Rao Bhamidimarri · Ailin Liu *Editors*

Engineering and Enterprise

Inspiring Innovation

Springer

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This volume is dedicated to Professor Nathu Ram Puri CBE, whose advice and guidance played an important role in taking forward my initial work on reinventing science and engineering curriculum. His creative thinking (sometimes described unorthodox by his peers) underpinning engineering business innovation set a benchmark for others to aspire for. His passion and commitment to creating pathways for generating future leaders of science and engineering businesses is unmatched. Professor Puri's legacy continues through the Nathu Puri Institute established through generous funding from Puri Foundation for Education, which also supports thousands of schools, colleges and universities around the world.

Rao Bhamidimarri

Preface

The global grand challenges of the twenty-first century are profound and wide-ranging. Health and well-being, water, energy and food will be the foci as the population approaches 9 billion. The primary mission of the twentieth century scientists and engineers requires redefining, embracing creativity and enterprise for sustainable development. This will require new approaches to science and engineering education to meet the demand for talent and leadership for generating next generation technologies and solutions.

Scientific and engineering professions have traditionally focused on scientific and technical knowledge and skills and contributed to a step change in wealth creation and improved quality of life across the world. These improvements have been primarily achieved through harnessing the powers of nature for the benefit of mankind. Yet the challenges of sustainability, climate change and resource depletion are better articulated and the non-technical factors, social, environmental and ethical, are increasingly recognised to be integral to the science and engineering professions. Thus, science and engineering education can no longer continue to be limited to science, measurement, modelling and synthesis of these. In today's globalised marketplace, the career success of engineering graduates and their employers demands that the graduates are creative and innovative.

Charles Vest, former president of MIT, speaking to the National Academy of Engineering conference in 2005 said, "I envy the next generation of engineering students because this is the most exciting period in human history for science and engineering". He went on to say that the engineering educators must tap into students' passion, curiosity, engagement and dreams. There has been a growing interest in innovating science and engineering education over the last 10 years.

The discipline context of education and practice offered professional opportunities for scientists and engineers over the last century, but only a few progress to be the leaders of the industry. Based on the work which I carried out initially at Massey University in New Zealand in late 1990s and then at Napier University in Scotland from 2004 to 2007, I proposed the development of a dedicated institute to promote entrepreneurship in engineering education. Professor Nathu Puri CBE, an alumnus of London South Bank University and highly successful industrialist and entrepreneur, agreed to support this development with a substantive donation. Thus, the Nathu Puri Institute for Engineering and Enterprise was born in 2013 with the primary objective of facilitating innovation of engineering education and practice. This is to be achieved through research and scholarship in partnership with industry, other higher education institutions and learned societies in the UK and overseas.

This volume consists of contributions from industry, professional institutions and universities on innovating science and engineering education. The topics considered range from educating scientists and engineers to give a business edge and embedding entrepreneurship to work integrated education and curriculum innovation.

I believe this volume forms an important contribution to the development of enterprise focused science and engineering education into the future.

Rao Bhamidimarri

Acknowledgements

This volume is an edited compilation of papers presented at the inaugural conference of the Nathu Puri Institute for Engineering and Enterprise. The editors are grateful to Professor Nathu Puri CBE for the generous donation, which made the establishment of the Nathu Puri Institute for Engineering and Enterprise possible. Excellent organisational and administrative support provided by Mrs. Oluwatoyin Cole was critical in ensuring that the manuscripts were ready on time for the publication. The support provided by the design and reprographics team at London South Bank University is gratefully acknowledged.

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Educating Engineers to Make a Difference

Educating Engineers to Make a Difference

Andre Krol

Abstract Graduates set out from university to navigate their own unique lifetime voyages through a rapidly changing, increasingly competitive and unpredictable world. Given all the uncertainties and infinite range of possible outcomes, how can universities—and indeed schools—best help them? The answer is to equip them with the knowledge and skills to "make a difference". Be it acknowledgment from their clients, leaders, peers or subordinates—others valuing their contribution will ease their pathway and open up new opportunities. Engineering graduates themselves recognise that existing curricula often result in competency gaps in business understanding and work processes. Engineering curricula could fill these gaps through problem based learning projects based on executive-relevant business problems. However, this should not be to the detriment of providing a solid grounding in core engineering concepts. Industry case studies drawn from the mining industry are used to introduce how such an approach might work in providing foundation level understanding of, for example, the following competencies to an undergraduates thinking process:

- Effectively working with other people
- Methodical problem solving
- Business understanding and planning
- Financial modelling
- Risk and opportunity analysis
- Sustainable development
- The stage-gate project development process
- Communication to achieve outcomes

Keywords Engineering · Competencies · Mining · Case studies · Problem based learning

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1 Introduction

Following formal chemical engineering education, the author worked primarily as an environmental engineer in consultancy and academic roles, with research interests in waste management and sustainable development. He changed course in his early 30s, moving to a business evaluation and development focused career in the mining industry. This background provided new learning and work experiences with engineers and other professionals from a broad range of academic, national and cultural backgrounds.

It is the author's perception that a significant number of engineers lack foundation educational concepts and/or understanding in key competencies which would improve their ability to "make a difference" in their early careers, a key factor in getting the necessary recognition to accelerate career progression. Making a difference during one's career generally means taking actions or making recommendations which result in improved achievement of an employer's objective.

A brief literature survey on competency gaps identified during formal surveys and research was used to validate and expand on this experience-based perception. The resultant validated competency gaps were mapped against the author's learning journey in the mining industry to suggest a possible problem based learning framework for use in designing engineering curricula to address business competency gaps.

2 Engineering Foundations

Marjoram and Zhong (2010) provide a useful definition of engineering: "the field or discipline, practice, profession and art that relates to the development, acquisition and application of technical, scientific, and mathematical knowledge about the understanding, design, development, invention, innovation and use of materials, machines, structures, systems and processes for specific purposes".

The many different engineering specialities connect to the natural sciences, and to the social and human sciences (Fig. 1). Together with the needs of the latter come constraints and the need to mitigate impacts that have led engineers to target sustainable development in the course of their work.

Jones (2010) identifies the important attributes of a professional engineer as technical, personal, professional and managerial competencies (Table 1), while noting that "the importance of each characteristic can vary with the individual, the position or during a career" and that debates about engineering curricula are "frequently conducted without reference to a wider concept that a first degree should be just the start of a career-long education process".

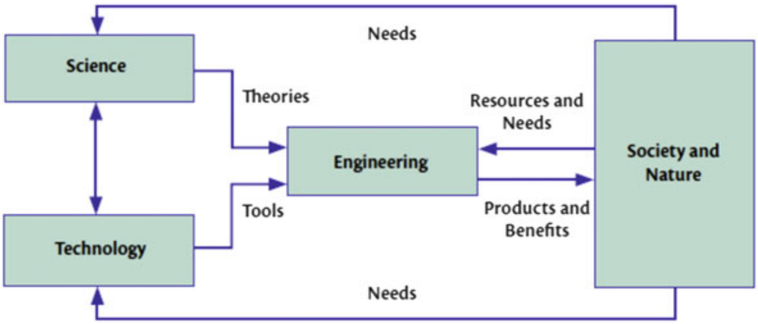

Fig. 1 Context of engineering (Marjoram and Zhong 2010)

Table 1 Important attributes of a professional engineer

Technical Ability to think mathematically, sound knowledge of appropriate basic science, good knowledge of a specific discipline, maintenance of current knowledge and practice
Personal Ability and willingness to learn, appreciation of limits to knowledge, good communication skills, appreciation of international dimensions
Professional Commitment to high standards, appreciation of personal and ethical responsibilities, ability to handle uncertainty, ability to communicate effectively
Managerial Ability to work in a team, appreciation of management concepts and issues, ability to lead and manage personal, financial and technical resources

Engineering is a foundation for the development of society, which continues on a dynamic, transformational and globally integration path—with fundamental change during my father's life (e.g. cars, aircraft, nuclear power), my life (e.g. satellites, information technology, the internet and mobile communication), and no doubt this will continue during my children's lives. This poses a number of challenges for engineering education (Kolmos et al. 2010):

- Knowledge can become outdated (though fundamental concepts will always be valid)
- Innovation is increasingly based on collaborative knowledge rather than individual knowledge
- Collaboration now involves interdisciplinary, intercultural and international interactions
- Skills necessary to identify and progress the appropriate balance between societal constraints and societal needs

So given the above, how do engineering curricula shape up?

3 Competency Gaps in Engineering Education

Male et al. (2010) cited a number of international studies examining perceived competency deficiencies in engineering graduates, and their own work based on survey responses from 300 graduate Australian engineers with 5–20 years work experience provided broadly consistent findings.

In particular they asked the question “Is there a skill, attribute or area of knowledge that you have observed to be lacking in engineering graduates who have completed their degrees within the last 3 years”. The highest ranking responses were:

- Practical engineering, i.e. applying engineering skills to practical issues.
- Communication and persuasion skills. Commented themes were writing, argumentation, listening and verbal communication.
- Business competencies. Commented themes included contracting, project management, commercial awareness, finance, economics, planning, marketing, budgeting and cost control.
- Problem solving. Commented themes were analytical skills, logical thought process, trouble-shooting, critical thinking, questioning of assumptions and systems/holistic approaches.
- Self-management and attitude. Commented themes included commitment to a high standard of work, willingness to exploit opportunities, community awareness, time/workload management, pragmatism.
- Teamwork, including leadership, negotiation and conflict resolution.

The last five of these attributes are generic and are particularly important for those graduates in roles outside engineering and/or requiring multi-disciplinary engagement. They can be summed up under the overall tenet that engineers should be able to demonstrate they can “make a difference” by solving business problems or grabbing opportunities, i.e. not just to do work for work’s sake. Throughout my career I have often had to remind people working on projects that “We are not here just to build this project, we are here to build a business”. The skills identified under the last 5 bullets above are required to assist identification, definition and selection of the most appropriate course of action, taking into account all materially relevant factors, and to persuade the organisation that this is what should be done.

4 Addressing the Gaps: Problem Based Learning Based on Real Industry Problems

Most of us had competency gaps when we graduated from university, and perhaps these were filled during further education at universities or in courses provided by our employers. However, in many cases we filled these gaps on an “as needed” or accidental basis during the course of work.

For instance, in my career I can identify learning milestones which addressed the generally perceived competency gaps. Table 2 provides a summary of some of these.

In each case these problem-based learning opportunities generally involved:

- A "burning platform"—tackling an important business issue for a clear client or sponsor
- Working with and learning from others—multidisciplinary teams—during an intense period of engagement

Table 2 Example personal learning milestones

Problem	Skills acquired and/or significantly further developed	Learning mode
Write and present a business plan for a new product or service	Financial Marketing Teamwork	Continuing education course Team project
How should the client government agency incorporate social and environmental issues in its policy and project decision making?	Sustainable development Environmental economics Mental models Systems/process analysis Financial and multicriteria decision support techniques.	Secondment to a research institute Own study and research Interviews
What's the right strategic plan for our business? Can we improve the business case for this project?	Holistic business understanding Hypothesis-driven, methodical problem solving Cashflow modelling Teamwork Communication	Member of mixed multidisciplinary teams drawn from company and management consultant
How do we improve the performance of this business? Where are the cost reduction opportunities?	Business strategic and annual planning Business reporting Lean manufacturing Working with and respect for operators and maintainers Communication	Client sponsorship of management consultants Leading, mentoring and working in numerous multidisciplinary teams
Is there a feasible and economic case for developing/expanding this mine/fixing this environmental problem? If so, what scope of work can we confidently approve for construction?	Project management Stage-gate development of projects Teamwork Moving from analysis to action Communication	Member or leader of study and project multidisciplinary project teams

- Facilitation by management consultants or "wise and knowledgeable" leaders
- Hands on use of problem solving, analysis and communication tools

A university might consider emulating this process by having student teams (potentially drawn from different courses) work on industry case studies. Potentially this could be considered as a lead into subsequent traditional discipline-focused final year design projects on one aspect connected with the case study.

A possible approach would involve emulating the problem solving approach used in industry for "concept study" review of a business problem:

1. **"Burning platform" business issue provided by a leader drawn from industry, who ideally agrees to be the project sponsor**. This would describe the situation and associated complications, be accompanied by a case study fact file, and the student groups would be asked to do a study concluding with a recommended course of action. By way of example, here are two potential case study topics based on actual mining industry situations:

    - A 50 year old marginally profitable mining and concentrator operation which economically supports a community of 10,000 people legally disposes of chemically inert tailings to a natural lake. The Government has forbidden such practice for new projects and has given existing operations 5 years to meet new requirements. The company must decide what to do and at a high level the options are to close, to fully meet the requirements, or to meet the fundamental objectives of the new legislation with some negotiated outcome.
    - A long life mining business producing a single product has identified a new ore body which could provide another product with a different specification that is in growing demand. However, the new mine requires new environmental and community approvals, and any expansion of the business requires investments in infrastructure as production capacity increases. Furthermore, the existing operation could also be expanded. As an added complication, any expansion may impact demand and pricing. The company must decide what to do and at a high level the options are to do nothing, to expand using either the existing and/or new mine, and to choose the appropriate expansion capacities.

2. **Analyse the situation and come up with recommendations, informed and if possible facilitated by people with appropriate expertise.** The analysis should make use of pertinent business problem solving tools such as:

    - *Working together effectively as a team.* The ability to work in formal and informal teams, often across organisational lines and remotely, is an essential skill in the workforce. The three essential elements for successful teams are generally cited as a shared goal or purpose, shared commitment and individual accountability to complete assigned tasks, and competent members in terms of how and what is contributed. The value and contribution of people with different professional skills, backgrounds and perspectives should be recognised.

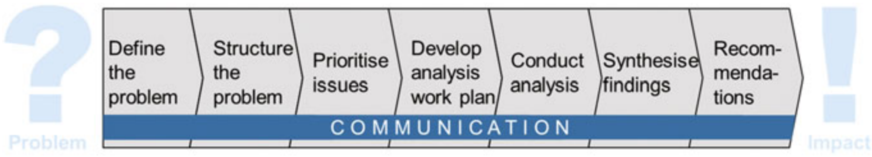

Fig. 2 McKinsey problem solving process (based on Minto 2010)

- *Methodical problem solving*. Figure 2 provides a typical framework (Minto 2010). A basic understanding and experience in problem solving techniques provides people with a generic framework they can use and build on throughout their career. All too often I have seen engineers jump to one option as they consider it the obvious thing to do, often with no or minimal review and analysis.
- *Key business and engineering management tools*. My personal favourites are tools that provide a holistic picture or analytical framework for the whole business or project, thus enabling consideration of all material aspects at an appropriate level of definition to assist with prioritisation and options analysis.

  – Mind map of how the business works—a good starting point to bring basic structure to individual or team brainstorming.
  – Simple cashflow model of a business or project—an essential tool to understand how money is made, the impact and relative importance of changes, and to evaluate different alternatives.
  – Risk (threat and opportunity) analysis—likelihood and consequent impacts of risks to assess their significance. Impacts to be considered include financial, reputational, safety, health, environmental, community and compliance impacts.
  – Stage-gate development of projects. Studying potential projects or project options in the mining industry is expensive and time consuming. Hence a stage-gate approach is used to filter project options (identify, delete the least promising and select the most promising) at the minimum possible level of analysis while considering all aspects which will be eventually considered in the definitive feasibility study (Fig. 3). At the Concept level of analysis which is appropriate for a student team exercise, the key outputs are generally:

    Description of identified project options
    Indicative cost and ranking of options
    Financial valuation of options
    Sensitivity analysis
    Fatal flaw risk analysis
    Recommended actions

- *Case study fact file*. The type of information supplied could include background information on the industry and its marketplace, an existing business plan, project study material and a financial model.

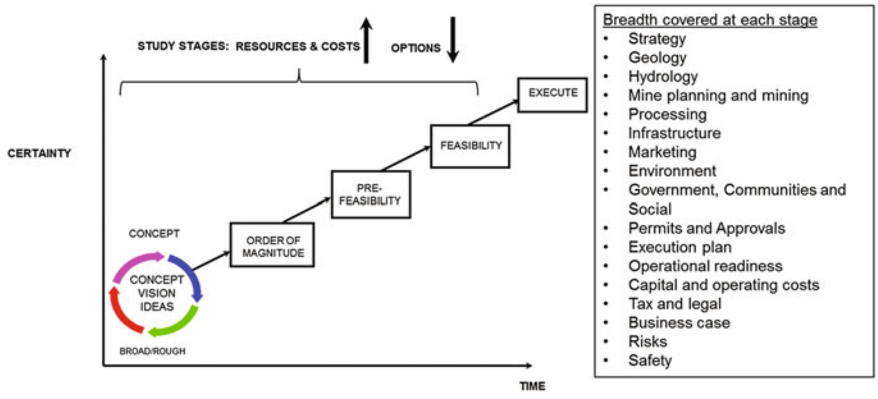

Fig. 3 Stage gate project development process with typical issues covered

3. **Communicating findings and recommendations to the project sponsor**. Good analysis leading to a valuable recommendation is of no use unless it is understood and acted upon by decision makers. Hence, the final product of such a project should be a presentation which provides compelling logic for the recommended action. Minto (2010) provides good guidance on how to structure such a presentation.

5 Conclusion

Engineering graduates may have competency gaps in the problem solving, analysis and communication skills that are valued by managers and which assist career progression. Such skills may be appropriately learnt through team problem solving exercises based on industry case studies. Including grounding in these skills as part of engineering curricula could provide graduates with differentiating capabilities in their engineering and other career paths.

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Planetary Engineering: Entrepreneurship at the Interface of Cultures

J. Otto Kroesen

Abstract This contribution answers the question: what capacities are required for engineers to participate in entrepreneurship for development, specifically in developing countries? Related to this main question is a number of sub-questions: (a) What extra demands does a different cultural and institutional environment pose on entrepreneurship? (b) How does the management style of the enterprises involved find proper and effective solutions at the interface of different and often opposing (traditional and new) value sets and institutional arrangements? (c) How are these different value sets and institutional arrangements imbricated in each other and in (the use of) the technology—and technology in them? (d) How does this affect the education and curriculum building of engineering students? The author will move to and fro between experiences from practice and insights from theory so that theory and practice inform and explain each other. The author will finally propose one superior value or capacity in order to deal with the cultural and institutional differences indicated: the capacity for planetary movement, i.e. the capacity to alternate (consciously and deliberately) between different value sets and to compose a management style that combines different elements, timely and temporarily.

