provide the skills needed for tomorrow when people are free to choose their own career path and course of study?

The lesson from industry here is that FE colleges can ask themselves:

- Do we really address the requirements of the employers we provide for?
- How can we understand the future skills needs of industry and how can we adapt what we do to meet these needs better? and
- How can we work with the SME employer-base to help them understand their own future needs and to help provide people to meet these needs?

Lesson 6: At the cutting edge of Innovative practice, learners are central in determining their own learning success:

The remarkable thing about the training experience in these companies is the quest for better outcomes that drives new ways of learning: it is the quest for better outcomes that drives many of the innovations in learning. This manifests itself in many ways, from '**inverting**' the training approach (by making it learner-led rather than teacher-directed) to the example of students setting out their own learning journeys. This idea is

"Innovation in organisations is inextricably intertwined with organisational culture"

– Michela and Burk (2000)

not completely new or unfamiliar to FE colleges. However, the way in which this approach is adopted using innovation as the driver is the real challenge highlighted in this lesson. Therefore, colleges may ask themselves:

- How much of our curriculum and our approach to teaching and learning is still mainly teacher-led and how well does this achieve our aims?
- How could we move to a learner-led model and with what impacts? and
- How do we ensure that the learner experience leads to real opportunities beyond college, into industry?

6.2 Developing the NEF T-Shaped Technologist®

And what exactly are colleges trying to achieve in delivering innovative STEM education? We champion in this report the 'T-shaped Technologist'. This concept provides a means to encapsulate the 'output' from STEM education that is of value to SET industry, that describes the attributes that are valued by employers, as illustrated by the case studies here. The T-Shaped Technologist makes explicit the attributes in technicians, applied scientists, technical engineers and so on that are of value to industry and enable economic growth and innovation in the UK.

We propose that colleges seek to create an environment for T-Shaped learning for STEM: new teaching practice that will embed these attributes within a new model for STEM education with a wide application to business and enterprise.

The T-shaped learning model meets the demand for a technical workforce by integrating three core stands of learning into a cross-cutting curriculum (and potentially co-curricular) framework covering:

- **Technical knowledge and experience** – largely discipline specific and defined by the sector; and including "know-how", those good, practical skills, but importantly also "know-why", a sound understanding of the STEM theory behind practice;
- **Transferable professional skills** - including business acumen, and the skills related to knowledge transfer and innovation;
- **Transferable personal qualities** – including enterprise and initiative, behaviours and attitudes – some of which are seemingly nebulous characteristics.

Developed together these three elements enable an individual to perform well in their chosen career/industry and to work across discipline/expertise boundaries.

A new model for vocational education in STEM may be built upon the best of current practice, but needs to make explicit the need for 3-dimensionality of curriculum and of assessment, linking assessment and curriculum across to the attributes represented by the horizontal bar of the T-shape.