Keywords Engineering education · Entrepreneurship for development · Intercultural management · Technology transfer · Values and technology

1 Introduction

Engineering differs from mere science in that it is focused on design. It doesn't only reduce phenomena to earlier causes, but it makes causal relationships subservient to future imperatives. Doing so it integrates dead matter into the process of life

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(Rosenstock-Huessy 2001). This implies that engineering takes place at the crucible. It should be both deep (understanding and manipulating natural phenomena) and broad (communicative and oriented to the future). By planetary engineering I mean the ability to alternate between these two capacities and to be good at both. That requires a high level of communicative competence and flexibility. For that reason I introduce the word "planetary". The planets are constantly on the move in unpredictable windings. I will come back to the meaning of that imagery. Engineering requires the ability to connect and go between different worlds. It even requires world creation. Engineers make decisions on how the future will or should look like, technically, socially. In this contribution I want to show what this world creation and this movement between worlds takes, on a theoretical level, but also in terms of engineering practice. I will draw my examples primarily from internships and master thesis projects in developing countries, which I happen to be supervising in great numbers.

2 Kibwezi—A Business Approach Towards Water Pumps

Let's first take a case study so that we start with the engineering practice. The example that I present is a typical example of the engineering way of approaching social problems as if they too were just another type of technical problems. So it is kind of a deficient case. But for that very reason it shows what is lacking to the 'business as usual' engineering education.

In the region of Kibwezi in Kenya Flying Doctors installed a great many (±400) water pumps, of which after several years only 200 appeared to be still working and maintained by volunteers (Oltheten et al. 2010). Organized in committees they were taking care of the remaining functioning water pumps, but being volunteers, it was increasingly difficult for them to keep up the quality and then of course there were the financial issues. As a solution students working on this case proposed a business approach and an improved logistical system. They developed this logistic model in extensive dialogue with the local volunteer committees. Ingredients: all of the committees in the neighborhood would have to adopt the same type of water pump, spare parts would be fetched from Nairobi once a month with a fully loaded truck, these spare parts would have to be stored and watched over carefully in a central storage facility, and a disciplined and transparent administrative system would have to be put in place in order to manage the continuous availability and cost recovery of the spare parts. In this approach the repair activities would become much more efficient and it would become possible to run the maintenance of water pumps as a business, generating an income for the practitioners involved.

However, it was underestimated what this takes in terms of a change in attitude at the interface of cultural value sets, the problem I mentioned above. Not only should the volunteers learn to deal with the new administrative system, but they would also lose their independence as water pump committees. They would need to adapt to more intense cooperation and generate more mutual trust and adopt a more intensely disciplined type of time management. In addition security at the storing facility would become an issue, including theft of the spare parts and/or corruption. In the end the system proposed by the students was not adopted. A follow-up internship, which was meant to work on the introduction of such a system was not accepted. The local volunteer groups liked the idea, but didn't like its implementation.

At the surface it seemed that only a more sophisticated logistics system was at stake. At a deeper level, however, the refusal of this sophisticated system might be explained by difficulties at the interface of different cultural values involved (Jackson 2011). The volunteer committees were functioning as independent closed in-group entities. They probably didn't like the idea of introducing a hierarchical management system, especially not in the usual African version, in which power distance is very strong. So both lack of mutual trust and the fear of too much hierarchical control might be an issue. Also the disciplined time management, tracking system, and labor division might be the cause of the reluctance to accept this new logistical system. It affects the independence of the water committees. If only judged from an economic perspective, it might be good, somebody might even make a living from it. But to attain that economic gain, from the perspective of the volunteers too much of the traditional African value system might have to be sacrificed. So they preferred to continue as they did, even allowing for the risk that more of the existing water pumps would probably be lost in course of time.

The case shows the uneasy relationship between traditional and modern values at the interface of different cultures: Independence of the committees, distrust towards cooperation with other committees (closed in-group orientation), resistance to more hierarchical control, resistance to the disciplined and accurate tracking system. For those reasons capabilities that are in principle available (the business approach proposed seemed to be viable) could not be converted into reality. Finally the case shows the need for a viable 'economic culture' (Porter 2000). Giving in to the traditional African value system also means, in this case at least, but in many more cases, that the business is not effective and competitive. But what is the alternative? Should more extensive training be mandatory to learn such a committee how to deal with a modern entrepreneurial business approach? Or, the other way around, is a trade-off possible between the traditional African values and new values introduced by an entrepreneurial approach? Finally, the lack of an enabling environment (UNDP Report Capacity Development 1997) on the level of institutions also turns out to be an issue. With an enabling environment one might think of bad roads, but also failing institutions, in this case the risk of theft from a central storage facility, or corruption if the workers at such a facility feel the need to help out friends or family. Anyway, a more complex management system, larger scale cooperation, the risk of theft of the spare parts, it all contributed to the lack of trust in the proposed solution.

3 Engineering Competences at the Crucible

What insight does this case give us into the requirements for adequate engineering education? By means of internships in developing countries I think we are taking the engineering education to a next level. A more conscious deliberation about the integration of technology into an (existing) social and institutional environment is mandatory. Also required is the ability to respond to new and surprising challenges in creative ways. These two demands go beyond the usual understanding of the importance of communicative abilities of engineers.

Let me explain that. Stressing communication skills as necessary for engineering has become commonly accepted. The usual training in communication can be described as shown in Fig. 1.

This model reflects the usual subject–object scheme in science. At the inside we have subjects with knowledge consisting in pieces of the puzzle, at the outside we have the forces of nature, or the forces of the market etc. It is generally accepted that communication is necessary to fine-tune the different contributions and to be effective in the application of technology. We can put *communication* at the inside over against *implementation* in the outer world. A group, or a society, needs to find common understanding, agreement on the important issues in order to be effective. For effective cooperation the different stakeholders, in the process, need to communicate. They need to create a common understanding or mental model of what they want to achieve. Usually training in communication abilities is required to evoke more commitment to each other, listen better, take the different contributions from each other into account, and coordinate affairs internally (Feely and Harzing 2003). All this is required in order to have a bigger impact on the realities of the outside world, in terms of good results and effective production. Many training courses contribute to that objective.

That is not sufficient anymore if we have to deal with cultural differences. Such cultural differences originate from different historical paths taken by different communities. For that reason they need to be understood from a larger time perspective derived from the history and tradition of a particular society (past). On top of that, in intercultural management it is necessary to sort out which cultural code

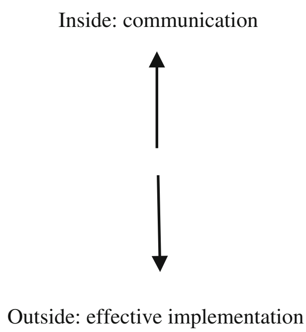

Fig. 1 Two spaces: inside and outside

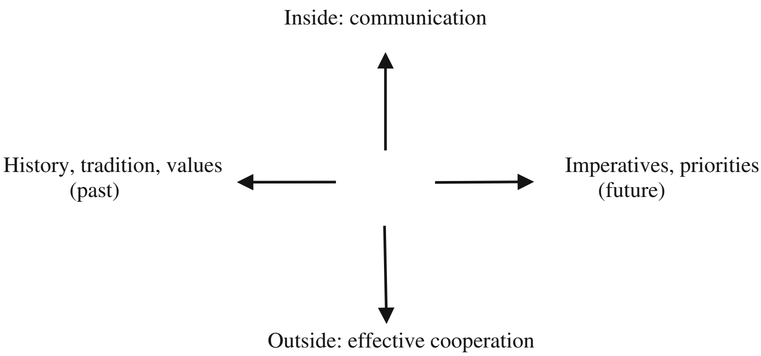

Fig. 2 Two spaces, two times

should, at which point in time, receive priority and this needs to be figured out in view of new imperatives that need to be met (future). This can be illustrated in Fig. 2.

In other words, effective cooperation across cultural differences, does not only anymore involve the space axis between inside and outside, but also the time axis of past and future. In order to cooperate effectively (outside), communication is necessary (inside) but this communication needs to take into account different historically constituted values shaping human behavior (past) and it also needs to take into account the right imperative to be followed at a given moment in time (future). The important thing is, that orientation on past and future becomes an unavoidable necessity. This is extremely important, because it appears now that orientation on past and future is becoming indispensable in order to get the work done. Our industrial society has a long tradition of blinding off this broader perspective of human orientation and destination. During the last 40 or 50 years the communicative dimension, claiming respect and valuing each other's contributions, has slowly become indispensable for effective cooperation. The intercultural debate now forces us to make the historical dimension (values, common ways of life) and the future dimension (new imperatives and priorities) also an indispensable part of such communication (Kroesen 2014).

Already the setup of these internships gives a perspective on this development. Most of the students participate in an internship as part of a minor of half-a-year, during their bachelors study. In this half-year minor, they are prepared during a period of three months for these internships by following courses on entrepreneurship, the history of development policies, intercultural communication and project management, including business and finance. Role games and the interpretation of practical cases are an integral part of this course. The intercultural debate in, but also outside the Netherlands, has been framed to a large extent by two sociologists of Dutch origin, Hofstede and Trompenaars (Hofstede 1997; Trompenaars and Hampden-Turner 1999), who did a lot of quantitative research on cultural differences. Similar to the long list of values that can be mentioned in virtue ethics this as well leads to a list of values, among others power distance versus egalitarianism, community spirit versus individual judgment, traditionalism versus initiative, status by position or by achievement and labor etc., with percentages exactly indicating the differences per national culture. Always when such differences between cultures are listed, the question emerges which one is better or worse, or by what criteria some priority can be established. I would suggest that there is no such criterion, except one: timeliness (Kroesen 2014). Timeliness means: a concrete historical constellation requires a specific priority, which is good for that constellation. Often such timely priorities are path dependent, which means, dependent on the trajectory a specific society or group has gone through. They should also be responsive to the constraints of this trajectory, and to the options that are open for future action from this perspective (Deneulin 2006). For example: sometimes one just should be obedient, and follow the group, but at other times one should be critical and independent. Inasmuch as we have to deal with always new situations we need to remain open and cannot make decisions in advance, at least not for novel situations and problems. We cannot do otherwise but listen to the imperative of each new historical situation.

4 Design and World Making

Actually technology and design is in this way becoming part of the human endeavour as such. The everlasting question from where we come and where we go is becoming part of technological design or, the other way around, the design of technology is becoming part of this continuous historical dialogue. Different technical designs promote different values. In turn different values materialize or are incorporated in different design options. In designing an information system, for instance, hierarchical values or more egalitarian values will predominate according to the accessibility of the information to different positions within the hierarchy (Friedman et al. 2006). This is a matter of choice and these choices are informed by value priorities about which we judge, but in this way our judgments and decisions as of this moment create the world in which the next generation will live. By designing technologies we are also creating institutions and by creating institutions we are creating future societies and opening up and closing of historical paths.

These considerations are the more important if we take into account that by its nature, technology implies large scale. Only thanks to large scale use technology becomes accessible, affordable and profitable. The large-scale of technology always entails the cooperation of a great many different stakeholders and actors and for that reason also a great many different interests and value laden perspectives. And these need to find common ground and orientation in order to be implemented. A technology often can only be effective if these different interests and values are coordinated, if they open up and listen to each other. We move through time as a society, just like we move in language, by means of grammar. The moods of grammar reflect our cooperation and discussion, conjugation and inclination, and our being singled out.

The crossroads imagery we used before can explain that more accurately. In science we may have to deal with subjects and objects, thinking and space, mind and matter. But as people living their lives in concrete historical and political developments we are not that much in control. Often we are thrown beyond ourselves into situations we do not understand. We feel lost, because it seems that nothing works in this new situation as it worked before. A new *imperative* makes itself felt and needs articulation at the front of the future. It's really new. It wasn't there before. It is not just new to you or me individually, but new to all of us. We don't even have the words for it. We use some familiar names maybe, but we have to adapt them to the new situation in order to express the new element. Environmentalism is such a word. The word "environment" already existed for a long time. But now the word environmentalism entered our vocabulary. It expresses the urgency to take the vulnerability of our natural environment into account. In former times it was not necessary, because nature was overwhelmingly powerful. Now it has become vulnerable. It is the experience of an imperative, not the result of an analysis in the first place. As soon as we start analysing we start to diverge, even if we recognize the new imperative. Probably we disagree as much about the problem as about the solution. That is where in grammar the *subjunctive* use of language sets in. In Fig. 2 we called this subjunctive the inside reality of intersubjectivity, where people are inclined to adapt to each other. As different individuals and subjects we try to join each other with proposals and propositions to make. We propose to each other. We invite each other to take over our point of view. In course of time we may find some common ground and shared understanding. Thanks to a shared history some agreement develops about shared codes. There phase 3 sets in, the phase of having a common history and tradition, a shared approach of reality, common ground. This is the phase of the *participative* mood, in which a shared history and common experience is expressed. Finally the new imperative can be institutionalized in the outside world. For instance the imperative of environmentalism may in part be realized by the introduction of an electric car. We might find more such solutions. Then phase 4 sets in, the *indicative* phase, the phase in which we can point to concrete results: here it is! That which first was a problem has found a solution and that solution has now become a fact of life. This hermeneutic circle going from *imperative* to *subjunctive*, to the *participative* mood and finally to the *indicative*, reflects the circle of life (Rosenstock-Huessy 1963). It is continuous, and as well repetitive as creative. By understanding this fourfold circle we may therefore have a better understanding of the sentence I started with, namely that engineering and technology reintegrate dead matter into the process of life. It is the most beautiful definition of technology I ever heard. This hermeneutic circle is at the same time a process of world making. Our solutions are the basis for future developments, future flourishing, future problems.

Everything said so far about the plurality of values, communication etc. is more emphatically true in intercultural management, because there is a wider range of values between different streams of culture. The gap between traditional values and the new values derived from Western modernity is larger. It is more difficult to achieve cooperation and even more difficult to get transparent governance, technology policy and regulation in place in developing societies, due to the different and conflicting value priorities. These societies happen to be at the crucible, at the interface of different values and cultures (Tshikuku 2001; Jackson 2011; Ayittey 2006). They have to find new solutions, to create a new world for the next generation. In many developing countries a transition is taking place between traditional and new and this leads to sort of a twilight zone. Old values are not functioning anymore as they once did. But a new set of values is not commonly accepted yet. In such a crisis situation often a society receives the worst from both, past and future (Rosenstock-Huessy 1993).

5 Value Sensitive Entrepreneurship

This theoretical exposition may sound rather abstract. So let me give some more examples. First a personal memory. I have cooperated with a consultant in civil engineering who worked for a long time in Bangladesh for a government agency on water issues. Like so many people he was depressed by the sight of the many rickshaws which occupy the streets of Dhaka, looking for customers and working hard for little money. If a farmer does not have any means of subsistence or lost his land due to debts, he will go to the city and become a rickshaw puller. My friend the engineer asked himself—he told me the story himself—whether these rickshaws and the life of the pullers could be improved by means of a gear. During three months in the evening he worked on the design and in the end he had figured it out. By the implementation of his invention the rickshaws would only increase in price by one or two dollars (it was in the 90s by then). But then he discovered that his invention would not work anyway… Why not? It turned out that the rickshaw pullers do not own the rickshaws themselves. And those who owned the rickshaws did not care about his new invention. They rented the rickshaws and they could find customers in abundance and they didn't care about their hard labour. It's Bangladesh, you know. So, he stopped there.

Reflecting on the case it is easy to see that the technical innovation bounced back on the institutional arrangements in Bangladesh. In terms of Fig. 2 a new imperative (phase 1) bounced back on existing institutions (phase 4). And these institutional arrangements in turn are a reflection of the cultural values predominant in Bangladesh, such as high power distance, low esteem of labour, and an indifferent attitude of people of high status towards those at the bottom of society. It is impossible to innovate the technology of the rickshaws without a cultural and institutional change. My friend gave up. But in a sense the story continues. I was surprised to find out a few years ago that a Dutch NGO, One World Foundation (www.1we.com), is now involved in entrepreneurship in rickshaw services. Normally a rickshaw puller earns three dollars a day and he has to pay two dollars for the rent of the rickshaw. What's left is one dollar, just enough for a meal of rice for the family. But this NGO installed a rotating fund for leasing rickshaws. If the rickshaw puller hires a rickshaw from this NGO he actually participates in a microcredit system and after a while he has paid enough to become the owner of the rickshaw, thus bypassing the usual rickshaw renters and starting a business of his own. It seems to work, since a growing number of rickshaw pullers participated in and even left the system already. But again we have to reflect on the institutional and cultural change which is promoted in this way. This rickshaw puller is now turned into an individual entrepreneur, and the Dutch NGO is promoting a more egalitarian social system within the hierarchical Bangladeshi society. The Dutch NGO as well as the rickshaw pullers following this line of action do intervene in the value system of Bangladesh and change its institutions. They introduce new values, different institutions and all that is what I call "world creation" (Cristaudo 2013).

It requires very specific engineering competences to invent and implement a business plan like this NGO is doing. The case is therefore instructive. The civil engineer I mentioned earlier was so much focused on the technology that he couldn't continue from the moment he discovered that the problem was not only with the technology, but with the institutional and cultural environment of Bangladesh. He was very competent but in a limited sense. The Dutch NGO installed a rotating fund for buying and selling rickshaws, and on top of that it put in place entrepreneurial training schemes for the rickshaw pullers and for their counterparts in Bangladesh and it took off.

Nevertheless, it is not easy to be successful even with such an entrepreneurial attitude. Two cases from interns in Surinam can illustrate this. The first one is about a bakery in Moengo (Hof Van't and Spoelder 2012). Moengo is a small town of nearby 10,000 inhabitants at 2 h distance from Paramaribo, the capital of Surinam. In former times it had more than one bakery of its own, but during the jungle war between two competing factions of the Surinam Army in 1986 during the military dictatorship all of this was destroyed. But after that for the people that returned, the bread would only come from Paramaribo, transported by car each day, produced in a factory. An old lady was daring enough to invest in a small bakery in which bread was baked in the old way. The oven is heated by burning wood in it. When the wood is burned and the oven is still very hot bread can be baked in it and the result is very tasteful. Two female students from industrial design took up this assignment. The assignment was to build the oven with local materials available and design a business and marketing plan by which the enterprise could start. The first meeting with this old lady was not very promising. The two students wanted to talk about the oven immediately and discuss the design options and the place of it and the money involved etc. But they had the impression this lady seemed to keep them at a distance and on their inquiry it seemed that she did not have the money either. Within a week I got a phone call from the two students to please put them on a different assignment. This one would not work. After a talk with the old lady it appeared that she did have the money and was willing to build this oven, but she felt overruled by the students and was hesitating to trust them. I gave the advice to the students to visit the old lady once more and chat about a lot of things and only return to the issue of the oven after they all felt comfortable with each other, say after there had been some laughter. The advice worked. They went to work in building the oven with the help of a former baker who had worked with this type of ovens in the past, an old man also. The two students were very much on the job and the old man enjoyed their energy, although they had many quarrels with him about the materials and about the design and the way to make progress. I think, if this old man wouldn't have liked the positive energy of these two girls, he would have left the project. He must have felt insulted many times, because they didn't want to listen to him and didn't respect his old age, and they were very direct. They were focused on doing and finishing the job. Nevertheless, it worked, and the oven was finished. Time was over for the students and they had to leave. They were so much focused on the oven itself that they didn't have the time anymore for the business plan. But this issue was solved by the old baker. He had worked as a baker in the past. He baked his bread and bicycled through the neighbourhood each day and he sold it each day, because people just loved it.

Other problems, however, lurked around the corner. The baker wasn't paid sufficiently. The old lady borrowed some money and had to pay back, but on top of that: the land on which the oven had been built was owned by a relative of hers. The land was just laying idle and he agreed to lend it to her without compensation. But now he heard that this bakery was so successful, he came and asked for his share. Although we wouldn't think of that as a very elegant thing to do, it is a very common practice not only in Surinam but also in many African countries. Family is all. Family solidarity requires that you do not make a point of the use of your land for the benefit of another family member, especially if you do not use it yourself. But if the other family member starts making money with the help of your property the same value of family solidarity legitimates to withdraw the original agreement and require your family members to share the benefit. Family is all, isn't it? In this way not enough was left for the baker. After half a year the baker, not having been paid for a long time, quit his job and the oven stood idle from then onwards.

In Surinam as well as many African countries it is habitual to maintain a sort of an internal bookkeeping system of charitable deeds between family members, neighbours, clan members etc. If somebody is successful in a business, his private property or a part of it is often morally claimed by family members in need. Outside the family there is less solidarity and distrust easily creeps in. This moral attitude also became an issue in another entrepreneurial initiative in Surinam, this time a craft shop (Starre et al. 2013). Now I want to explain how this—call it—jealousy was cleared away by an effective strategy of the students. A schoolteacher (female) in Moengo put in place a small craft shop where handicraft (garments, bags, shawls etc.) was sold to tourists passing by. The craft shop was in need of innovation and the students did some fundraising in the Netherlands and the schoolteacher in Surinam borrowed money from the bank. The assignment of the students was to innovate the shop and look for ways to enlarge the production and bring the crafters together in a cooperative effort. The innovation of the craft shop was not the big problem. It was not easy, because the Dutch students had to deal with Surinam businesses and that already takes an effort in intercultural communication, as well as alertness in order to prevent being cheated etc. Nevertheless, the enlargement of the production and cooperation between the crafters was the bigger problem. The students solved this problem by means of a two-pronged strategy. First they introduced an excel sheet to keep track of all the garment and other things produced in a transparent way. They calculated the innovation costs, the running costs of the shop and the overhead costs that needed to be put on each piece and on the basis of that they set prices for sale. Secondly, they had many meetings with the crafters and the shopkeeper to discuss the procedures and prices, explain the overhead cost structure, but also: have fun with each other and build relationships of trust. This two-pronged strategy of transparent bookkeeping and price calculation, and building up confidence by a long series of meetings laid the foundation for a cooperation between the crafters and the shop which still holds until now.

Clearly the students didn't need only the competence of designing a business plan, they also needed communicative abilities, like showing interest in each of the participants, bonding and creating trust and confidence. In the process they also changed the culture and institutional environment of Surinam. A schoolteacher would normally not be very transparent in dealing with uneducated women like these crafters. Power distance and difference in status would stand in the way of such egalitarian relationships. The excel form is maintained until this day, but the schoolteacher had to be reminded several times to maintain this transparency in order not to lose the confidence of the crafters. In this way the power distance gap is closed a bit. On top of that group cohesion between the crafters and team spirit is promoted and thereby relationships of trust beyond family loyalties. The entrepreneurial opportunity couldn't have been realized without this change of the cultural and institutional environment. Engineers that want to be entrepreneurs as well, especially in developing countries, need these capacities. They contribute to the social transition taking place in those societies. And they need to be trained to be capable to do so in a responsible way.

6 Training and Education for Entrepreneurship

Normally institutions of higher learning tend to emphasize that they offer unbiased, value free knowledge and skills. Since Weber science is supposed to be value free and it is only the political will of the scientists (or engineers) that introduces priorities and values into the debate (Weber 1973). However, sociologists of knowledge already taught us that even in the choice of our objects of study we already adhere to specific values and social priorities. Moreover, practical training and internships entered institutions of higher learning, first with the intention to prepare the students for their jobs in a merely practical sense, later and increasingly also to educate them and turn them into responsible citizens. The discourse of "competences" was introduced. With the introduction of entrepreneurship even a specific human type, endowed with a particular set of value characteristics enters the scene of institutions of higher learning (Isaacs et al. 2007) as a matter of study and promotion. In intercultural management this trend towards value laden teaching is even intensified more, in that students have to learn to deal with different cultural value sets. Training is required to do so. Training in intercultural management is required in a twofold sense. (1) *Flexibility* is required to adapt to different cultural codes. When in Rome, act like the Romans, the saying goes. Students should be able to interpret concrete behavioural phenomena within a broader framework of cultural differences and be able to respect those differences in their behaviour. But there is yet another layer in intercultural management: (2) *Participation* in the institutionalization of a particular business culture at the interface of different values. We can also call this: world making. We may take the craft shop in Surinam as an example once more. The students succeeded in creating a more egalitarian business culture with a transparent tracking system by means of an excel sheet, and by means of many meetings, in order to build trust. This already involves the two values of egalitarianism and trust between members of different families in a situation where in principle family is all. This made the business more effective and contributed to the success. This is the job of creating a business culture and institutionalizing particular values. It interferes in the culture and institutions of Surinam.

It cannot be predicted in advance behind a desk how such a business culture should look like. It can only be developed by trial and error, by bad luck or a lucky strike, by listening and talking. Depending on time and situation, depending on the constraints and opportunities of the particular path the institution under consideration is following, a particular institutional innovation may be possible and even imperative. Imperative, because without it the business might not survive. This is what Porter pointed out in his concept of "economic culture" (Porter 2000). Not every set of values is equally conducive to economic success. Without due planning, labour discipline, initiative etc. a business might not be competitive and not survive in the market. Not every set of values is equally conducive to economic success in all circumstances.

Another example: in many sub-Saharan countries the cooperation of different ethnic groups (and languages!) in one enterprise often appears to be problematic (Kroesen and Rozendaal 2010). How to solve that issue in a particular concrete business plan? It means that either companies have chosen to confine their membership to one tribe or ethnic group, or otherwise they have to put in place a conscious strategy of training and education to make the cooperation work and to build trust. For instance, a company might decide to have the workers trained to work at different workstations in order to mix the different tribes. The decision might be taken not to allow ethnic languages in the company and to wear the same uniforms or overalls and to install a strategy of intentional bonding between the different groups by means of identification with the company (Kroesen and Rozendaal 2010). Often also sectoral cooperation between different companies is problematic because of lack of trust. Often there is competition, but no cooperation between different companies, like there is in the Western market. This is due to the existence of closed in-groups in many African societies which results in the compartmentalization of civil society not allowing for changing coalitions and shifting memberships (Kroesen and Ndegwah 2013; Tack 2010; Kefale and Aredo 2009). This has consequences for development, for instance in that chain management for vegetables may not only require cooling, but also large-scale cooperation, also over large distances and between different companies and ethnic groups. On top of that chain management requires accurate planning and disciplined and precise labour. These are not only technical innovations, but also institutional and cultural innovations, introducing different values. It is necessary to overcome the compartmentalization and lack of trust between competing institutions. In the West it is more usual that such companies do compete, but also cooperate. Although the Western world in its neoliberal fashion talks a lot about competition, turning it almost into a gospel, often people don't even realize how much cooperation in markets and between companies and companies and government institutions etc. is the actual basis and condition for such competition. It is just taken for granted that institutions and people cooperate even despite competition. In Africa or India this is more difficult. The experience of participating during an internship in such low trust societies for a while and learning to deal with institutional compartmentalization like in Africa and also India, often helps a lot to get a deeper understanding of one's own hidden values. In confrontation with the other I learn who I am.

In short, the students have to learn how technologies, values, society and development dovetail into each other in a business plan or a feasibility study. In a sense capacity is built at both sides, the students doing the internship and their target group. Building capacity for entrepreneurship in developing countries also requires the capacity to deal with these value related institutional matters, from the side of the students. I called this earlier: participation in the institutionalization of a particular business culture at the interface of different value sets. This is also an important issue on the level the design of a concrete prototype. Even this is, as stated before, not value free. That may mean, that if the students design a prototype for low educated practitioners, they should for instance be able to take this low level of education as a design demand for easy and simple maintenance and operation of the prototype. They have to show that they can give a comprehensive account of all these aspects in their business design or product design and in the end also in their report. In that report they are also required to reflect on their own behaviour in such projects: did they operate tactically and effectively in the context they worked in? What did they learn from obstacles they met, sometimes even from crisis situations?

7 Conclusion

The comprehensive project approach presented here is illustrated by many examples, in which technologies, values and institutions interact. In these examples the insight I started with is becoming more concrete, i.e. that engineering doesn't only reduce phenomena to earlier causes, but it makes causal relationships subservient to future imperatives. Doing so it integrates dead matter into the process of life. Engineering is only partly a matter of natural science. In its other half it is part of the social sciences and its mission is that matter should not matter in reaching socially desirable objectives. In engineering *causation* (by the past, by natural causes) and *destination* (by the future, by social necessities and imperatives) meet. By the examples mentioned it also becomes clear what this comprehensive approach means in terms of capacities. Future engineers need the capacity (learning goal) of what I propose to call "planetary movement". They have to move between different value sets. They have to create bridges between cultures, bridges also between past and future. In the competition between a plurality of different values there is no good and bad, higher and lower, backwards and modern. All values have value. But these many values are in need of some higher value or meta-value that decides about their timely and temporary operation. I would consider that one value as the higher value that we all need to endorse. One categorical meta-value makes all values possible. It is the value to stop timely, and to move from one value to the other, before maintaining the prevailing line of action causes too much damage. It is the power to change timely and the power to push through only temporary. It is the value and capacity for timely change. The perception of new imperatives and needs makes us change. We have to alter our course and open new avenues into the future. And yet these new values need to be connected to and coordinated with older layers of culture like respect for the elders, valuation of the moment (instead of too much planning) and attention for personal relationships. The all-important question is: when and how long? Therefore we all need the capacity for planetary movement, (i.e. moving, derived from the Greek "plano"). In the earlier days the earth and the stars were considered to be fixed, while the planets were moving in unpredictable windings. Nowadays human beings themselves should behave like the old planets, constantly on the move and alternating between different cultural repertoires in an unstable universe. It is in such processes of continuous revolutionary change that the future is engineered. It is engineered by the capacity to communicate in a "planetary" way, moving between different value sets, creating a bridge between them and creating temporary worlds that humans can inhabit.

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The Social Entrepreneurship Option for Scientists and Engineers

Richard Hull and Robert Berry

Abstract Social Entrepreneurship education is in its infancy, especially compared with more general Entrepreneurship education, so it is not at all surprising that there is very little research into this area. Indeed, as far as we are aware there is very little practice of specifically tailoring social entrepreneurship education for scientists and engineers. This latter observation is, however, surprising, as some have suggested that a significant proportion of social entrepreneurs are scientists and engineers seeking to turn their skills to solve social problems. In addition, the funding and evaluation of scientific research increasingly requires discussion of social impact, a topic central to contemporary social entrepreneurship. Following a preliminary discussion of the recent emergence of "tech for good", we explore two central issues to be addressed in educating scientists and engineers about the complex world of social entrepreneurship: the long tradition of social responsibility amongst scientists and engineers, and different approaches to the analysis of innovation. Although the popular image of scientists and engineers is that they are disinterested neutral observers there is a long tradition of scientists and engineers becoming embroiled in the role of science and technology within contemporary society. J.D. Bernal famously aroused the wrath of Karl Popper in the 1930s with his calls for greater political oversight of scientific research, and in the late 1960s the British Society for Social Responsibility in Science engaged in controversies such as university engagement in research into chemical weapons. Social responsibility, we would argue, has long been a distinctive characteristic of many, even most scientists and engineers. Teaching them about social entrepreneurship and social enterprise will need to understand, work with and develop this tendency. The concept of social innovation, dating back to the 1990s, broadly describes developing new solutions to social problems. Scientists and engineers are of course familiar with the processes

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of technological innovation so again we have a very good potential fit between scientists, engineers and social entrepreneurship. However, many of the most effective approaches to the socio-economic analysis of innovation are based on some form of social constructionist perspective and hence potentially clash with scientists' and engineers' training. This is our second key issue. These preliminary thoughts will be illustrated through discussion of the current education about social entrepreneurship with a UK-based scientist/engineer working with a project centred on a bio-waste energy plant in India.

Keywords Social enterprise · Social entrepreneurship · Social innovation · Technopreneur · Innovation studies · Entrepreneurship education

1 Introduction

1.1 Scientists, Technologists and Impact

The last decade or so has seen much growth in UK Universitys' focus on business engagement. Most now have Pro Vice-Chancellors with business and innovation oriented portfolios typically including substantial knowledge transfer organisations. These organisations are staffed with people skilled in patent development and management and business engagement expertise, for example developing knowledge transfer partnerships (KTPs) and substantial bids for the European Regional Development Fund (ERDF). Incubation units are also quite common, supporting students and staff in the development of new companies. The focus is on translation, and most often on the translation of science and engineering research. The science and engineering schools and departments are the major beneficiaries of these investments.

Universities have long been recognised as centres of innovation and potential economic growth. Opportunities to deliver that innovation and growth are supported through a broad range of UK and EU government funded programmes such as KTPs, EPSRC doctoral training centres, ERDF initiatives for business interventions, Catapult centres and many others. The impact is good, but needs to grow and the UK is lagging in delivering on innovation—a Eurostats report from 2010 shows the UK ranked 3rd in the EU for patents filed in 2010, but only 17th for innovation (Eurostat 2015). The recent Witty review (Witty 2013) makes a number of important recommendations to further strengthen that capability with much emphasis on business engagement, enhanced investment for Higher Education Innovation Funding (HEIF), stronger engagement with SMEs, and technology translation through so-called Arrow programmes.

In 2013 HEFCE introduced significant changes in the periodic national research assessment exercise, and the most recent Research Excellence Framework exercise

(REF) has just completed. These changes require academics and their host institutions to consider impact from a much broader perspective than the traditional one of academia (e.g. through acknowledgement in peer-reviewed journal publications). The REF definition of impact is:

> For the purposes of the REF, impact is defined as an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia (HEFCE 2012)

This is significant—but for most engineers and scientists the comfortable approaches remain the traditional impact pathways such as patents, KTPs, spinouts and so on. Whilst these do not preclude social enterprise, the science and engineering research community is not particularly well prepared to even think in those terms when it contemplates or plans the impact of its research. The difficulties are in part due to a traditional emphasis on more comfortably countable and monetised activities—e.g. patents, spinouts (employment), product and a technical problem-solution focus. Benefits to society, culture, public policy, the environment and quality of life are much harder to conceive and to deliver.

Taking a broader Social Entrepreneurship and Social Return on Investment (SROI) view could help enrich our approach. Such an approach could result in real and substantial impact for much more of our research from Engineering and Science departments. This motivates gaining a better understanding of Social Entrepreneurship.

In this paper, following a brief definition of Social Entrepreneurship we first illustrate some of the issues surrounding the social entrepreneurship option for scientists and engineers through a discussion of the recent emergence of "tech for good" as a label to describe various activities using technologies specifically to address social problems. We then outline two key areas of importance and challenge in the social entrepreneurship education of scientists and technologists: the history of social responsibility in science and technology and its relevance to understanding social problems; and the development of differing and challenging perspectives upon innovation. Finally, the second half of the paper illustrates these two key areas through the lens of a case study based on the work of one of us, a highly experienced engineer working on a technology-based social innovation project in India whilst also studying social entrepreneurship.

1.2 Social Entrepreneurship

Joseph Schumpeter is often called the founder of entrepreneurship studies but he also made an even more significant contribution to the study of socio-economic change by demonstrating that capitalism is essentially restless, at its very heart and core. The internal contradictions of capitalism generate waves of change in the social, economic, technological and political arrangements, throwing up crises, problems and novel solutions (Schumpeter 1934). Social entrepreneurship is arguably one of a number of potential solutions to the current problems created by the crisis of financialisation (Hull et al. 2011).

Social entrepreneurship is a newly emergent field of study but its roots go back to the mutual aid work of Friendly Societies in the UK from the late 17th century onwards, the related reforming activities of Quaker businesses from the 18th century onwards (Weinbren 2007) and Robert Owen's development of co-operative principles in the 19th century (Cox 2010). As a newly emergent and clearly politicised field, social entrepreneurship is also subject to heavy contestation over its precise meanings and definitions (Ridley-Duff and Bull 2011).

For the sake of simplicity we will talk about social entrepreneurship as the activity of developing social enterprises, which we will loosely define as 'commercial activity that prioritises social goals above financial gain' [discussion of the many other definitions and their context can be found in Ridley-Duff and Bull (2011)].

1.3 "Tech for Good"

The last 15 years have seen a flowering of initiatives focussed on "tech for good" with a significant increase in the last seven years, especially marked by awards ceremonies sponsored by large firms like British Telecom in the UK and Intel in the USA. Many of these awards ceremonies have initially been IT-based. One of the oldest awards schemes, the Tech Awards, has been run since 2000 by Silicon Valley's Tech Museum of Innovation with significant sponsorship from local firms like Intel and Cisco (http://thetechawards.thetech.org/). Since 2008 the UK's Nominet Trust, with seed funding from Nominet, one of the world's largest internet registries, has been funding internet-based projects focussed on social change and in 2013 launched their Nominet Trust 100, a global mapping of 'tech for good' organisations using technology to tackle "big social issues" (Munford 2014).