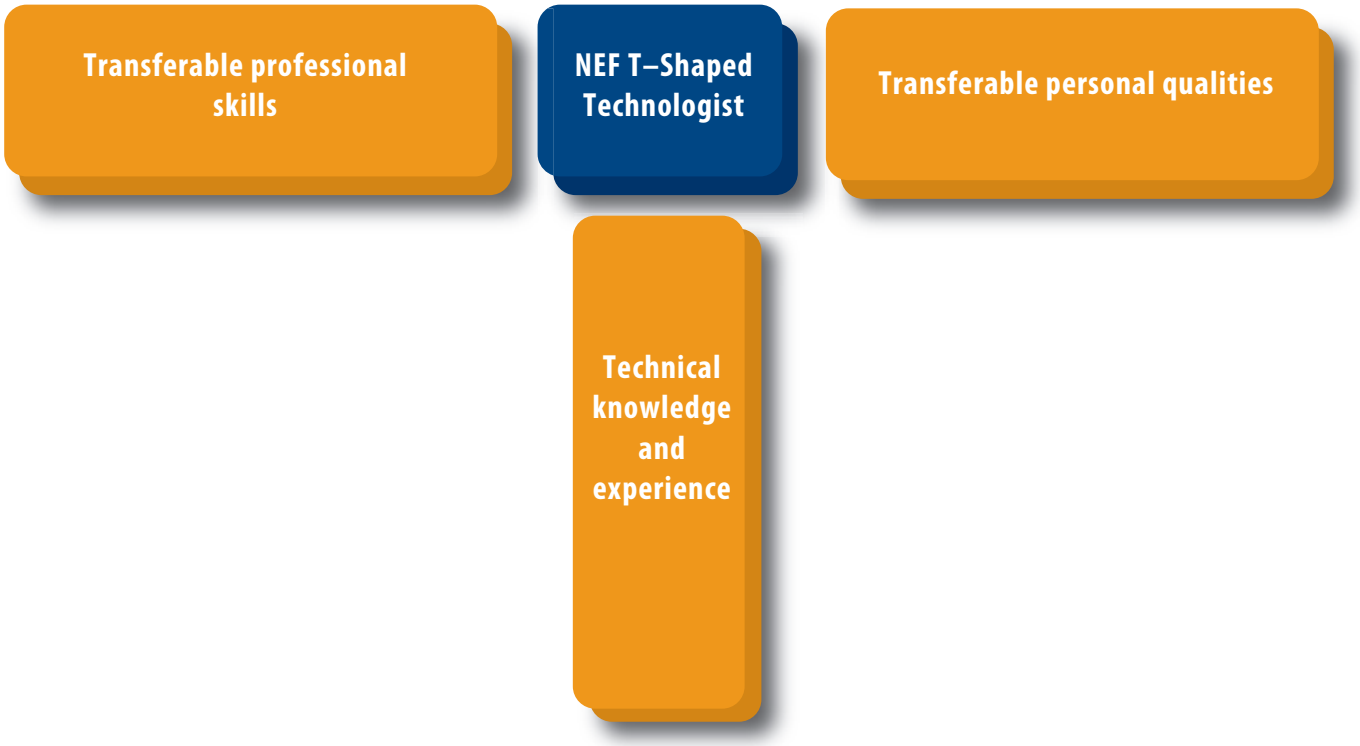


Figure 6
The NEF T-shaped Technologist®

The T-shaped Technologist learning framework would therefore offer a means by which to:

- Implement a new approach to vocational learning underpinned by a robust framework focused on the development of new T-shaped Technologists;
- Realise a cross-cutting curriculum – the imaginative and the logical, the technical and the academic, with enterprise and work at the core;
- Emphasise the application of technical knowledge and skills, and applied technologies – the relevancy of the learning;
- Develop personal and professional transferable skills and behaviours of value to SET industries, in a robust way as an integral part of the learning experience;
- Adopt new and innovative approaches to assessment, as well as recognise (and accredit) co-curricular learning and development as an integral element of the students' experience;
- Integrate employer engagement and knowledge exchange, with the support of dynamic, highly capable and industry-experienced lecturers;
- And support education innovation in its broadest sense: by setting ambitious targets, providing a compass encouraging in turn those values and behaviours that set out the values and behaviours of learner institutional self evaluation, driving continuous improvement and innovation.

4.3 Towards an innovative community of learning in Colleges

So how does innovation in STEM education happen? Successful innovation is a complex process requiring a shared understanding of the problem, the need. It is also a strongly social activity, based on collaboration, reduced fear of failure, and structures that support trust and information (Messmann & Mulder, 2011).

It is with this in mind that we emphasise here that what is required if more than "innovation"; it is "open innovation" that will drive better STEM vocational education – where colleges and individuals within welcome external ideas as well as internal ideas at any time, and consider internal and external routes to creating new and better ways to do teach and learn.

But can leaders and managers in Further Education drive open innovation? We propose 3 steps and a 'scaffold' for a new culture of open innovation, bearing in mind that the processes that need to be put into place to drive open innovation will vary as colleges are at different points in their innovation maturity journey, but leadership, structures and support are essential if innovative STEM vocational education is to happen.

A "scaffold" for a culture of open innovation

Many factors impact on innovation in organisations, but the primary one is that of organisational culture (Michela & Burk, 2000). This is determined through multiple factors: structure, policies and practices, rituals, beliefs, values, norms and language – and essentially the way in which 'things are done around here'. Culture gives an organisation a sense of identity – who we are, what we stand for and what we do.

The following diagram (Figure 7) illustrates the elements that should be embedded in a culture of open innovation – these are merely scaffolding elements to provide a values compass for the steps given.