More recently in the UK the Tech4Good awards have been run since 2011 sponsored by BT and Microsoft, again focussing on the use of digital technology for social good (http://www.tech4goodawards.com/); and in 2014 the UK's "innovation think tank" NESTA launched their own celebration of "tech heroes for good", again focussed only on digital technologies (http://www.nesta.org.uk/news/10-tech-heroes-good). Indeed, such as the attraction of the "for good" nomenclature that there is now an organisation Apps For Good (http://www.appsforgood.org/), which emerged from the Brazil-based Centre for Digital Inclusion and is focused on using technology in schools in new ways; it also runs an awards ceremony.

Broadening out there is TechForGood.TV, a web site and YouTube channel that highlights a range of technological developments including 'maker spaces' which are community-oriented workshops. There have also been initiatives to bring together professionals using technologies for social good, such as the Nonprofit Technology Network that started out in Silicon Valley in 2000, mirrored by the work of the Technology Trust in the UK.

Indeed, the blogosphere buzz around the concept of "tech for good" is so strong that there has recently been a reaction in the form of a provocative article "The rise of 'Tech for Ungood'" which explicitly sets out to challenge the "hype around 'Tech for Good'" (Miller 2015). The article was published in the UK's principle webzine for social enterprise—*Pioneers Post*—and written by the Research and Evaluation manager of UnLtd, a key UK intermediary organisation for social entrepreneurs. Finally, another key social entrepreneurship organisation, Ashoka, has recently adopted the phrase 'social technopreneur' to refer to anyone using technology for social good (Ashoka 2015) without, unfortunately, acknowledging the origins of the phrase in Pakistan (Deep Pakistan 2013).

Clearly then, there is currently extensive activity and enthusiasm for the notion of developing and applying technology for social good, with much of the activity located squarely within or on the margins of social entrepreneurship.

This phenomenon should be of considerable benefit for introducing scientists, technologists and engineers to the world of social enterprise. As always however, life is not that simple and there are a number of reasons to be cautious about this recent enthusiasm for 'tech for good', quite apart from the already voiced concerns about the negative consequences of the 'rugged individualism' of so many tech entrepreneurs (Miller 2015).

Firstly, as with nearly all socially-conscious activity sponsored by corporations (often to fulfil their Corporate Social Responsibility targets), there is a marked emphasis on implying that the activity is new or dramatically different from any previous work; there is virtually no recognition of prior attempts to achieve similar goals, except when it is to say that those attempts have failed; and there is virtually no recognition of any underlying systemic or structural causes of the social problems being addressed.

Thus for instance there is no mention of the work that the International Telecommunications Union have been devoting to enabling improved communications in developing countries since at least 1952 (ITU 2015), let alone the earlier activities of the communications workers' unions in the same areas or the extensive practical and academic initiatives within the field of development communications, focussed for over 40 years on improving communications in developing countries. Finally, there is equally little acknowledgement of the ways in which practitioners of ICT4D, or ICT for Development, have for many decades been specifically addressing the pertinent policy issues in areas like digital inclusion and expanding the use of mobile telephony (see e.g. Heeks 2009; Narasimhan 1983).

The second major problem with the recent gushing enthusiasm and activity around 'tech for good' is a problem that has beset many technological enthusiasts and evangelists; namely a lack of recognition that old technologies are often more appropriate than the latest gadget. For instance, a simple foot pump for water was one of the key technologies deployed in the early 1980s by the social entrepreneur Paul Polak through his non-profit organisation International Development Enterprises. In subsequent years this organisation has been equally focussed on finding and deploying many other basic and simple technologies alongside the enterprise skills for the subsidised marketing of the products to enable people living in rural poverty to improve their conditions (IDE 2015). In fact this organisation was mimicking the long established practice of Appropriate or Intermediate Technology that was first articulated by Fritz Schumacher in 1965 and then promoted through a variety of organisations such as the Intermediate Technology and Development Group (since renamed Practical Action—see Practical Action 2015; Dickson 1974).

Combining some of the early work in applying new information and communication technologies for social good within the workplace (especially in Scandinavia, in collaboration with trades unions) together with a focus upon finding the most appropriate technological solutions as opposed to the newest or most 'advanced' technologies, the field of Participatory Design emerged in the 1970s as a specific set of principles for engaging end-users in the design of innovations (Schuler and Namioka 1993); the ideas were belatedly taken up from the 1990s onwards, and have now been adopted by many in the field of Social Innovation (often now under the new label of 'co-design') but again with no acknowledgement of their history (see e.g. Mulgan 2013).

To conclude this section, the enthusiasm and activities around 'tech for good' are clearly a useful corrective in a world where most of the commercial development of new science and technology seems driven primarily by the short-term interests of corporate shareholders. However, although this enthusiasm and activity should potentially assist in educating scientists and engineers about the world of social enterprise, on closer inspection there are a number of deeper issues for such education raised by some of the short-comings of the 'tech for good' phenomenon, especially its lack of attention to some of the lessons learnt from the long history of socially responsible science and technology. In the next two sections we will address these issues in more detail.

2 Social Responsibility in Science and Technology

The enthusiasm and preference for new technologies over old or simple ones is often associated with a belief that science and technology have considerable power to change the world around us and indeed within us, for better or worse. That may seem to many to be a self-evident truth but it is often accompanied by the argument that it has historically been scientific and technological advances that have been the most significant cause of social and economic development and furthermore that we should only be interested in the consequences of science and technology, their effects upon society and economy, and we should not concern ourselves with their origins. Within the fields of Innovation Studies and Science and Technology Studies this view is labelled 'technological determinism' and has been characterised by the belief that science is the disinterested pursuit of new knowledge about the world and new technologies are merely the neutral appliance of such new knowledge, often achieved through individual acts of entrepreneurial skill by 'heroic inventors'. This view argues that if the proper scientific methods are employed then new knowledge will naturally arise and provide opportunities for exploitation. Furthermore, what is important are the effects of this exploitation, the effects upon society and the economy in generating economic growth or improving health, for instance; and those effects are the consequence of the inherent characteristics of the science and technology and bear no relation to their origins (MacKenzie and Wajcman 1985).

Indeed, until the 1950s there was a general belief amongst policy makers as well the scientific community that science was best left to its own devices because, they argued, being the disinterested pursuit of truth there should be no attempts to steer scientific research in any particular directions.

This view began to shift partly due to the clear ‘success’ of the development of nuclear weapons in the late 1940s, demonstrating that it is possible and sometimes desirable to steer research in particular directions. Secondly, the emergence in the 1960s of environmentalism demonstrated the woeful effects of unchecked technology-based industrialisation and prompting calls for research and development into more environmentally friendly methods and technologies. Finally, the use of chemical and biological weapons in the Vietnam war provoked many scientists to question the ethics of those colleagues who had helped develop such weapons. It was in this context that there emerged movements of scientists and technologists in the USA and UK arguing for increased social responsibility in scientific research and technological development. In the UK the British Society for Social Responsibility in Science was formed in 1969 with the strong support of well-established figures in science and technology such as Nobel Prize-winner Maurice Wilkins, Francis Crick, Lawrence Bragg and Bertrand Russell (Bell 2015a, b). Another supporter was J.D. Bernal who had argued in his 1939 book *The Social Function of Science* that specific developments in science and technology were in fact significantly affected by their social, economic and political contexts, and thus that governments should make determined efforts to steer the directions of research and development in the best interests of people and society (David 2005). This argument for science planning provoked strong reactions not least from Michael Polanyi and Karl Popper who both argued strongly for the traditional position that science and technology be left alone.

Although a one-dimensional version of “Bernalism” (David 2005, p. 8) may have been almost universally adopted, such that every government now accepts the need for some form of planning and monitoring of science and technology, there remains the deeper disagreement about the influence of society upon science and technology. Namely, to what extent does the social, economic and political context actually influence scientific and technological change? Or, to turn the question around, to what extent should scientists and engineers respond to perceived social problems in choosing their R&D?

Putting the question in this way raises issues around the ways in which social problems are perceived and understood, which in turn points to one of the significant challenges in educating scientists and technologists in social entrepreneurship. This is a challenge because most scientists and technologists are trained to look for a ‘technical fix’ in the same way that one would fix a machine—

if we see a specific social problem then we look for ways to correct the problem. Scientists and technologists are not usually trained to look at the underlying causes of social problems, which is usually seen as the job of the social sciences and politicians.

Indeed, there are some within the world of social entrepreneurship who adopt a similar approach. For example, the young US-based entrepreneur Tom Mycoskie identified a problem of disadvantaged children having no shoes in Venezuela and so set about fixing that problem with Toms Shoes and the model of “buy one give one” where, for every pair of shoes he sold, he would give away a free pair to those children. However, as many have argued, this ‘technical fix’ approach runs two risks. Firstly it ignores the underlying causes of the disadvantage and thereby merely helps to perpetuate those underlying causes. Secondly, it discourages the ability of those communities to produce their own shoes or other solutions to the disadvantage causing the lack of shoes (Joyner 2014).

One useful approach to this challenge is to distinguish between ‘tame’ and wicked’ problems, a distinction originally developed in studies of town planning (Rittel and Webber 1973). Tame problems are those amenable to quick solutions and easy wins whereas wicked problems are more intractable and entwined with other, often deeper problems. For example, a tame problem might be that too many motorcyclists were dying from head injuries following road accidents; the solution was to insist on the wearing of crash helmets. A wicked problem would be whether to enforce this legislation in the case of people such as those of the Sikh religion which requires the wearing of special head-wear incompatible with a crash helmet; or more pertinently, the example of disadvantaged children in Venezuela without shoes, where the underlying problem of poverty is clearly multi-faceted and complex and likely to have been previously addressed in many different ways. For people learning about social entrepreneurship one of the key challenges is to understand that social problems are far more likely to be significantly difficult and wicked problems and that it is necessary to understand the history of previous attempts to deal with such problems.

In the case of educating scientists and engineers about solutions to social problems, this is even more of a challenge as there is a tendency to assume that linear progress applies as equally to the social world as it does to the natural world. The default assumption is the linear model of scientific and technological progress, whereby each advance or solution to a problem represents the culmination of trial and error in all previous attempts, and therefore there is no need to understand the history of previous attempted solutions.

There are two objections to this. Firstly, it is clear that solutions to social problems are heavily politicised and subject to revision, reversal and revival—take the example of apprenticeships in the UK, which have recently been re-introduced after many decades out of fashion. Secondly and perhaps more controversially, it is increasingly argued (especially in academic fields such as Innovation Studies, the Social Studies of Science and Technology, and the History and Philosophy of Science) that the linear model does not at all fully reflect the development of science and technology; the science may become as equally politicised as social issues, for instance in climate change, and in the teaching of evolution in the USA; old rejected theories may be revived, for example in the re-emergence of Lamarkian theories in evolutionary biology; dead theories may live on, zombie-like, despite rejection by the majority of the community, for example cold fusion; and major changes in overarching paradigms, such as relativity theory or plate tectonics, cannot retrospectively be explained as linear progression. In the next section we explore in more detail some of these issues around different perspectives on innovation.

3 Understanding Innovation

The concept of Social Innovation emerged in the 1990s in the UK and referred to attempts to find novel solutions to social problems in the context of significant reductions in government spending on welfare and an increasing focus upon applying novel techniques, especially the increased involvement of the private sector. Indeed, it is partly because of this context that the notion of Social Innovation has been criticised as merely a cloak for the application of Neo-Liberalism and the steady destruction of the welfare state (Curtis and Anderson 2014). There are, however, quite different perspectives upon Social Innovation that emphasise its potential for radical social progress, for instance through increasing workplace democracy and increasing local control over economic activity (Moulaert et al. 2013; Gibson-Graham et al. 2013). Competing perspectives upon technological innovation further compound these differences.

As already noted Joseph Schumpeter made significant contributions to our understanding of economic development, and that especially included the analysis of technological innovation. Schumpeter was the first economist of the 20th century to demonstrate the notion that innovation (including organisational change) was absolutely central to economic development. However, for most of the 20th century his theories were considered to be marginal and heterodox and ignored by main-stream neo-classical economists who believed that science and technology are exogenous factors, external to the economic system, which just magically arrive "like manna from heaven" (Freeman 1994).

Indeed, although most policy makers would now accept the 'Bernalist' argument about the need for planning and monitoring of scientific and technological R&D—a logical consequence of Schumpeter's arguments—they choose to ignore the broader implications of his work (Freeman 2007; see also other contributions in Hanusch and Pyka 2007).

One of those key implications is the need to focus upon the necessary linkages between social, economic and organisational factors in the analysis of the origins and processes of technological innovation. Mainstream neo-classical economics continues to focus excessive attention only upon either market demand as 'pulling' technological change, or scientific change as ‘pushing’ it. As suggested above, many scientists and technologists also retain this view (echoed by the more conservative understandings of social innovation as being either demanded by social need or pushed by new business and/or technology-based techniques).

Neither of these approaches pays sufficient attention to issues like formal and informal regulation, industry associations, differing national systems for promoting and regulating science and technology, the role of professional associations (especially for instance in medicine and the life sciences), the labour markets for scientists and technologists, professional ethical codes of conduct, the military-industrial complex, structural inequalities for instance in gender or ethnicity, the financial and managerial dynamics of large industrial firms, etc.

By contrast, in a ground-breaking (and often misunderstood) work on the history of science, Kuhn (1962) demonstrated that even in the most abstract of sciences such as Astronomy the role of social, political (and religious, in the case of Astronomy) factors played a significant role in the ways in which new scientific theories are accepted as valid. And by the late 1960s there emerged Neo-Schumpeterian approaches to the analysis of innovation and science and technology policy which precisely argued for the inclusion of sociological and institutional analyses of the many various factors affecting technological innovation (Coombs et al. 1987). By the late 1980s a significant portion of this work focussed on the analysis of the strategies and activities of those companies most clearly engaged in technological innovation and in particular new methodologies for analysing the networks of factors and relationships surrounding specific instances of innovation (Coombs et al. 1992).

Whilst there are a variety of perspectives upon the significance of local and global socio-economic and political factors there is now widespread acknowledgement within Innovation Studies that specific instances of innovation are best understood in terms of the dynamics of specific networks of relationships, especially financial relations but also including for instance institutional and professional issues and arrangements (Green et al. 1999). There is equal acknowledgement of the central role of Neo-Schumpeterian economic analyses, especially those using evolutionary metaphors such as selection environment (see various chapters in Hanusch and Pyka 2007).

Perhaps coincidentally, and perhaps not, an analogous strand of work has emerged within studies of social enterprise which stresses the central significance of what are called the ‘eco-systems’ of support available to social enterprises, which obviously includes the different types of financial support but also the networks of relationships, professional associations, accreditation bodies, political support and trades unions (Bloom and Dees 2008).

In summary then, we have argued that there are two key issues for social entrepreneurship education of scientists and technologists. Firstly, there is a need to understand the long history of social responsibility amongst scientists and technologists and especially to understand the lessons learnt from that history of social involvement, such as the distinction between tame and wicked problems and the importance of acknowledging the political element of social issues. Secondly, there is a significant challenge to enable scientists and technologists to broaden their horizons beyond the linear model of progress, especially when it comes to analysing social problems but also analysing the dynamics of both technical and social innovation. In the second half of this paper we illustrate these arguments through the lens of a case study based on the work of one of us, a highly experienced engineer working on a technology-based social innovation project in India whilst also studying social entrepreneurship.

4 Case Study: Open Field Burning of Agricultural Waste in Punjab

4.1 Background to the Problem

The northwestern Indian state of Punjab is known as the bread-basket of India. A significant amount of the rice and wheat that is sold in India, and now exported from India to the world, is grown in this state and the neighbouring state of Haryana (McKee 2012). Farming is a major industry, and land ownership is an important part of the Punjabi culture. Land is passed from generation to generation; in spite of its skyrocketing price surrounding areas such as the Union Territory of Chandigarh (capital city of both Punjab and Haryana) farming families strive to hold on to it. The result is that most farms are quite small with an average size of about 3–4 acres.

The intensity of farming in this region imposes significant pressure on the farming community. In the Punjab, rice is typically grown from June to November, and wheat from December to April. The planting window for wheat is tight; it must be sown within about 20 days of the rice harvest; studies have shown that up to 1 % loss of output can result per day delayed beyond the optimum planting date (Mavi 2014). The rice straw remaining after harvesting must be removed before sowing wheat.

The rice straw residue is seen to have limited intrinsic value; indeed its presence is a barrier to the subsequent year's wheat crop. In southern parts of India it is sometimes collected for animal fodder, but it is poor food, being high in Silica content. If the farm is within 10 km of a green energy power plant, the straw could be collected for energy production; similarly proximity to a paper manufacturer affords a market for the straw. However, most of the straw has no market, and approximately 12 million tonnes is burnt annually in Punjab alone (Sood 2013).

The burning contributes significantly to pollution, visibility and health problems in Punjab and across the country. The problem is multiplied by all of the states growing rice, and by the open field burning of other forms of agricultural residue. In total, 93 million tonnes of agricultural residue are openly burnt annually across India (Mavi 2014).

4.2 Energy Harvest

In 2012 Aston University and the Indian Institute of Technology (IIT) Ropar initiated a project to explore alternatives to open field burning. The project was funded by the Oglesby Charitable Trust (The Oglesby Charitable Trust 2015) and Aston University (Aston University 2014), with local support provided by IIT Ropar (Dua 2013).

The opportunity to translate Aston's engineering research in the application of a thermochemical process known as intermediate pyrolysis was identified, and equipment from a then completed research project with IIT Delhi was transferred to the Punjab (Sen 2010). The EnergyHarvest project began to look at processing rice straw to produce energy products (Aston University 2014). The core idea was that by demonstrating that rice straw had value, farmers would recognise an incentive to stop burning their post-harvest fields.

Laboratory trials at IIT Ropar were conducted and found to be successful. The products of pyrolysis—biochar and combustible gas—were collected and post-processed. The gas was (partially condensed) and successfully blended with diesel; uncondensed gas and blended diesel was used to power an electrical generator set. Preliminary biochar trials demonstrated improvement in soil productivity. Field trials were then conducted with three villages in the Ropar District; in one case generating electrical power for a previously unpowered school. The next phase of the project is now underway in partnership with Punjab Agricultural University, Ludhiana to provide wider exposure to the farming community and further validate the value of the outputs.

4.3 Analysis

- **Context and Drivers for Impact**

Recent changes in UK university research funding from HEFCE have placed added emphasis on planning, effecting and describing the impact of research. This is also true for the Research Councils UK and their individual discipline-oriented funding councils. Academic impact is no longer sufficient; consequences for society, for the environment, for government policy must be considered and demonstrated.

It is arguable that this shift should suit Engineering Schools particularly well, for Engineering by its very nature sits at the intersection between science and need. In short, engineers solve problems. Ideally they do so subject to general and discipline-specific codes of conduct mandating a high degree of personal and professional ethical behaviour.

The opportunity to translate technology developed in the UK to a long-standing environmental challenge in South Asia was seen as quite compelling.

- **Challenges**

The first, and perhaps most obvious challenge faced, is the recognition that this opportunity was much more than just technically interesting. The project was initiated because of the strongly affirmative answer to the question “Do you think we can reliably pyrolyse rice straw, given its high Silica composition?” In retrospect, perhaps a more useful question would have been “What do we need to do, and what form should a solution take that would convince one individual farmer, and then thousands of such farmers in Punjab to cease open field burning?” Open field burning is very much a social issue. Any real impact will require significant changes in individual, village and state behaviour.

There are a number of examples in which leading with technology to solve problems has failed (Beder 1998). Indeed, in our meetings with local farmers we came across a very large modern power plant in the Ropar district only recently built at large cost, and with large government subsidy, in order to support the harvesting of rice straw and reduce open field burning. Rice straw was collected from local farmers and sold on to the local plant. The plant closed very shortly after commissioning; not for technical reasons, but because rice straw had been bulked up with sand by the middleman before being and sold on to the plant. Middleman corruption hadn’t been considered in the establishment of this very expensive, failed initiative.

Achieving an understanding of why farmers burn the residue; how villages view the burning; how the state and nation view the burning; of what alternatives may be available and why they are discounted; and many more questions required months of experience, watching, asking questions and discussion. At the same time we learnt that there is enormous confusion surrounding the issue, with broad disagreements regarding what actually takes place, as well as significant self-interest biasing the opinions of many stakeholders.

Trust—a key requirement for any social change—also emerged as important. The village trials were important in building trust and demonstrating value. But we also learnt that farmers have a close network. They learn from each other, and they have a great deal of respect for certain key organisations with whom we were not associated at the start of the project.

Trust plays a role at a higher level as well. We knew the project would require additional funding. Further, we began to appreciate that the project would require substantial Indian engagement. So, an understanding of Indian charities and structures was required; but most importantly we also saw the need for trusted Indian leadership.

Scale is one of the uniquely challenging and exciting aspects of working in India; it is particularly important for this project. Waste management solutions typically require that the material not be moved around extensively, else the cost of transport rapidly overtakes the value of any ultimate application. This certainly holds for agricultural residue; it is bulky, heavy and subject to rot and decay. Also, we had witnessed directly that some large scale solutions had fallen foul of corruption, and we wished to avoid that if we could.

Complexity remains an issue for the project. The technology brought from the UK is technically complex requiring specialist training. In addition to the base cost of the equipment being high, the costs of training add to the challenges of ultimately disseminating the solution at scale. The technology is also patented (by Aston University), and this adds a further dimension to the challenge of dissemination—in particular dissemination into a culture of innovative, aggressive and highly competitive small businesses with some having little regard for IP law compliance.

- **The Innovation Network**

This project operates in a complex network of organisations. Understanding and navigating this network is essential to making progress.

First, the project is sponsored and led by Aston University with funding from the Oglesby Charitable Trust. The activity in India is hosted at IIT Ropar.

The key stakeholders are

- Farmers: they need to have the rice straw removed and at the moment it is expedient to burn it. Many agree that burning is a problem; indeed burning actually costs the farmers money—they must replenish nitrogen in the soil, and water as well.
- Local community: the local communities we have met with want to see an end to the burning. However, others argue that burning doesn't take place, which is ironic at times because it is clear to any visitor that burning does indeed take place.
- State government and agencies. A number of state government agencies have been charged with finding solutions to this problem. Some of these ideas include:

  – Deep ploughing of the residue back into the soil. This is expensive and in some cases not practical. Deep ploughing requires large and expensive tractors that are not cost effective for small acreage farms.
  – Green energy plants. A number of these plants are being established in Punjab, and they are capable of using rice straw as fuel. However, transport and storage constraints mean that only farms within 10 km or so of the plant can provide material. Paper mills provide a similar pathway.
  – At the same time State government agencies have expressed interest in our project and how we can help with this challenge. However, navigating state government agendas and the realities of politics is something for which we were not prepared.

- State Universities. Several state universities are particularly important in the agricultural world in India, and it has been our good fortune to partner most recently with Punjab Agricultural University, Ludhiana.
- Corruption is, unfortunately, deeply ingrained in many aspects of Indian life. We have learnt to be mindful of the role it may play in disseminating our ideas.

- **Lessons**

A number of lessons are noted in the foregoing. Here we identify a few more explicitly.

Scale. We have resisted the state government's encouragement to scale the project vertically (i.e., by making the plant physically larger). Instead we believe that the value must be visible and tangible to the farmer who must make the decision to burn or not to burn. A number of previous large-scale projects have failed because of emergent corruption, and we wish to avoid this outcome. However, there are case studies from the world of social entrepreneurship that suggest a different way forward; in order to reach the thousands of small farms affected we will scale this horizontally (by multiplying the plants and retaining a farm-scale solution). An open social franchising approach appears most attractive (Richardson and Berelowitz 2012). We also draw on the experience of others with this approach, adopting the model of "village scale" solutions (Yunus and Weber 2011; Simanis 2012; Kalam and Singh 2011).

Complexity. The project has matured over the past few years and now has a stronger understanding of the environment in which it operates. New options are emerging as a consequence of focusing our attention on a more helpful core question: "How can we contribute to the elimination of open field burning?"

A set of simpler solutions around simpler technology is now emerging from the project and we believe these will have a better chance of adoption and wider dissemination.

Interestingly a number of these solutions digress from our original plan to apply our core patented technology to this problem. These alternatives include:

- Pelletising the rice straw for sale to power plants that are further than 10 km away from the paddy field. Pelletising compresses the straw, increasing its density and removing water content. This makes it a better fuel, and also enhances its transportability and storage qualities.
- Instead of blending condensable gas with diesel we are looking at controlled combustion of the gas to produce heat. Heat can then be applied to a number of useful agricultural purposes such as refrigeration and food processing.
- Particularly important in the consideration of these alternatives is the willingness to abandon the very technology that initiated the engagement in the first place.

Trust. We have expanded our network and partnerships to include the Punjab Agricultural University (PAU) in Ludhiana. PAU is a highly regarded academic institution that provides advice to farmers about farming techniques, new crops, new equipment and so on. We recognised a need for a partner to help with designing, conducting and sharing results from the agricultural trials of biochar. A bonus of this partnership is that PAU holds two Kisan Melas (Farmer Fairs) every year to which tens of thousands of farmers attend. It is an ideal way to reach many of these key stakeholders with our findings, and they will receive these findings with a particularly high degree of trust since they will be coming from PAU.

5 Conclusion

A key lesson from our experience is the value of social entrepreneurship education for engineers. We believe that in the context of growing pressure for Research Impact this could provide a means to ensure that a number of projects will have a much stronger chance of actually making a difference. In contrast to the prevailing view of impact and investment recovery through Intellectual Property (e.g. patents) and commercial partnership exploitation, we believe social entrepreneurship opens up wider avenues for Engineering Schools and Departments to have global impact.

Many of the challenges faced by this project are a consequence of working in a different culture. But whether in India or East London, the translation of technology to address social challenges will share a number of these challenges, and Engineers interested in making such impact would greatly benefit from a grounding in social entrepreneurship history, structures, policies, frameworks and practice.

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Re-inventing Engineering Curriculum

Rao Bhamidimarri

Abstract The strengths and weaknesses of the traditional engineering education in the context of today's industry needs has been a focus of the professional institutions and learned societies over the last decade. The need to broaden the engineering curriculum to equip engineering graduates with skills and attributes for them to succeed professionally, to foster creativity and innovation and to thrive in a multi-disciplinary context is recognised. The role of engineers in revitalising national economies has also been discussed widely. This paper captures the results of research undertaken with support from industry. A conceptual model for engineering curriculum is proposed incorporating design thinking and business skills. The undergraduate engineering curriculum at London South Bank University was redeveloped based on these concepts. The curriculum philosophy is discussed and the implementation of the redesigned curriculum is reported.

Keywords Curriculum innovation · Skills · Graduate attributes · Conceptual model · Design thinking

1 Introduction

The challenges of this century are profound and wide ranging. Health and well-being, water, energy and food are the foci as the population approaches 9 billion. This will require creative and innovative engineers, who can not only set the agenda for the industry of the future, but also have the leadership and business skills for implementation. Thus the primary mission of the 21st century engineer requires redefining, embracing sustainable development.

Engineering profession has traditionally focused on technical and professional knowledge, and skills for decades, contributing to a step change in wealth creation

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and improved standard of living across the world. These improvements have been primarily achieved through the mission of harnessing the powers of nature for the benefit of mankind. However, as the global grand challenges of sustainability, climate change and resource depletion are better articulated, the non-technical factors; social, environmental and ethical; are increasingly recognised to be integral to the engineering profession. At the same time, in a competitive economy, the business context is vital. In today's globalised market place, the career success of engineering graduates and that of their employers demands that the graduates are also creative and innovative. Thus, engineering education can no longer continue to be limited to the study of engineering science, measurement, modelling and synthesis of these.

The potential challenges faced by the US were discussed in the report by the National Academies (2005), which identified a way forward for increasing the quality and numbers of science and engineering graduates for the US to retain its leadership in the global economy. In the UK, the Royal Academy of Engineering articulated the areas for development in engineering education through their reports, Educating Engineers for the 21st Century (2007) and Engineering Graduates for Industry (2010). The Confederation of British Industry (CBI) identified not only a serious shortfall in the numbers of engineers required by the UK industry, but also pointed to the gaps in graduate attributes sought by the employers (2012). The skill gaps identified in these reports vary from basic functional skills such as literacy, numeracy, communication and team working to higher level skills including research and analytical abilities.

There have been various initiatives in engineering colleges in the US, UK, Australia and some European countries to address the skills gaps. One such example is the iFoundry at University of Illinois at Urbana-Champaign (www.ifoundry.illinois.edu), which offers courses in business and leadership for engineering students as well as an innovation certificate. Olin College received the first group of students in 2002 and developed a novel engineering programme in partnership with the students (Goldberg and Somerville, 2014). Many other engineering institutions introduced modules in business and entrepreneurship either as part of the engineering curriculum or in addition to the core curriculum.

2 Leadership and Management in Engineering Industry

The engineering and technology companies were established and led by scientists and engineers until the middle of 20th century. This is because engineers have a practical and pragmatic orientation, analytical problem solvers and architectural thinkers. With the growth of business schools over the last five decades, however, the top roles have been increasingly filled by people with finance and commerce education, although there are increasing numbers of companies hiring engineers as CEOs in recent years. Aquino reported (2011) that 33 % of the S&P 500 CEOs had engineering education. A recent survey by Harvard Business Review (2014) reported that 10 out of the 50 best performing companies have an engineering education.

The perception that engineers are technical "geeks" with limited social and business skills continues to hinder the career progression towards the leadership roles. The traditional engineering curricula provided limited or no opportunities for the development of leadership, people and financial management, communication and other "soft" skills, whilst equipping the graduates with strong analytical and problem solving abilities. In view of the emphasis on technical content, undergraduate engineering curriculum offered limited opportunities for fostering creativity and innovation. These limitations are increasingly being recognised the educational institutions, employers and the professional engineering institutions.

An analysis by this author of the leadership of the engineering and technology firms in New Zealand in revealed that 7 out of 10 engineering and technology companies were headed by individuals from professions other than engineering and technology. The CEOs were typically from finance professions. Further investigation revealed that the industry leaders, who were educated as engineers, invariably had further education and training in management or entered their family businesses following graduation as engineers.

Over the last three decades, Silicon Valley provided an environment for technology start-ups led by engineers to develop into high technology multi-national companies. Many of these CEOs subsequently moved to head up other companies. Several of the engineers who moved into leadership roles typically supplemented the engineering education with an added MBA or executive management education. However, the bolted on management education has not always proved successful as this approach does not bridge all the identified gaps and not all engineers who pursued this option have succeeded in translating the business management knowledge into engineering context.

3 What the Employers Want

In order to assess the engineering graduate attributes sought by the employers, 320 business and industry leaders were approached. The people approached occupied chief executives, presidents, directors, vice-presidents and managing directors. A simple questionnaire was designed to gauge the employer expectations of current and future engineering graduates. 71 completed questionnaires were returned representing 22 % response rate. The survey tried to consider inherent and learnt, technical and non-technical attributes. This was followed by one to one interviews with 30 selected respondents representing the entire spectrum of the engineering businesses in terms of scale of operation, turn over and profitability.

Of the companies that responded, over 50 % employed 200 or more people with 13 % employing less than 20 people. 38 % of the responding companies have an annual turnover of over £10m with some over a billion pounds, with an additional 21 % of companies having an annual turnover between £2m and £10m. The businesses of the respondents ranged from chemical manufacture to aerospace and defence, from construction and consultancy to product innovation and design, and from low cost manufacturing to high value added products.

73 % of respondents held the positions of Chairman, Vice-President, Chief Executive, Regional and Group Directors. The rest of 19 questionnaires were completed by people holding positions ranging from Business Development Director to Personnel Director.

Maximising profits was the primary business objective for 42 % of the respondents, while 28 and 22 % identified increasing market share and technological innovation respectively as their second priority.

The following personal skills and attributes that were seen as particularly important (Fig. 1):

- Communication skills
- Commitment
- Motivation
- Confidence

Being responsive to change and having the ability to thrive in a challenging environment were also noted as important as self-confidence (Fig. 2).

The preferred business skills were identified as commercial awareness, financial and people management, and sales and understanding market awareness skills. Of the technical and professional competencies problem analysis, critical evaluation, project development and delivery, and the application of the engineering techniques and tools were preferred.

It is interesting to note that only one respondent identified risk taking as an important attribute while work experience was seen as important in employing engineering graduates. This may be because the questionnaire and the interviews focused primarily on employers views on fresh engineering graduates entering the companies.

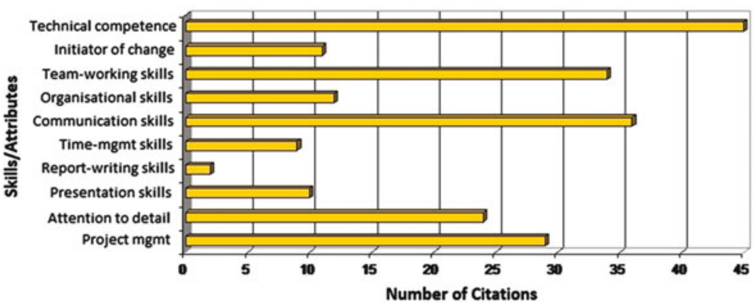


Fig. 1 Skills and attributes the employers expect the engineering graduates to learn through the programme of study

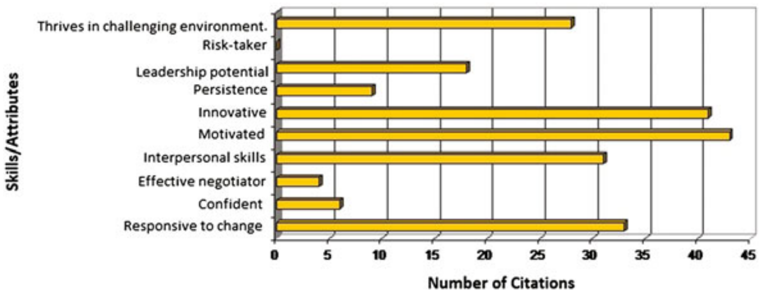


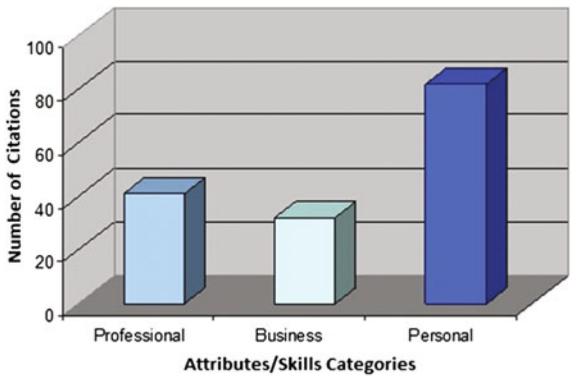
Fig. 2 Generic and inherent skills and attributes sought by employers

4 A New Approach to Engineering Education

The research programme considered the inputs from the industry leaders and the published information on the qualifications of the CEOs of engineering businesses as well as the career progress of engineering graduates. Extensive cross analysis of the feedback from the questionnaires and interviews was carried out. Published information on the CEO's educational background and the company performance was also considered. Curriculum innovations being mooted in engineering schools internationally were reviewed and visits several of the engineering schools were undertaken. The survey revealed that the personal attributes of the graduate engineers were seen as more important compared to professional and business competencies (Fig. 3).

Based on this research, a multi-disciplinary approach to engineering curriculum is proposed in this study.

Fig. 3 Key qualities the employers feel the current engineering graduates lacking



5 Curriculum Philosophy

The research conducted into entrepreneurship education revealed that over half of the higher education institutions in the UK offer courses in entrepreneurship primarily in the context of business education. An estimated 10 % of all students in higher education undertake elements of entrepreneurship in their programmes. Vehicles to promote entrepreneurship education have been developed. An example, the Scottish Institute for Enterprise promotes programmes such as the student intern programme, a social enterprise challenge, an international enterprise summer school and master classes in entrepreneurship for students in higher and further education. While these programmes have brought entrepreneurship into focus in higher education, they remain business education rooted and are commonly bolted on to the core discipline based curricula.

Focus on creativity and entrepreneurship in most undergraduate engineering programmes however, has not developed beyond optional modules being made available to students. There are several universities offering postgraduate programmes with an entrepreneurship focus. The Hunter Centre for Entrepreneurship at the University of Strathclyde makes several undergraduate and postgraduate modules available to engineering students. A number of other institutions including Nottingham, Sheffield, Warwick, Imperial and UCL also courses that the students can choose to opt to study alongside their primary discipline based programmes. London South Bank University offers a customised postgraduate programme in enterprise.