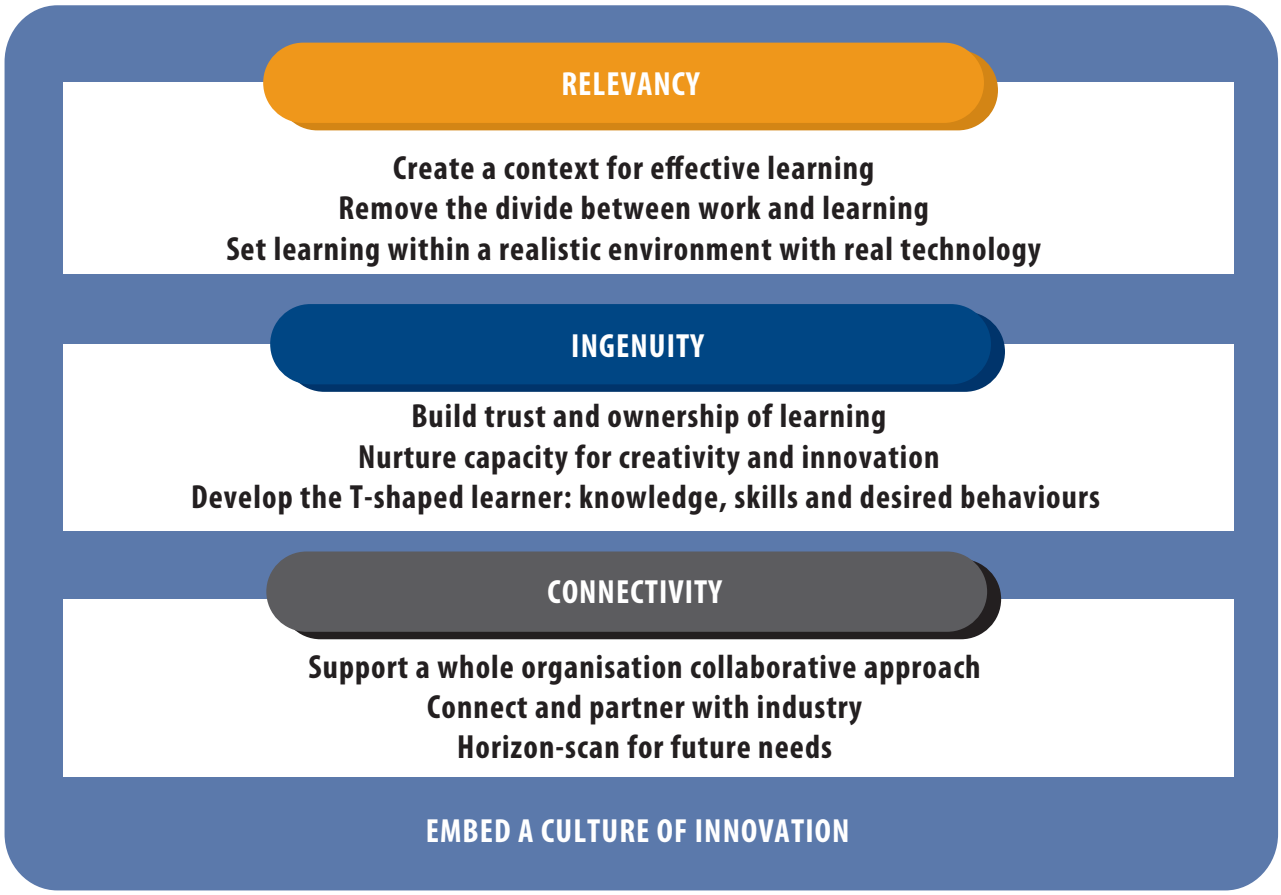


Figure 7
A Scaffold of Values for Open Innovation in STEM Vocational Education

Relevancy is critical to creating innovative learning. The use of contextual learning supported by individual learning styles will ensure learning is meaningful and applicable to the learner. The best learning is done when a learner does not separate the learning task from the work task. The best education occurs when the teaching & learning is driven and enriched by the world outside.

The capacity for ingenuity of the organisation, of staff, of learners is critical to innovation. Clearly supporting staff to own innovation and encouraging ingenuity will engender new ways of teaching and learning. As additional aspect of this element is that of building ingenuity, trust and ownership of learning into teaching, so as to focus on fostering a capability in the learner to question, to imagine and to be creative – and this too will support innovation.

Connectivity is the element that underpins open innovation. Building connections internally and externally of a college ensures multi-knowledge flows that refresh and keep the innovations moving continuously. Whether with industry as

a direct partner, or through industry as a customer, supplier or adviser, keeping the connection with companies is vital for colleges wanting to create an innovative community of learning. Aside from the enrichment of teaching & learning though relevancy, it is only this close collaborative and continual proximity to industry that will enable colleges to interpret their future needs.

Step 1 Develop a Strategy and a Vision for Open Innovation

Thus the first step for a college leader is to develop a clearly articulated innovation enablement strategy. The aim of the strategy will be to define the objectives of the College in creating an innovative organisation, set out some steps to foster innovation, identify the expected benefits and set clear targets. For example an innovation strategy may address the following questions:

- What is the **vision for open innovation**?
  - What future is the college aiming for?
  - What is the context? What is the motivation for innovation?
  - Is there a moral purpose?
- What are the **objectives for innovation**?
  - What are the key objectives? What is the college attempting to achieve?
  - Are there concrete problems to be addressed? For example where is innovation hoped for: curriculum development, teaching practice, collaboration, new markets, new delivery, etc.
  - How does the innovation strategy align with a STEM strategy for the college? Is there an immediate need to focus on parts the curriculum initially?
- What needs to be undertaken to achieve the objectives?
  - How does the college's existing capability and organisational culture support innovation? Do the current leadership team support innovation?
  - How does the strategy align to the business objectives for the college?
  - Who and what organisations are expected to form part of the ecosystem?
  - What lessons are to be addressed? From this report, for example, or from other cases from local employers, within the college and in the community.
  - What processes, support and resources and activities are needed to support these objectives? (E.g. management and personnel structures, incentives, financial investment, resources, cross-departmental structures, professional development etc)
  - Are there some "short-term wins" identifiable?
  - How are barriers addressed? How are enablers indentified?
- What are the metrics for success?
  - How will achievement of the objectives for innovation be measured?
  - What are the measures of performance? How are innovation goals for individuals, departments and cross-departmental teams aligned to the business goals for the college?
  - How are risks and uncertainties managed? How is "failure" managed?

"A teacher needs to be able to answer the fundamental question is 'Why am I learning this?"

– Delegate at NEF Think-Tank

- And what is the plan for communication?
  - Who are the stakeholders?
  - How will the aims for innovation be communicated and disseminated across the college? And to the community and employers?
  - What are the plans for engagement internally and externally?
  - Will there be an initial team of "innovation experts"? How quickly will organic growth of innovation be expected to set root?

One of the main outputs of the strategy development will be the vision – a single shared vision. And clear communication of the strategy and vision are key in helping college staff understand the organisational need for innovation.

Step 2 Implement structures and collaboration to support open innovation

Once a strategy and a vision pieces are in place and communicated, innovation can be powered through the provision of **structures and mechanisms that support open innovation**: idea generation, the communication of ideas, a continuous learning culture, flexibility, autonomy, empowerment, decision-making, cooperative teams, group interaction, reward and recognition, resources, time and IT (Messmann & Mulder, 2011) (Zhou & Shalley, 2008).

Furthermore, staff will need to be supported in freely communicating their innovative ideas as well as developing and evaluating these ideas, and more, in developing the capacity for innovation in the first place.

Where there is a concern that innovation is likely to stagnate, it is worth recalling that innovative and creative ability can be fostered and developed in adults and the young (Craft, 2005; Amabile, 1996) so **professional and practitioner development mechanisms** should be put in place for innovation.

And mechanisms will need to be created to invite individuals, lecturers and managers, and teams, departments and cross-departmental groups, to share good practice and invite collaboration to develop and create:

- Dynamic **curriculum development**, by breaking out of the processes that inhibit and stifle innovation, stretching of existing programmes, setting expectations of continual improvement, exploiting cross-boundaries in disciplines
- New frameworks that make use of **industrial facilities/expertise/real world experience** to support theoretical learning and giving learners a glimpse of the future
- **Alternative delivery patterns** that fit with learner/industry needs and support wok-based learning
- Pathways that allow **flexible entry and transfer** between disciplines, and vocational and academic contexts in STEM
- **Teaching & learning using technology** that exploits the forms of communication that young people are now familiar with and will be part of their working future
- **Organisational structures**, funding and resourcing policies in colleges that enable departments and teams to exploit strengths and be innovative.

Step 3 Reduce fear of failure

But culture also grows from the way the business is focused and the way risk and failure are managed. And it is this last aspect that affects the take up and promulgation of innovative practice in an organisation the most. In colleges, this is no different. Over years of imposed change through regulatory and funding reforms FE Colleges have principally evolved an organisational culture that at worst is risk averse, and at best, is innovation cautious. That is not to say, innovation does not exist in colleges; this report clearly indicates the opposite, but the tendency to limit the appetite for open innovation still permeates through a greater part of the college system.

And it is an consideration to realise that new and "better" in teaching practice does not always lead to improvement in student learning (Looney, 2009) (James, 2007) (Hannon, 2011). It is also important to realise that just as managers do not like innovation, neither can practitioners adopt new practice without **strong motivation, such as clear learner benefits or a network of collaboration** (Cordingley & Bell, 2007) and without the strong demotivating effects of the fear of failure. But managing failures and risks is still necessary. Good risk management will ensure that identification of what is meant by failure, and the impact of failure before any implementation. And good failure management will support the concept of "failing fast", where rapid recognition of failure is not followed by recrimination but by support to recover and to move onto new ideas (MacIntosh et al, 2012). Even more: since it is in the nature of innovation that failures can, and should occur – sometimes **failures need to be rewarded** in recognition that these are steps to innovation (Berkun,

2010). And sometimes, where changes can take time to lead to any improvements in learning, good failure and risk management will recognise where it may be worth waiting: as was noted in the Rolls-Royce case study, delayed results can sometimes be beyond expectation.