Internationally, Germany has had established programmes for several decades in "economic engineering", which attempted to integrate business and engineering. More recently, MIT and Stanford have led the development of programmes that attempt to integrate engineering and entrepreneurship at postgraduate level. The enterprise focus in engineering education also has emerged in several other US universities such as Lehigh, Maryland and North Carolina. The Republic of Singapore has invested substantially during in the last decade in innovation and enterprise leading to enterprise focussed academic activities, particularly in engineering and technology at National University of Singapore and Nanyang Technological University through additional modules and seminars on entrepreneurship.

However, it is increasingly recognised that optional modules in the undergraduate engineering curriculum are unlikely to foster the attributes thought to reflect entrepreneurial activity.

In 2002, with a substantial gift from the Frank Olin Foundation in the USA a specialised engineering college was opened to offer an engineering curriculum that takes into account the attributes increasingly sought by the employers in new engineering graduates. This is an example where attempts are being made to integrate undergraduate engineering curriculum with design, communication, business and entrepreneurship studies. While the curriculum at Olin incorporates the elements of active, project based learning and interaction with industry, much of the learning remains elective-based. Subsequently, several other universities and colleges such as Georgia Tech and Greenfield Coalition of colleges and universities initiated activities to introduce entrepreneurship in undergraduate education.

6 An Innovative Engineering Curriculum

The primary objective of redesigning the undergraduate engineering curriculum is to facilitate the development of future engineering leaders, who not only have a thorough knowledge of engineering analysis and design principles, tools and techniques, and synthesis of elements of relevant knowledge but also have gained an appreciation of business, social and environmental contexts of engineering. The ethos of life-long learning is to underpin the education process in order for the graduates to capitalise on the emerging opportunities in a rapidly changing technical and global environment.

6.1 Cornerstones of the Curriculum

- **Design** thinking will play a key role in the development of engineers to be creative product innovators and problem solvers. This plays a key role developing skills to integrate technical and non-technical knowledge through the study of design processes and contextual issues. This is achieved through specialist and embedded design studies throughout the programme.
- **Engineering** discipline studies will focus on principles of engineering science, engineering mathematics and integrative technology studies and will develop analysis, measurement and modelling, synthesis and problem solving skills.
- **Business and enterprise** studies will focus on the study of the principles and tools in finance and business management in order to develop commercial awareness. Ability to identify opportunities and create value added products and services will be achieved through the study of real time case studies and modules on entrepreneurship and enterprise development.

The author developed a conceptual model bringing together the key curriculum components of knowledge to foster innovation in engineering education. This is shown in Fig. 4 and depicts the contribution of each of the component to an integrated programme that equips engineering graduates to operate effectively. The programme of study developed and implemented based on these principles not only equips the graduates technically and professionally, but also prepares them with creative abilities and business acumen. The graduates with the relevant multi-disciplinary education with a strong self-directed learning are likely to be better placed to progress into management and leadership roles in the modern engineering business environment.

7 Implementation at London South Bank University

The author led a fundamental review of the engineering curriculum at London South Bank University in 2012 and redeveloped the curriculum based on the model shown in Fig. 4. A key objective of the curriculum change was to transform the curriculum to one that is student-led. The industry is rapidly embracing digital technologies and ability to think, design and innovate in a virtual environment is increasingly important. Therefore an integrated virtual engineering environment including digital design and prototyping facilities was developed and established to enable all engineering students to gain experience in designing and operating in a virtual environment.

Two new substantive modules were introduced and these are (1) Design and Practice, and (2) Innovation and Enterprise for students in all engineering programmes.

1. **Design and Practice**:
   This module requiring 330 h of student learning focuses on creative thinking and problem solving techniques including mind mapping and brainstorming; conceptual design and synthesis. These techniques are linked to practical work ranging from experimental design, undertaking investigations, analysis and interpretation of results progressing to prototyping and model building. Organisation, team working, oral and written communications and presentations are also learnt through this module.

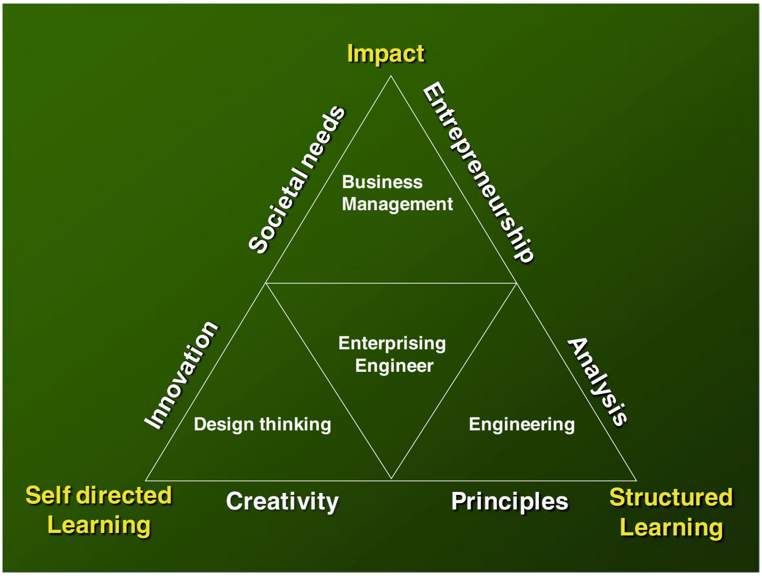


Fig. 4 Curriculum structure for fostering enterprise in engineering education. © R. Bhamidimarri, 2014

2. **Innovation and Enterprise**:
   In this module requiring 150 h of student learning, the students study innovation and enterprise processes for development of ideas into financially viable and profitable businesses, including opportunity specification, market research and testing, design methods and processes, project and operations management and financial evaluation. Development of a business plan and a business strategy, innovation and intellectual property management are also studies as part of this module.

I addition to these mandatory modules, the study of project management is introduced across a range of courses.

The distinctive feature of the curriculum is reflected not just by the content but the way the curriculum is implemented. The personal attributes and "soft skills" that the industry leaders identified to be lacking in the current engineering graduates are embedded through the learning and teaching and assessment methodologies across the curriculum.

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The Impact of EngD—Dynamics of Collaborative Relationships Through Employer Engagement in Doctoral Research Training

Fumi Kitagawa

Abstract The important role of doctoral engineers as the next generation of scientific and technology leaders, who will underpin the competitiveness of the industry base, has been recognised among international R&D stakeholders and policy makers. In the UK, the Engineering Doctorate (EngD) programme was established 20 years ago as a scheme distinct from, and complementary to, the traditional PhD. The EngD is differentiated from PhD programmes as it expects doctoral researchers (Research Engineers: REs) to work closely with industry, by helping researchers acquire industry relevant skills as well as industry based research experience, while based in a company. This chapter draws on a pilot study conducted in 2013, which investigated the various forms of impacts resulting from EngD programmes—including the perceptions of business partners who fund research projects and host the REs, and the career destinations of the former REs. Four key routes to impacts are proposed as a conceptual framework in order to understand the variety of impacts of the collaborative doctoral training.

Keywords Engineering doctorates · Employer engagement · Innovation · Skills · Human capital

1 Introduction

The important role of doctoral engineers as the next generation of scientific and technology leaders, who will underpin the competitiveness of the industry base, has been recognised among international Research and Development (R&D) stakeholders and policy makers. In this light, this chapter examines one of the collaborative engineering doctoral training schemes in the UK, where industry sponsors directly engage in research training through collaborative R&D.

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It is pointed out that firms involved in collaborative research with PhD students 'rarely have very high stakes' in the research carried out by students working at the universities, particularly when the nature of the research tends to be academic (Thune 2009). In order to make engineering doctoral training more relevant to industry needs, the Engineering Doctorate (EngD) scheme was established more than 20 years ago, following the recommendations from the Parnaby report (1990). In the case of the EngD, collaborative projects are always industry driven. The EngD is a postgraduate research (PGR) programme, financially supported by one of the UK Research Councils. It differs from a PhD programme as it expects doctoral students, who are called Research Engineers (REs), to work on projects which are industry-based. The first EngD Centres started in 1992, and the EngD programmes are known as one of the long standing collaborative research training mechanisms between academia and industry in the UK. Recently the EngD scheme went through major changes as part of the reform of broader doctoral training programmes. The scheme was renamed as Industrial Doctorate Centres (IDCs) in 2009, and then integrated as part of the Centres for Doctoral Training (CDTs) in 2013. However, the key feature of the scheme still remains. The REs spend majority of time within industry (about 75 % of the 4 year EngD programme) instead of carrying out research at the university. The REs also take taught modules on industry and business relevant skills, and build industry based research experiences.

This chapter is based on a pilot study conducted in 2013, which aimed to identify a variety of forms of impacts of the EngD programmes (see Kitagawa 2015 for backgrounds and contexts of the study as well as findings). The study started by asking: *In what ways can the interactive and multi-dimensional nature of the impact of the EngD scheme be best captured?* The analytical frameworks and possible methodologies to identify and evaluate actual evidence of impacts from research and training are diverse. This chapter develops a framework through which multiple forms of impacts from the collaborative relationships are captured. Methodologically the pilot study adopted exploratory and mixed methods. One of the objectives of the study is to identify available data-sets and appropriate methodologies in order to understand the complex processes and contexts of impacts. By triangulating data from different sources, the study aims to enhance understanding of the accumulative nature of the impact of the scheme over the years from multiple perspectives.

The following sub-questions are asked in this chapter:

– What do we know from the existing data and evidences about impacts related to the EngD projects?
– What are the perceived impacts from industry sponsor's perspectives?
– What do we know about destinations and career progressions of the EngD graduates, and what are the key differences between the EngD and other PhD graduates?

The remainder of this short chapter is structured as follows. Section 2 explains the research design and evaluative methodologies adopted in the pilot study.

Section 3 presents the key findings from the study highlighting impacts in relation to industry perspectives and career development. Section 4 sets out conclusions and identifies recommendations for future studies.

2 Evaluative Methodologies

There have been a number of recent studies that aim to quantify and measure the impact of collaborative research programmes based on certain tangible outputs or outcomes (see DTI 2007; de Campos 2010). The evaluation methodologies in general range from pure quantitative to pure qualitative and mixed techniques (Salter and Martin 2001). Butcher and Jeffery (2007) give a cautious note that measures of success which rely solely on tangible products can generate an 'incomplete picture of achievement'. Understanding impacts from collaborative relationships between university and industry requires an approach going beyond tangible outcomes. Conceptual as well as methodological frameworks with a more specific focus on processes (see Lowe 2013; Upton et al. 2014) are needed. This would require contextual understanding of interactive processes between actors as well as changes in the organisational and individual behaviour (Rogers et al. 2012).

As already mentioned, this study originates from a pilot evaluative study designed and conducted in 2013 in collaboration with the Association of the Engineering Doctorates (AEngD) and the Engineering and Physical Sciences Research Council (EPSRC) in order to develop a conceptual framework and identify methodological approaches that help capture the impact of the EngD scheme. The impact of the EngD scheme has been evaluated over years through several channels, including experts' reviews and externally commissioned studies. There have been attempts to identify quantifiable 'financial benefits' and 'economic impact' of collaborative schemes including the EngD and other publicly funded collaborative research schemes (PA Consulting Group/SQW 2007; see also DTZ/EPSRC 2011). These studies are based on earlier EngD Centres, not including the recent IDCs. There was also recognition that whilst the unique benefits of the EngD scheme is widely recognised by both academic and industry stakeholders, impacts deriving from the interactive nature of collaborative relationships are not captured through hard evidence.

As explained in the pilot study report in detail, there is a number of literature and evaluation reports published over the past 20 years that this study could draw on. Key findings from the studies on impact from academic research and research training can be summarised as follows (Kitagawa 2015):

- A number of routes from research to impact come through *innovation processes*.
- Impact from academic research and research training occur through the *movement of skilled researchers* into industry or to other research organisations.

- In terms of human capital development, there are *different types of skills and knowledge* formed as an outcome of university-industry sponsored collaborative R&D and training schemes.
- *Networks and linkages* are catalysed by the university-industry sponsored collaborative schemes.
- Research impact may occur due to the *behavioural changes*.

Synthesising the review of literature, relevant evaluative reports, and drawing on other desktop research, the "EngD routes to impact" framework was developed. Figure 1 illustrates the framework in a schematic way: inputs, outputs, outcomes and routes to impacts at the EngD scheme level. Assessing the economic impact is one and limited way of understanding the EngD impact. A broader range of routes to and forms of impact is captured in the rest of this chapter. The indicators include direct inputs, outputs and outcomes from EngD programmes—new resources, 'added value' including qualifications (e.g. Chartered Engineers), intellectual property rights (IPRs), and identified 'business impact'; knowledge production measured by the number of peer reviewed publications, research capacity building measured by the number of students trained, networks and interactions, policy or product development and wider economic and societal benefits, including increased productivity and GDP growth.

The pilot study aimed to identify existing data-sets in order to identify impacts of the EngD scheme. Data sources for the pilot study included a number of different

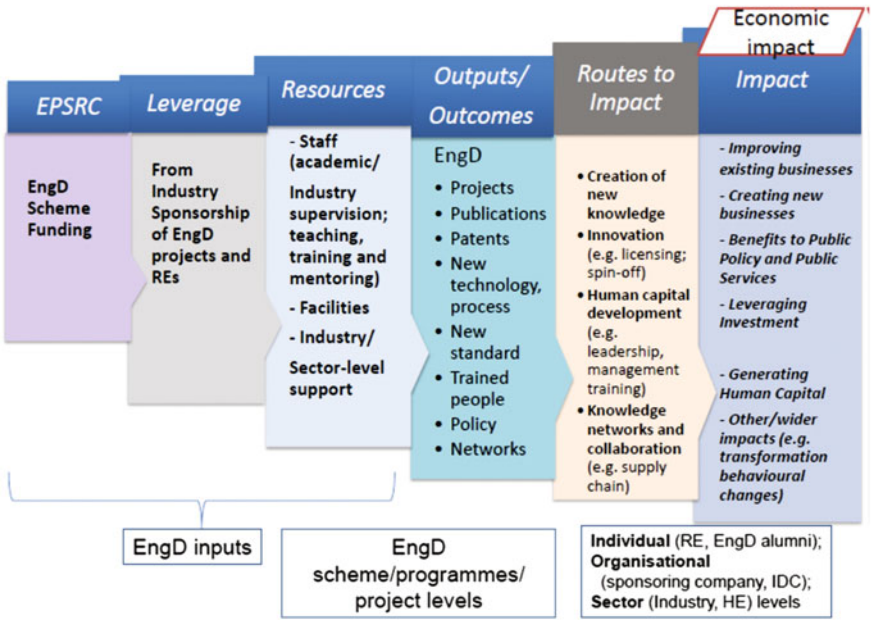

Fig. 1 The EngD/IDC routes to impact framework (*Source* Kitagawa 2015)

forms. Firstly, the mid-term self-evaluative documents (submitted to EPSRC as of May 2011) provided by 18 IDCs funded under the call in 2009 were analysed in order to identify common frameworks for analysis. Secondly, semi-structured interviews were conducted with 35 individuals who have direct experiences of the EngD programmes, including 20 EngD alumni and 15 industry partners. Whilst the data-sets collected in the interviews were relatively small and limited in terms of the generalisability, efforts were made to include the diversity of the contexts to be represented in the study—industry sectors and different types of IDCs across the UK. Thirdly, in order to supplement interviews, the destinations of the EngD graduates was analysed using the Destination of the Leavers from Higher Education (DLHE) survey available from the Higher Education Statistical Agency (HESA). In the following section, key findings from these different elements of the study are presented. These include extracts and summaries from the project report (for details, see Kitagawa 2015).

3 Key Findings

3.1 Framework Identified from the IDC Mid-Term Reviews

A number of common types of impacts, experiences and themes emerged during the analysis, and differences between individuals, organisations and sectors were also demonstrated. In summary, the four types of routes to impacts are identified based on the interviews with both industry partners and alumni, as well as the analysis of the mid-term self-evaluative documents.

Generation of new knowledge leads to increased in-house knowledge and research outcomes in the short-term, and a long-term approach to technology problem solution and business change. Standard formation and policy change based on knowledge generated from the EngD projects are long-term routes to impact, leading to sector-wide and/or broad social change.

Innovation-related and commercial routes to impact include *new product/service development*, *new market entry*, *improvements to business processes* and *cost savings*. Licensing of patents and the formation of spin-out companies are other impact routes to commercialise the EngD projects.

Human capital and skills development routes include: (1) individual RE career paths developments; (2) organisational absorptive capacity development at the industry partner; and (3) the sectoral-wide impact by creating a pool of skilled talents.

Knowledge networks and collaborative relationships: EngD projects provide benefits at an industry-wide level which could not be captured by one company alone. Knowledge generated by one firm often diffuses into the industry as a whole through collaborative relationships and open innovation, through supply chains or through movement of human capital.

3.2 Industry and Alumni Perspectives

Interviews were conducted between June and August 2013 with 35 individuals who volunteered to share their views and experiences on the EngD projects and programmes (see Kitagawa 2015). The interview findings provided evidence to the conditions, forms and routes to the impacts which supplement the findings from the documentary analysis. Many of the industry respondents have had close engagement with IDCs/EngD Centres, for example, being an active member of the advisory board of these Centres. According to the interviews with the industry sponsors, the EngD programme is seen as a unique scheme and supported by the industry partners because of three main reasons:

1. the “portfolio of the projects” compared to the specialised nature of the PhD;
2. the time REs spend within the industry, which is much longer than the PhD and
3. the direct contacts and control industry partners have over the nature of the project.

Many industry interviewees expressed that they have greater control over the EngD projects than PhD projects, and therefore have a stronger sense of ownership. From the industry’s point of view, the collaborative R&D of the EngD scheme is characterised by the access to excellent academic research and interactive opportunities, combined with a variety of forms of engagement, including the use of facilities at the universities, opportunities to consulting senior academics, and access to wider research networks as part of the EngD/IDC programme. The nature of the EngD projects are mostly applied in nature, and often based on industry problem solving. Direct and face to face relationships and spatial proximity (e.g. use of facilities) seem to matter in certain collaborative contexts.

There are some financial incentives for firms to participate in EngD/IDCs, as it is relatively cheap to work with doctoral students financially supported by the EPSRC. In order to ensure that their agendas are shared, EngD/IDC management committees typically consist of a mixture of academics and industrialists who have some projects with the university. They try to optimise training opportunities for doctorate students under the EngD/IDCs. For an industry partner in certain engineering sectors, for example, the IDC scheme helps to attract engineers to the sector at a time when labour market competition for graduates is very intense. For small R&D intensive companies, having REs is seen as significant additional manpower to the research capability of the organisations.