Now step back...

The ultimate aims of the above steps are about creating an environment of trust, a community where open innovation happens organically. And once this starts to happen, only then it be said that a culture for open innovation has been embedded. Of course, sustaining and maintaining will be necessary – but this would be a light touch, assuming the culture is truly embedded – requiring re-visiting of the strategy and ensuring alignment of processes, business and STEM objectives to these values and to the expectations of innovation.

Once embedded the whole process becomes **cyclical diffusion**, where people and networks become enthused and as the values related to relevancy, ingenuity and connectivity become drivers for innovation in STEM vocational education.

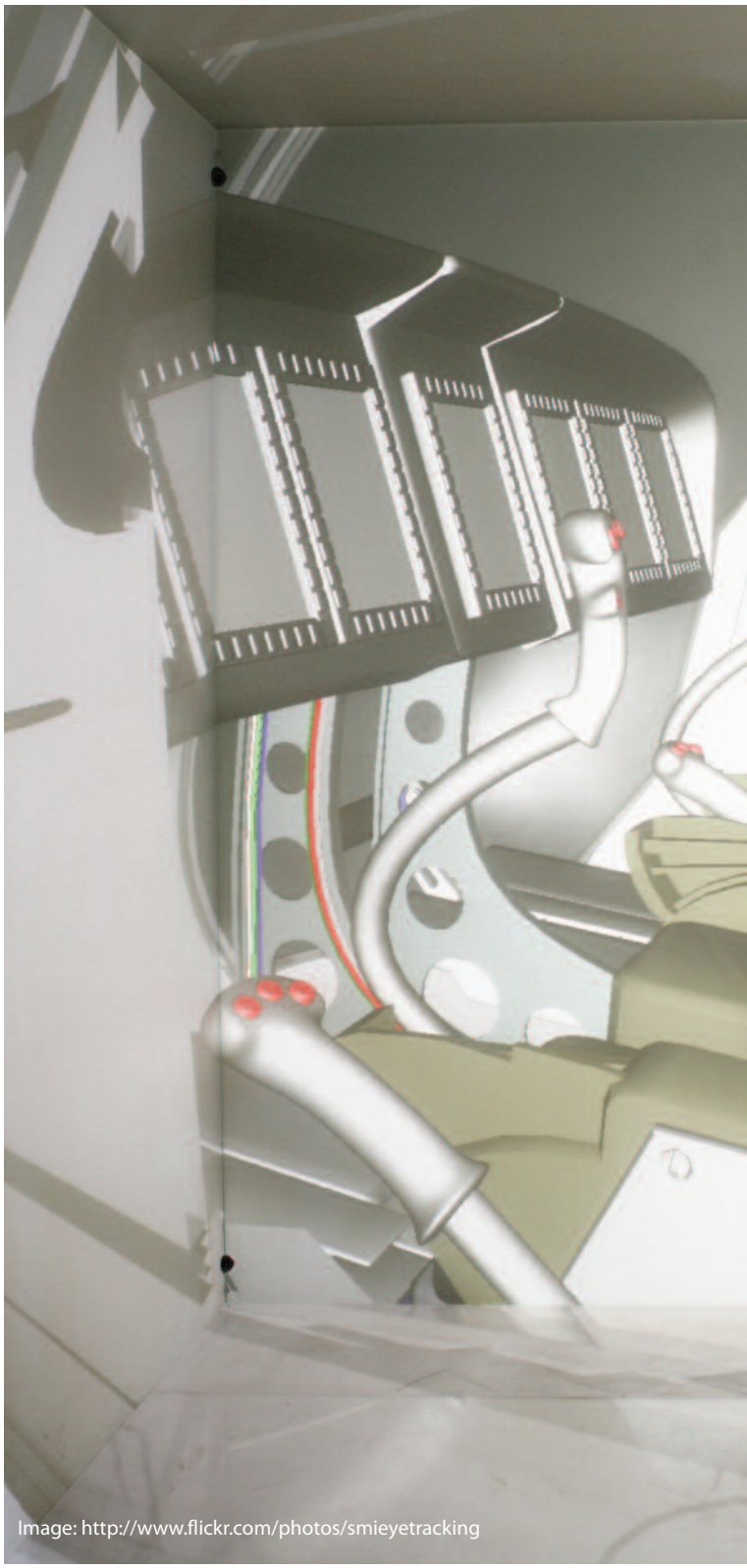


Image: http://www.flickr.com/photos/smieyetracking

5. CONCLUSIONS AND RECOMMENDATIONS

This report is the culmination of a research study which sought to identify **authentic innovative training and learning practices** used by SET industries that could inform and enrich teaching and learning of vocational Science, Technology, Engineering and Mathematics (STEM) in Further Education.

We recommend that colleges look to meet these criteria for innovative STEM teaching and learning:

a **There is an explicit and clear description of the desirable output from the teaching and learning experience**
It is a truism to say that innovation is not "innovation" if it is not effective. So, what exactly is innovative STEM vocational teaching and learning aiming to achieve? This report purports that there are certain attributes, skills and behaviours in the individual that are the desired output and they are modelled in the T-Shaped Technologist. These attributes are those that prepare learners for a future career in SET sectors.

b **The practice embeds a deep understanding of how learning happens**
This includes:

- ensuring that the rationale for learning, and its relevance, is clear;
- identifying the role of trust in teaching – learning relationships;
- exploiting ubiquitous learning – inside

"Education leads to new ideas, so to new business and to growth."

– Head of Training, Rolls-Royce

and outside the classroom, formal and informal;
- enabling learners to take ownership of their learning;
- taking advantage of technology; and
- aligning curriculum and assessment to the requirements of the output, and those of the real customer.

c The provision is shaped by a collaborative effort and influenced by the real customer

We look for an ecosystem or a community of learning that:
- involves all partners and connects to the wider community: learners, teachers, industry, employers, college leaders and policymakers;
- fosters open innovation and shared working;
- shares resources: people, experts, products and experiences;
- supports new frameworks, new delivery patterns;
- enables new pathways; and
- embraces new cross-curricular and multi-disciplinary teaching and learning.

d There is a fundamental drive to find new and better ways of teaching and learning

Education can be said to have succeeded when it inspires and enables. We propose in this report that where a culture for innovation is supported and valued, the result is likely to be inspiring. There is a drive to enhance quality of education, which should support innovation. However, what is not always understood is that failure is often a necessary part of innovation. And what is also clear is the need to identify barriers and enablers: both

actual and those that are a product of the system. Processes that are in place to drive innovation will vary as colleges are at different points in their innovation maturity journey, but leadership, structures and support are essential if innovative STEM vocational education is to happen.

This report explores these themes and extends them further, particularly with reference to the issues of STEM learning and the value added to vocational education and training. The findings from the industrial case studies, and other examples of good practice, add to the analysis of this criteria.

There are also wider recommendations for policy and Government:

- **The STEM curriculum and qualifications offered by FE colleges** are the key to encouraging the success of many of these lessons from industry. Developing 'values-led' education to support a competitive economy requires linking training with desired outcomes, together with the required attributes of character, knowledge and understanding. We need curriculum that really develops thinking capacity, encourages real learning, qualifications that demonstrate high-level skills, and a focus on the ability to apply knowledge. The knowledge that learners acquire when they leave from a college will not be sufficient for them to function effectively in 10 years' time. Theoretical underpinnings are crucial, but even more essential is "learning to learn" to be able to move with the current speed of development in science and technology.
- **Effective and innovative STEM industry training** has happened where leaders have prioritised training and set outcomes using the metric: how well does training lead to the world we want rather than how many people have been trained? The logic is for Government to do the same. This means being bold in determining what it is we really want from our colleges of Further Education. What outcomes do we need to see flowing from organisations whose fundamental aim is to help generate socio-economic prosperity? The answer must have something to do with achieving social returns on investment, ensuring value for money and instilling a coherent ecosystem for STEM vocational education that supports colleges in their fundamental duty to address the needs of their communities and learners.

We need to get away from the perverse incentives of output measures and to search for new outcome metrics for colleges that encourage high quality STEM education and training that works. We need to stop tinkering with qualifications and look for a model that will drive real improvements in STEM education and training. The proposed T-Shaped Technologist learning model addresses many of the required characteristics needed to create an innovative (effective) open learning environment in our vocational training system.

But the first step for FE colleges is to get started: it is only in the doing, with the right intent, with the support of a scaffold for open innovation, that innovative STEM education can hope to happen.

REFERENCES

Adey, P. (1999). *The Science Of Thinking, and Science For Thinking: A Description of Cognitive Acceleration Through Science Education (CASE)*, InnoData Monograph, International Bureau of Education. Available from www.ibe.unesco.org accessed July 2012.

Amabile, T. (1996). *Creativity in context*. Boulder, CO, Westview Press.

Cordingley, P.; Bell, M. (2007). *Transferring learning and taking innovation to scale*, The Innovation Unit.

Berkun, S. (2010). *The Myths of Innovation*, O'Reilly.

BIS & DfE (2011). *Specification of Apprenticeship Standards for England*, Department for Business, Innovation and Skills & Department for Education, London http://www.bis.gov.uk/assets/biscore/further-education-skills/docs/s/11-521-specification-apprenticeship-standards-england

CBI (2011). *Building For Growth: business priorities for education and skills*. London: CBI.