Whilst the findings of the interviews are limited in terms of generalisability, they provide views of the firms with experiences of the EngD projects with certain diversity in terms of sectors and size. The impact of the EngD is recognised as sector-wide, beyond individual projects and technologies. Some IDCs have developed networks and relationships between firms, acting as the ‘core part of the R&D supply chains’, by providing technical expertise, sharing equipment and providing training courses. These are examples of a strong sector-based ‘open innovation’ approach.

3.3 Overview of Graduate Destinations

In order to better understand the factors and processes that influence the skills and human capital development, destinations and career trajectories of the EngD graduates were examined, through national data-sets available under the UK DLHE survey data. This section summarises the key findings from the DLHE survey data analysis drawing on the pilot study report (see Kitagawa 2015 for the data-sets and methodologies).

The DLHE survey collects data of the UK and EU domiciled graduates from the UK higher education institutions (HEIs) six months after qualifying from their higher education course. For the purpose of the study, the EngD graduates' records were provided by the EPSRC and matched by the HESA with the DLHE survey data of doctoral graduates. Due to the consistency issue of the data set, which makes the comparison across years difficult, the EngD graduates data presented is small. Data on three cohorts of students—125 EngD graduates (2008/09–2010/11 academic years combined) was matched and made available for the pilot study. An equivalent set of data on Industrial CASE PhD graduates funded by the EPSRC was also made available. Industrial CASE PhD studentship is another form of collaborative doctoral scheme and the student must spend at least three months at the partner company/organisation. It should be stressed that the main purpose of the analysis is *not* to compare these different types of doctoral programmes, but to illustrate various contexts of impacts related to the doctoral programmes with varying forms of industry collaboration.

For the three year cohorts examined, EngD graduates' destinations demonstrate some of the characteristics of the scheme and the nature of the impact that are distinguished from those of other science and technology PhDs and the Industrial CASE. In terms of the employment six months after qualifying from the course, 91.2 % of EngD graduates are in Full-time paid work (including self-employed). This compares favourably to Industrial CASE graduates (79.6 %), Other PhD (all disciplines) (73.9 %) and Other S&T PhD (principal subjects A-K) (78.8 %).

There is a question in the DLHE "How did you find out about this job?" Relatively higher number of the EngD graduates found their jobs through "Personal contacts, including family and friends, networking" or "Already worked there". 24 % of the EngD graduates found a job as they "already worked" there (including but not necessarily the sponsoring firm), which is higher than Industrial CASE graduates (10 %) and Other PhD (all disciplines) (16 %). This could be a result of the different lengths and extents to which the students are engaged with the future potential employers during their doctoral training forming networks and social capital.

In terms of the sectors of the employment, 85 % of the EngD graduates work in non-Education sector—32 % of EngD graduates work in "Manufacturing", 27 % in "Professional, scientific and technical activities", 15 % work in "Education" sector. Whilst the EngD scheme primarily intends to train students who want to work in industry, the career dynamics of the EngD graduates include mobility across multiple boundaries—between academia and industry, between industry firms, between sectors, and sometimes between national boundaries.

In terms of the graduates' geographical destinations and sectors of employment after the EngD programmes, there is a regional variation. In London and South East the EngD graduates work in a broad range of sectors including "Professional, scientific and technical activities" "Information and communication" "Human health and social work activities" as well as "Education" whilst majority of graduates in East Midlands are employed in "Manufacturing" sector, reflecting the industry characteristics of each of the region.

Salary data in the DLHE is limited in terms of the size of the samples available. It is difficult to draw a general conclusion from the salary data presented here and careful interpretation is required when using the information. From the preliminary analysis, the findings suggests positive impact for the EngD graduates—for those who are in full-time employment, 33.3 % of the EngD graduates earn more than £35 K per year. This compares favourably to other PhD graduates. An earlier study (PA Consulting Group/SQW Consulting 2007) also demonstrates that the EngD graduates earn higher salary than the comparable PhD graduates. Further comparative information needs be sought on salary benefits between EngD alumni and cohorts of otherwise identical individuals (e.g. those who hold PhDs instead of EngD post graduate qualifications; those who had worked in industry over 4 years after undergraduate qualifications or Masters qualifications) (see PA Consulting Group/SQW Consulting 2007).

4 Discussions

The EngD scheme provides a unique model of employer engagement in doctoral research training. The impacts and benefits of the scheme has been recognised over the years. The key findings of the pilot study, "Understanding the EngD impact—a Pilot study", which is summarised in this chapter, demonstrate the impacts from direct interactions and people mobility.

For industry partners, different forms of collaborative R&D relationships through the EngD projects and the programmes lead to both tangible (e.g. publications, patents, new technologies, products) and intangible (e.g. enhanced technological knowledge, enhanced skills and knowledge of existing employees within an organization, strategic relationship with other sponsoring firms, research networks, sector-wide policies and strategies) forms of impacts. It is important to position the EngD/IDC scheme and any other collaborative doctoral programme as part of the broader spectrum of the R&D eco-system, and to understand the reason why the industry partners choose to participate in the specific programme above all other collaborative R&D channels. From the industry's point of view, the collaborative R&D of the EngD scheme is characterised by access to academic research and interactive opportunities, combined with a variety of forms of engagement including the use of facilities at the universities, opportunities to consult senior academics, and access to wider research networks as part of the EngD/IDC programme.

The evidence seems to suggest relatively higher impact of EngD graduates in terms of career development and progression (e.g. management career; higher salary; professional qualification) than other PhD graduates. Career development and pathways of the former REs are diverse where different forms of EngD impacts are embedded, including technology and product development, continuing collaboration with the universities, and networks across the industry partners. For example, there are a few cases reported in the IDC mid-term review (2011) where former REs acting as industry supervisors for EngD projects, continuing direct interactions between the Centres and industry partners. In particular, the EngD programmes have provided unique employer engagement opportunities in research training for those who already had a number of years of industry career before the doctoral training. A recent study on manufacturing research argues that EngD doctoral researchers work at the frontiers of 'innovation, substantial and varied industry problem-solving experiences, and insights into future challenges (and opportunities)', and the scheme contributes to training and developing 'the next generation of science and technology leaders' (O'Sullivan 2011).

Doctoral students may help industry in reducing uncertainties in innovative activities and raising 'absorptive capacity' by acquiring, assimilating, transforming and exploiting external knowledge (Zahra and George 2002). This provides the key challenge in measuring and evidencing the impact of the scheme over the years. The methodology adopted in this pilot study has a number of limitations and the findings need further verification. Interviews were limited in terms of scope and representation. Existing data on the career destinations and progression of collaborative doctoral graduates is limited. We need to better understand the dynamic processes of technology and skills development through a variety of forms of employer engagement in research training (see CBI 2010) and diversity of career development (see Viatae 2012). Broader data sets such as the number of co-publications, co-patent applications, combined with social network analysis (see Youtie et al. 2013) may provide more information and analytical tools in order to identify and track career trajectories as well as the variety of collaborative relationships formed through the collaborative doctoral training scheme between academia and industry.

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A full report is available on the website of the EPSRC and AEngD (Kitagawa 2015).

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Embedding Enterprise and Innovation in STEM Education

Sa'ad S. Medhat

Abstract Devices get more powerful. Connectivity reaches ever further. Speeds get quicker. Data gets bigger. Technology is disrupting virtually every aspect of life and work, from 3D printing, cloud computing and advanced robotics to biotechnology and human genomics. This is a dramatic change, and it calls for a more flexible and agile workforce, able to move between various disciplines and industry sectors. This paper attempts to address three key interrelated questions. How can we prepare students for a future that is impossible to predict? How can the learning environment enable this change to take place? And, what are the role for the lecturers? Last year NEF: The Innovation Institute did a piece of policy work called ***Inventing the Future: transforming STEM economies***—this included think-tank meetings and surveys (Inventing the Future: Transforming STEM Economies 2014). More than 100 leading STEM-based organisations were interviewed about their current and future skills requirements. In our survey, a mere 16 % of companies said that their skills needs were being fully met. At the other end of the spectrum, 32 % said that finding people with the right skills was a serious struggle. This is the current situation; but what about if we look forward ten, five or just two years? What kind of competencies will students need then? The answers are eye opening.

1 The Changing World

Android developer. Data scientist. User interface designer. Big data architect. Cloud services specialist. These roles barely existed in 2008. Today they are some of the fastest proliferating job titles among LinkedIn's 250 million users (Confederation of British Industry 2014).

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The world of work is changing, and the pace of change is accelerating. Technology is the defining factor to this change but underpinning this factor is the way in which technology is being applied, and this is something that can't be easily predicted. The internet of things and cloud computing have transformed many industries. In coming decades areas such as robotics, digital fabrication and biotechnology will further revolutionise the way we live and work.

Jeff Dobbs, KPMG's global sector chair of manufacturing says on the rate of change: "The manufacturing world is entering an era of hyper-innovation where advances in technology and material science are rapidly changing what we consider 'possible' and creating new business opportunities along the way. Ultimately those organisations that do not balance investment in 'incremental innovation' with investment in 'breakthrough innovation' may find themselves left behind technologically."

Forecasts of the future can only be tentative: it will be some years before we fully understand the effect of disruptive technology and breakthrough innovation on the workplace and society. New technologies may quickly replace those that seem radical today.

Irrespective of their stage of economic development, countries are placing an increasingly higher value on STEM (science technology, engineering and mathematics) education as a means of encouraging innovation to drive up national living standards.

For example, in South Korea, advances in education, particularly tertiary education, have played a significant role in the country's economic growth since 1960. Today, approximately two thirds of South Korea's output growth can be attributed to knowledge accumulation rather than labour or capital. The country now shares a similar challenge to many of its neighbours as well as countries in the West: how to sustain or accelerate growth as the population stabilises and ages. Only innovation will solve this and many of the major issues of the twenty first century.

This poses an enormous challenge for our education system. The debate on how to make technical courses more relevant to industry is aired on a regular basis. But this is being eclipsed by a much bigger question: how do we prepare our students for a future that nobody can predict? How do we create a generation of workers that are flexible, adaptable, and innovative?

Over the next decade twelve areas of expansion are predicted, and shown in Fig. 1. These are technology areas, not sectors, and in that fact is the realisation that sectors themselves are changing rapidly. The boundaries around traditional scientific disciplines are dissolving: many of the most exciting developments of research, product development and manufacturing are fuelled by the convergence of disciplines.

To deep-dive into one of these areas, for example advanced robotics, the expanse of developments and the impact on numerous sectors is immense. In the world of robotics, there are myriad of exciting possibilities opening up both for the home and the workplace. The driverless car has caused excitement but the immediate application is the AI technologies emerging in new car design. These technologies deliver 'assisted driving' to reduce the risk of car crashes caused by human error. Telepresence robots 'a Skype on wheels' are already being trialled for application in

Fig. 1 Twelve technology areas of expansion

the care sector, to support independent living, care monitoring and delivering back pictures in real time of resident to a care worker or relatives. The advent of drones for delivery or surveying is well publicised in everything from construction, agriculture to courier services and web retail.

In using technology across sectors, there are the consistent economic drivers of the need to reduce size, weight and power consumption. Solutions or products that achieve these three fundamentals will gain market dominance. Application of technology to meet such goals requires a different skill set, beyond technological capability. New skills portfolios will include creative problem solving, analytical skills, multi-disciplinary working and innovative thinking, but as the business landscape changes and companies joint venture, merge or become acquired, other skills will needed as well to support that innovation aim. Julian Hellebrand, Executive Vice President, Lifecycle and Programme Management for Cobham says on the new softer skills: “Employing more than 10,000 people on five continents, Cobham has grown organically and through the acquisition of some 50 companies in the past decade. So our employees also need to be adept in the so called softer skill areas such as partnership building, client engagement and communications.”

2 Preparing Students for Unpredictable Future

The day of a job for life is over. Students of the future, once they graduate will experience portfolio careers, some with established companies, although many will be establishing businesses themselves. Enterprise learning therefore, has to be inculcated into programmes and courses as standard. The accent on technology, not just in the subject matter but in how the content is delivered needs to addressed. Technology will become ever increasingly incorporated into our lives, defining our actions, and by this notion, everyone will be a technologist.

Currently, our education system is not delivering future technologists, and the potential for the entrepreneurial mind-sets are not being fully developed. Still too much emphasis is placed on to getting a job rather than developing an opportunity. The process of education is seen as linear, like a production line, turning out a product, shaped to be something from the perceptions, occupations and technologies of yesteryear. Education in this form can't continue. Its proliferation is the reason for the massive STEM skills gaps experienced (Murthy 2014).

It is recognised by the companies and futurologists alike that through the advancement and drive of technology, the educational level and competencies will shift dramatically. For example a school leaver a decade down the line will be expected to achieve an educational level and competency equivalent to HND students today. Educational redevelopment today is vital to support such a shift. Such redevelopment will need to embrace ***better use of technology***, implementation of ***T-shaped technologist learning model*** and application of the '***design for learning***' ***methodology*** in course design, development and delivery. Through these three measures, the T-shaped technologist of the future will be able to be nurtured and shaped.

Better use of technology in education will be addressed in more depth in the Learning Habitat section of this paper. However, the general point to note here is that technology-based learning will become, by necessity, more sophisticated, with learning and assessment methods tailored to the individual, rather than whole course cohort needs.

The ***T-Shaped Technologist Learning model*** enables courses to be designed so that they develop in students a range of transferable professional abilities, personal qualities and technical skills that will support their future progression, and drive their aspiration for enterprise development. These three areas are identified in the Fig. 2.

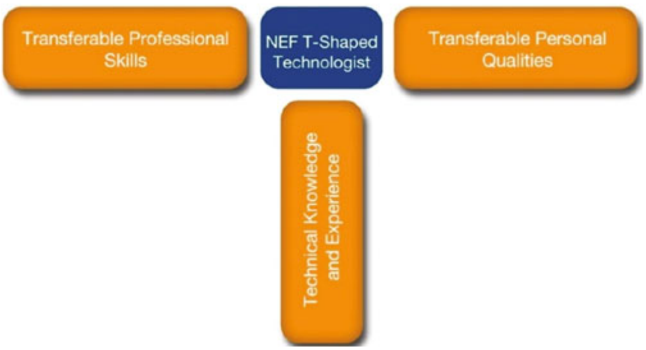

Fig. 2 T-Shaped Technologist Learning Model

Across the top of the 'T' are the overarching professional skills and personal qualities:

- **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.
- The bottom of the 'T' provides the robust underpinning support of technical knowledge and application that extends beyond a siloed discipline. **Technical knowledge and experience**—including "know-how", those good, practical skills, but importantly also the "know-why", a sound understanding of STEM theory behind practice;

At the heart of the T-shaped Technologist learning model is *five core* principles to support development of new framework for learning and assessment:

1. Success has to be based on real measures of the attributes students develop through the educational process. These measures will encourage development of a range of intelligences (not just in a small band), and the measures focused on will be positively placed to what students can do across these three areas (Technical, Professional and Personal) as opposed to what they can't do—a state that immediately builds barriers to future development for a student. By building into programmes the development of technical skills and competencies, attributes and behaviours that are valued by employers, students are provided with real opportunities, and a means to demonstrate these capacities;
2. The focus has to be more outcomes-defined thereby moving away from an obsession with 'outputs' and into a focus on the impact of education on communities;
3. Education moves towards the support of 'deep or long-term' learning, where lecturers are facilitators and coaches, with a good understanding of STEM, industry and new technologies, and versed in the art of understanding the young;
4. Skills are demonstrated in different and work-based settings, as a means to ensure that new skills have been acquired and can be practised by the student;
5. Applying knowledge to new situations is the ultimate form of effective assessment of learning.

Throughout these principles, innovation in both delivery and subject matter design should be weaved as the golden thread that connects all areas.

3 Design for Learning

The ***Design for Learning*** methodology identifies twelve guiding principles for curriculum developers to consider when developing new educational courses and programmes, to ensure effective learning transfer, instead of just teaching takes place. The difference being learning transfer happens when an association, meaning and relevance is given to the information being delivered. This enables the information to be encoded, and therefore the learning 'transfers' from the short-term to the long term memory via the hippocampus thus internalising the knowledge, and making it more valuable to the student.

Design for Learning principles can be regarded as synonymous to ingredients in a good recipe that help to make courses that are memorable, real, fun, meaningful, accessible and that cultivates a confidence and sense of self-achievement in students.

All the ingredients in Design for Learning (Fig. 3) inter-relate and interact to develop a self-aware student ready for tomorrow's challenges.

1. ***Multi-platform Access*** encourages open innovation and collaboratory approaches to course co-creation and co-assessment with industry partners.
2. ***Flexible delivery*** focuses on course unitisation through different delivery modes and formats, thereby making the learning accessible to students when and where they need it.
3. ***Adaptive learning*** that uses brain-based approaches to adaptive path development to enable students to follow different paths and to pace their learning to reflect their individual intellectual capability, supported by learning technologies to narrowcast learning and assessment requirements.
4. ***Interactivity*** in the course, delivering an element of fun and purpose to the learning. Through the use of such learning technologies as augmented reality to

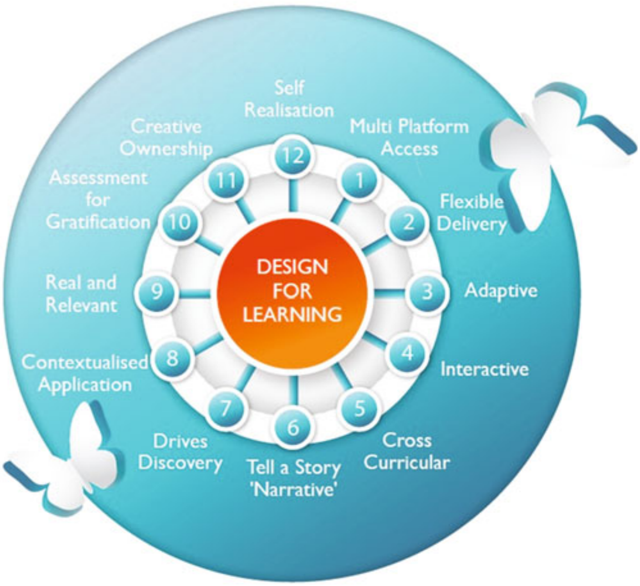

Fig. 3 Design for Learning

create real-life scenarios and simulations for the student, thereby engaging the kinaesthetic 'doing' aspect to the learning, and supporting the learning transfer.