CERI (2009). *Working out change. Systemic innovation in vocational education and training*. Centre for Educational Research and Innovation, Paris: OECD.

Christensen, C.M.; Raynor, M.E. (2003). *The Innovator's Solution*, Harvard Business School Press.

Craft, A. (2005). *Creativity in schools : tensions and dilemmas*. London: Routledge.

DIUS (2008). *Innovation Nation*. Department of Innovation, Universities & Skills, TSO.

Evans, R. (2011.). *The Technical and Vocational Education Initiative* (TVEI) 1983-1997. November 2011. Available from http://www.technicaleducationmatters.org/node/192 accessed July 2012.

Ferrari, A.; Cachia, R. ; Punie, Y. (2009). *Innovation and Creativity in Education and Training in the EU Member States: Fostering Creative Learning and Supporting Innovative Teaching*. JRC 52374. European Commission – Joint Research Centre -Institute for Prospective Technological Studies.

Green, K.; Fletcher, M. (2012). *The Challenges of STEM Provision for Further Education Colleges*. October 2012, 157 Group.

Hannon, A. P. (2011). *Developing an Innovation Ecosystem for Education*. The Innovation Unit .

Harrington, S. (2012) Closing the gap between classroom and workplace, *HR Magazine*, 06 Jun 2012. Available from http://www.hrmagazine.co.uk/hr/features/1073478/closing-gap-classroomworkplace?goback=%2Egde_3721961_member_185293679 accessed June 2012.

HM Treasury & BIS. (2010). *Plan for Growth*. London: HM Treasury.

James, R. (2007). *Evaluating Teaching Innovation*. Centre for the Study of Higher Education.

Kahn, S. (2012). *The One World Schoolhouse: Education Reimagined*. Grand Central Publishing.

Lage, M.; Platt, G.; Treglia, M. (2000, Winter). Inverting the Classroom: A Gateway to Creating an Inclusive Learning Environment. *Journal of Economic Instruction*, pp30-43.

Leadbeater, C. (2006a). *Why Good Managers Hate Innovation*. Presentation available from http://www.charlesleadbeater.net, accessed June 2012.

Leadbeater, C. (2006b). *Personalised Learning*. Presentation available from http://www.charlesleadbeater.net, accessed October 2012.

Looney, J. W. (2009). *Assessment and Innovation in Education*. OECD Education Working Papers, No. 24, OECD Publishing.

MacIntosh, J.P.; Mahrra, J.K.; Tyler, L.R. (2012). *Transformation: DIG for realism*, February 2012, Institute for Security and Resilience Studies, University College London.

Messmann, G.; Mulder, R. (2011). *Innovative Work Behaviour in Vocational Colleges: Understanding how and why innvations are developed. Vocational Learning*, 4, pp63-84.

Michela, J.; Burk, W. (2000). Organisational culture and climate in transformations for quality and innovation. In Ashkanasy, N., Wilderom, C. & Peterson, M. (Eds) *Handbook of organisational culture and climate*. California, Sage.

Microsoft (2007). *Innovative Teaching: Understanding and Expanding Innovation*.

NAE & NRC (2009). National Academy of Engineering and National Research Council, Engineering in K–12 *Education: Understanding the Status and Improving the Prospects*. L. Katehi, G. Pearson, and M. Feder, eds. Washington D.C., The National Academies Press.

NEF (2011). *The Intelligent College*, June 2011. Available from www.thenef.org.uk

OECD (2012). *Better Skills, Better Jobs, Better Lives: A Strategic Approach to Skills Policies*. OECD Publishing.

Ofsted (2011). *The Annual Report of Her Majesty's Chief Inspector of Education*, Children's Services and Skills 2010/11, The Stationary Office.

P21 (2009). *Framework for 21st Century Skills*, December 2009, The Partnership for 21st Century Skills. Available from www.p21.org accessed September 2012

Reiter-Palmon, R.; Herman, A.; Yurkovich, J. (2006). Innovation. *Encyclopaedia of Industrial and Organizational Psychology*.

Shear, L.; Novais, G.; Moorthy, S. (2010). *ITL Research: Executive Summary of Pilot Year Findings*. SRI International.

Simplicio, J. S. C. (2000). Teaching classroom educators how to be more effective and creative teachers. *Education*, 120(4), 675-680.

Smith, H.(2005). From CIO to CPO via BPM, White Paper, September 2005, CSC. Available from www.bptrends.com accessed April 2012

UKCES (2011a). *UK Employer Skills Survey 2011: First Findings*. December 2011, London.

UKCES (2011b). *The supply of and demand for high-level STEM skills: Briefing paper*, December 2011.

Wilby, P. (2006). Storming of the Classroom Castle, *TES Newspaper*, 19 May 2006, updated 27 June 2012. Available from www.tes.co.uk accessed July 2012

Wolf, A. (2011). *Review of Vocational Education – the Wolf Report*, March 2011, DFE-00031-2011, Department For Education.

Zhou, J.; Shalley, C. (2008). *Handbook of organizational creativity*. Hillsdale, NJ: Lawrence Erlbaum.

ACKNOWLEDGEMENTS

This project was supported by the Gatsby Foundation, and we are grateful for their support and guidance.

We are also grateful for the support of the many individuals and organisations who responded to requests for support and advice, or taken part in consultation meetings, both formal and informal, both leading up to the project and during the project.

There are numerous members of the NEF Team including Dr Elizabeth Brookfield, Dr Alison Todman, Wendy Au-Yeung, Dr Emma Whitelaw, Robyn Burriss who have contributed and supported the creation of this report. Many thanks!

NEF Panel 19 April 2012

The following members of the NEF Panel took part in a discussion on the 19 April on the nature of innovation and the requirements of STEM education and training.

- Dr Reza Sahandi, Bournemouth University
- Carol Frost, Centrica
- Prof Derek Bell, Campanula Consulting
- Dr Leon Smith, DEFRA
- Mike Pilbeam, EMC^2
- Tony Maloney, National Grid
- Lindsay Chapman, National Physical Laboratory
- Lance Walker, Productivity4you Ltd
- Dr Allyson Reed, Technology Strategy Board
- Graham Schuhmacher, Rolls-Royce
- Dr David Whan, Royal Society of Chemistry
- Dan Fox, UCL Institute for Security & Resilience Studies/The Territorial Army
- Hazel Elderkin, Unilever UK

Authentic STEM Vocational Teaching and Learning Think Tank 23 July 2012

The following representatives of industry and colleges took part in a Think Tank held on the 23 July 2012 at the Royal Society of Chemistry.

- Dave Commons, BRUSH Electrical Machines Ltd
- Pete Hutton, BRUSH Electrical Machines Ltd
- Andrew Hewison, City & Guilds
- Simon Witts, City & Guilds
- Bill Roffey, College of North West London
- Paul Campbell, Costain Nuclear
- Sada Joshi, Harrow College
- Jo Lopes, Jaguar Land Rover
- Richard Holden, Lloyds Banking Group PLC
- Gareth Humphreys, MBDA Missile Systems
- Steve Frampton, Portsmouth College
- Anthony Lawson, SPX Service Solutions
- Hugh McPhillips, The Association for Welding, Fabrication, Training and Education
- Susannah Tyson, The Oldham College
- Dr Keith Williams, The Open University
- Clare Ballard, Thatcham
- Vic Reid, Tyne Metropolitan College

Intelligent College Network Meeting 9 August 2012

The following college representatives took part in discussions on innovation in education:

- David Kreyling, Chelmsford College
- Gary Howard, City College Norwich
- Corrienne Peasgood, City College Norwich
- Peter Catton, City of Bristol College
- John Devine, City of Westminster College
- Joanna McGillivray, Forth Valley College
- Clive Robinson, Macclesfield College
- Jon Rawson, South Nottingham College
- Michael McAlister, South West College
- James Smythe, The Sheffield College
- Vic Reid, Tyne Metropolitan College
- Ray Ferris, Uxbridge College

Site visits and interviews

Many thanks go the following people and companies for allowing us to spend time at their organisations interviewing them, their staff and learners:

- Chris Edwards, Technical Training Manager, Arla Foods
- Pete Hutton, Technical Training Manager, BRUSH Electrical Machines
- Dave Commons, BEM Apprentice Scheme Manager, BRUSH Electrical Machines
- Dave Drury, Campus Chancellor and Head of Training, Nuclear Generation, EDF Energy
- Elliot John, Fleet Training Manager, Nuclear Generation, EDF Energy
- Mike Latham, Group Head, Central Technical Training, Nuclear Generation, EDF Energy
- Jo Lopes, Head of Technical Excellence, Jaguar Land Rover
- Gareth Humphreys, Apprenticeships Manager, MBDA Systems
- Bryan Ashford, Learning & Development Manager – Electricity Transmission, National Grid
- Will Large, Learning & Development Strategy Innovation & Quality Manager, National Grid
- Craig Smith, New Talent Development Manager, National Grid
- John Tyler, UK Head - Learning & New Talent Development, National Grid
- Dave Kynaston, Vice Principal, Reaseheath College
- Graham Schuhmacher, Head of Training, Rolls-Royce
- Neil Fowkes, Apprentice Scheme Manager, Rolls-Royce

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