5. ***Cross curricular*** focus that combines several disciplines, enabling for development of more interoperable skills that will support career mobility in their future employment path (people can move more easily between sectors and roles).
6. ***'Telling a story' or narrative***, which builds that critical association with the subject and events that have meaning and relevance (so important for that learning transfer).
7. ***Discovery*** should be built into course design that facilitates students to make their own discoveries and establish meaningful long term memory connections as they learn.
8. ***Relevancy*** requires that genuine data or real life scenarios should be used in the classroom and workshop. For example: Nova Labs in the USA is providing high school students with the same data that NASA provides to their professional researchers to help track tropical storms. They are mixing fascinating narratives around storm stories with big data to create a new kind of educational tool. In this way, high school students are able to compete and collaborate with professional researchers, scientists and engineers.
9. ***Context*** in course design is essential to enable students to develop an awareness of how their learning can be applied across different sectors, applications and situations. Engagement with business and industry is a necessity to build case studies and give reference to real application of theory: e.g. how a mathematical equation is used within a construction context.
10. ***Assessment for gratification***, which uses gamification techniques of continual feedback to build confidence and competence in the student. The use of gamification will enhance the validation of learning. For example, international education company Kaplan has developed a gamification platform which, it says, can boost student grades by 9 %.
11. ***Creative ownership*** opportunities need to be built into course design. Creativity is a practical skill and needs to be encouraged and developed in students. Courses need to be designed so that they include techniques to help students think differently. To explore new angles, and solve challenges that have a real and relevant context themselves. Collaborative creative problem-solving activities facilitated by lecturers, supports the drive to discover, improves the student's self-esteem and heightens motivation—a key component in transferring learning to long term memory.
12. ***Self-realisation*** and self-awareness form the foundation of personal growth and success, and new course design has to recognise this as a goal for the student. Self-realisation is a skill that can be developed in students, leading to a greater sense of achievement, optimism and giving them confidence that they are ready to move on to the next level of study, or embark upon their chosen career path. This makes for a more rounded and professional student.

4 A New Role: The Technologist

It has already been stated that the student of tomorrow will have a precursor to whatever career path they chose, and that will be a technologist. Effective use of technology, T-shaped learning and incorporation of design for learning methodology will shape a more innovative and enterprising individual who will have the following:

- An adaptive ability that helps to respond quickly to technological change
- Able to operate in different sectors and contexts with confidence, in response to demand
- Higher functioning capabilities in:
  - Digital
  - Logic
  - Design, and
  - Interaction
- A good level of dexterity and sensory skills
- An entrepreneurial mindset, able to imagine or invent new applications for products or technology in different sectors

The key to developing the technologist of the future will be an educational system that achieves in melding all of the above qualities into someone who is also naturally innovative, forward-thinking and possessing of a strong business acumen. Innovation and enterprise are therefore the very tenets that will define the success of an educational programme in STEM.

5 The Learning Environment

Methodologies and models are important, but unless the learning habitat is right, the other two will fail at the starting block. In developing the learning habitat, two things have to be recognised: (a) students learn things at different rates, and, (b) technology is already changing behaviours and attitudes at a speed never before seen.

Ask any parent and they will tell you that even babies and toddlers interact with tablets and smart phones. Young people innovate online, build apps and interact with sophisticated gaming software. There is evidence that new technology is impacting on the very circuitry of neurological responses in our brains (Frey 2012). At the very least it is having a huge impact on new business models of cooperation and collaboration that are becoming natural to young learners.

A learning habitat that supports and develops such students' needs to incorporate a good balance of technology, techniques and learning styles as shown in Fig. 4. Current education is not embracing the possibilities of technology, and for a

Fig. 4 Learning Habitat

learning habitat that enables adaptive learning to flourish, a structural rethink of the educational eco-system is required. This means a change in the mind-sets, models and approaches that transform the learning experience for the individual learner must be considered.

6 Concluding Remarks

Today, there are two primary goals for educators. Firstly, is to produce people who have the right abilities, who can contribute to society and the economy, and who can fulfil their own potential. Secondly, is to provide replacement for the rapidly aging workforce across many of the economic sectors. The following recommendations are aimed at educators, business leaders and policy makers to consider as enablers for enterprising innovative learning.

For Educators

- Co-design, co-accredit and co-deliver to overcome expert teachers' shortages and promote innovative brain-centred learning
- Optimise learning and scientific literacy by establishing a specific research function that undertakes horizon-scanning frequently to enable inextricable linkage between pedagogy to technology and use this as a transfer function to a catalyst to drive learning improvements

- A renewed focus on "Learning" that embraces flexibility and cross-curricula provision. This would require better teacher/lecturer training in areas of innovation and enterprise

For Industry

- Provide better forecast of skills and employment needs (new and replacement demand characteristics)
- Aggregate demand in the supply-chain and through active partnerships provide better student workplace experience (e.g. Apprenticeships)
- Co-fund and co-develop educational programmes and regional infrastructure
- Second industry experts to colleges and universities to influence or run technical and scientific departments

For Government

- Ensure constructive alignment between supply and demand, and quality and funding by providing local/regional horizon-scanning annually
- Establish an apolitical "Educational Charter" with a national guiding principles supported by regional economic development actions that support enterprise development
- Redefine the educational levels and avoid using "levels" as proxy for funding nor linking age to learning ability.

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Transition: Influence of Role Models on the Progression from Student Life to the World of Work

O. Folayan, P. Enegela, Y. Bankole, I. Colombo and N. Folayan

Abstract Research conducted by Engineering UK (Engineering UK Report, State of Engineering 2013) and other sources (Royal Academy of Engineering. http://www.raeng.org.uk/policy/diversity-in-engineering/what-is-diversity) indicate that people of black and minority ethnic origin (BME) are underrepresented in technical apprenticeships/courses and in the engineering profession (6 %). On this premise, it stands to reason that an even smaller proportion of active and successful role models exists not least because visibility and access to said role models is limited. The positive correlation between a role model's influence and a young person's career choices is very well understood but few established Science Technology Engineering and Mathematics (STEM) mentoring programmes have been targeted specifically at BME communities. This paper describes key aspects of the Transition programme, a talent retention scheme which aims to provide young engineering graduates and apprentices with a realistic lens into the engineering industry. Transition is a series of talks, seminars and workshops designed to prepare young trainees and university students for progression from student life into the world of work. It provides an avenue for students and graduates to meet key industry contacts, share questions, knowledge and experience of working in various sectors of Engineering.

Keywords Transition · Ethnic minority · Engineering · Role models

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1 Introduction

Ethnic minority communities make up circa 12 % of the total working population in the UK and it has been projected to double within the next 50 years.[1] Ethnic minorities in the UK represent a younger, growing marketplace; 1 in 5 pupils in state-maintained secondary schools in England is from an ethnic minority background (Schools, pupils and their characteristics 2014). Similarly, in state maintained primary schools, 1 in 4 children is of minority ethnic origin (Enegela and Ekpiri 2014).

In 2007 in response to the publication of numerous articles about educational failure of young black men in the UK and against a backdrop of reports about increasing gang membership, low aspiration and underachievement, the UK Government initiated an independent study examining the aspirations and attainment of black men (REACH Independent Report 2007). The report highlighted the fact that many male children specifically of black origin are without positive role models. A separate study completed the following year by the cabinet office social exclusion task force which looked more broadly on attainment amongst young people in deprived communities in general highlighted that even families with high levels of aspiration amongst these communities still had a low degree of attainment amongst them[2] (Strand 2007). These findings are corroborated by another survey carried out by the University of Warwick (Jones and Elias 2005) which consolidated information from the Labour Force Survey (LFS) and the Youth Cohort Study of England and Wales (YCS), with data from the Higher Education Statistics Agency (HESA). The survey revealed that members of certain BME groups are significantly less likely to work in a Science Engineering and Technology (SET) occupations than other groups. All of these studies emphasised the need for positive role models whilst stressing the role of community level social structures and the voluntary sector in helping to increase both aspiration and attainment at all levels of education and vocational training.

One of such voluntary organisations is AFBE-UK, a nation-wide network of professional engineers which has worked for years with community groups, inner city schools, colleges and other industry stakeholders to help inspire young people of BME origin to consider engineering as a career choice. The organisation which was formed in 2007 also works with higher institutions of learning and apprenticeship to help young people make the successful transition into working life. The elements of the Transition programme discussed in this paper provide a model that enhances talent retention whilst ensuring continued attainment above and beyond the confines of a classroom or lecture theatre.

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[1]Ethnic minorities will make up a third of Britain by 2050, Policy Exchange. http://www.policyexchange.org.uk/media-centre/press-releases/category/item/ethnic-minorities-will-make-up-a-third-of-britain-by-2050.

[2]Report on 'Attainment amongst young people in deprived communities' Cabinet Office Social Exclusion Task Force, 2008.

2 Statistics

The under-representation of women, those from certain ethnic minority groups and people with disabilities in Science, Technology, Engineering and Mathematics (STEM) occupations is well documented (Jones and Elias 2005; Booth et al. 2008). There is also evidence of under-representation of people from lower socio-economic groups amongst those applying for STEM degrees although more research is required cf. footnote 3. Similarly, an entire school of thought is dedicated to diversity in management academic literature and the recurrent conclusion is that a lack of diversity has a negative impact on the competiveness of businesses (Higher Education Statistic Agency 2012).

An illustration of a typical engineer career progression is provided in Fig. 1. The flowchart traces the engineer's passage from secondary education, through the formative years of their career to their transformation into a seasoned professional. The depiction of the engineer's journey shows the various developmental phases of the engineer's journey to professional success. It also highlights the hurdles facing

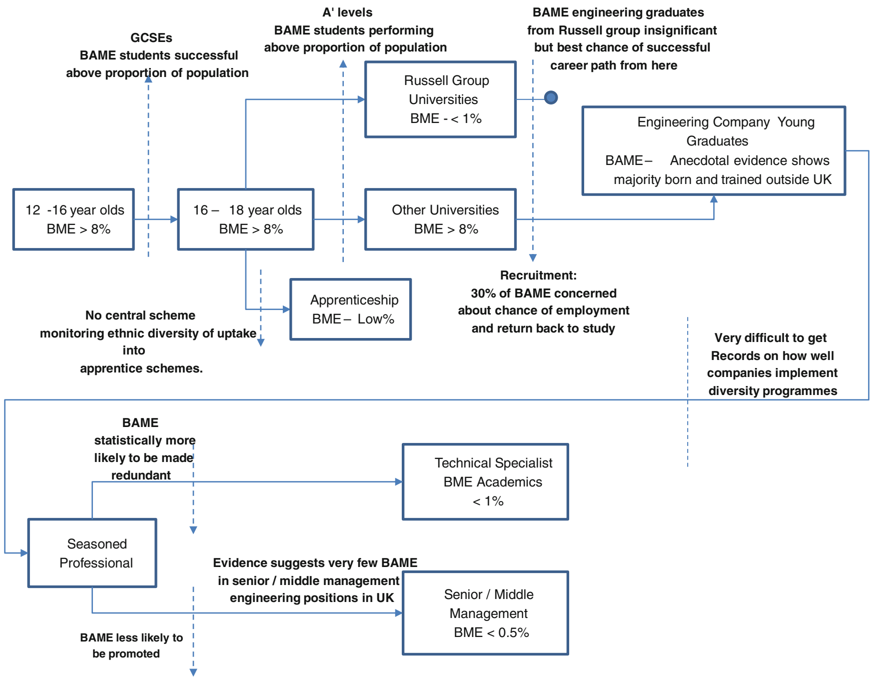

Fig. 1 Flowchart of BMEs in engineering career progression

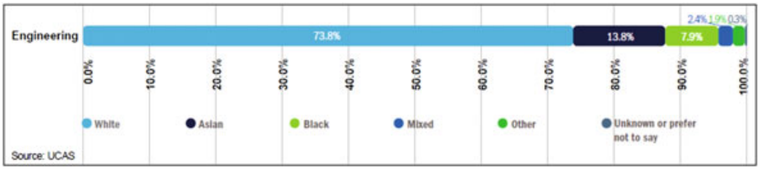

Fig. 2 Breakdown by ethnicity of applicants across HE subject areas (2011/12)—UK domiciled (Engineering 2013)

BME groups going through the UK educational system and identifies a low proportion of (<0.5 %) BME individuals in Senior/Middle Engineering management.

A survey carried out by the Campaign for Science and Engineering (CaSE)[3] revealed that the proportion of BME students studying relevant STEM subjects at A′ level is significantly higher than other ethnic groups. This data suggests that there is an equal level of interest in STEM subjects and that the aspiration for progress amongst these communities was not hampered by socio-economic factors.

This level of aspiration and even achievement at tertiary education level is evident not only by the number of applications made to engineering courses but also by the number of completed Bachelor's degrees. As an example, the 2011/2012 academic year Universities and Colleges Admission Service (UCAS) statistics show that BME students account for about 20 % of candidates applying to study Engineering at university. Figure 2 shows the full ethnic breakdown of applicants for the Engineering discipline.

The survey also reveals that BME students accounted for 25 % of the 13,680 engineering first degree graduates from the same academic year. Despite this high percentage, an analysis of the annual destinations of leavers from Higher Education found[4] that black or minority ethnic graduates were 31 % more likely to return to university (for post-graduate study) than their white counterparts. Whilst some of this is further evidence of higher aspiration held in these communities, it is also thought to be due in part to the perception held by BME graduates that their career options are limited. This suggestion agrees with the findings of a study by Booth et al. (2008) at the University of Salford in which BME undergraduates' concerns about whether or not their ethnicity would affect their career prospects affected their career choices after their degrees. Although the primary effect of the study carried out by the University of Salford pertained to graduates leaving the area, there is a clear contrast in the careers paths of prospective engineers of BME origin compared to other groups.

[3]Improving Diversity in STEM A report by the Campaign for Science and Engineering (CaSE) May 2014 (http://sciencecampaign.org.uk/CaSEDiversityinSTEMreport2014.pdf).

[4]Destinations of Leavers from Higher Education https://www.hesa.ac.uk/index.php?option=com_pubs&task=show_pub_detail&pubid=1708&Itemid=.

The Engineering sector is vital to the UK's economic growth accounting for 19.6 % of GDP in 2009. However, entry into the sector has continued to decline.[5] The projected future demand for engineers coupled with this drop in uptake in engineering positions further emphasises the important role experienced professionals can play in raising awareness of the opportunities available and the various pathways that exist for those wanting to develop a career in Engineering.

A survey conducted by AFBE-UK revealed that most young people feel that their educational experience would be improved by learning through creative activities and positive role models from their own communities (Bibalou et al. 2012). A lot of the participants, many of whom were engineering students of BME origin said that they would choose other sectors after university without first fulfilling their potential in engineering. This too was due in part to difficulties encountered in finding employment in engineering after graduation.

Furthermore, the adjustments that needs to be made by hired graduates from the learning at university to application in the workplace is significant highlighting the need for industry engaged learning. Wood and Kaczynski (2007) make a strong case for graduates' lack of work-readiness. They state categorically that, "few university graduates are prepared for the realities of work with even fewer displaying the skills necessary for success in gaining employment" (Wood and Kaczynski 2007).

It is in order to contribute to industry-engaged learning and to make students and apprentices work-ready that programmes like Transition are not just helpful but vital.

The Transition programme allows university students to engage with and learn about opportunities within the industry before they graduate. It also provides a link in the steps vital to becoming a successful engineer, bridging the gap between successfully completing an engineering degree or apprenticeship and getting off to a good start once employed in the industry.

3 Transition

After making a career choice, the obvious next step is to actively pursue career opportunities. Unfortunately, it is often the case that young graduates and other individuals who are new to any specific job market often overlook the essential aspects to be covered in facilitating a good kick-off to that new career such as having a detailed resume/CV, researching interview skills and understanding what qualities the employers will be looking at before making an offer.

At this stage, immense effort and sacrifice would have been made to successfully qualify as a graduate engineer and the reward of such labour should soon become

[5]The Experience Gap (The unspoken skills gap), http://www.nce.co.uk/Journals/2015/03/11/s/l/d/The-Experience-Gap-FP1.pdf, March 2015.

apparent. The graduate, however, still faces unique challenges. Relevant employment, appropriate remuneration for the effort, societal pressure etc., all still exist and it is imperative that assistance is provided to aid graduates in job placement, mentoring advice especially from experienced Engineering professionals. Many prospective candidates who may be suitably qualified to fill a role remain on the job searching path, either because they have failed to make a good enough impression about themselves to get their feet in the door. Transition definitely addresses these issues and proffers solutions to challenges faced by job seekers, as there is direct engagement of prospective candidates (Enegela and Ekpiri 2014).

Aberdeen, the energy capital of Europe, is home to two reputable universities: the University of Aberdeen and Robert Gordon University (RGU). Every year, around 30,000 (home and international) students drawn by the quality of teaching and research in both Universities visit Aberdeen and it is here that the Transition programme began.

The core objective of Transition is to provide an avenue for prospective interview candidates to identify errors they could potentially make at various stages in the job search. Naturally, the candidates either devise methods of enhancing their prospects from the feedback they are provided, or take on board "tips" passed to them by the professionals with whom they interact during the event.

A typical Transition event is split into the following 3 activities:

- A CV review
- A mock interview
- Group case study.

During the CV review, industry professionals assess the quality of university student's CV and direct feedback is provided to the student. The assessors highlight areas of the CV which could be more detailed, and assist the candidate to identify skills they may have missed out which would enhance their employability.

The mock interview presents the candidates an opportunity to answer competency-based interview questions posed to them by a panel of assessors. Emphasis is laid on a structured approach to the questions, which enables the candidate answer the questions asked using a "story" that describes the situation faced, task to be completed, actions undertaken and results obtained.

With the current trend in Human Resources Acquisition and Talent Management, it has become a common practice to assess an individual's ability to work in a team, manage time and other colleagues' expectations, or emerge as a leader from a leaderless group. In the assessment centre, the candidates are split up into groups in which they work in a team to solve a problem. Real-life challenges surrounding business or engineering decisions are presented to the candidates in order to assess their decision-making abilities under pressure, as the time provided to read, understand and digest the data/information provided is limited. The assessors then evaluate to each candidate during the group discussion, identifying areas of strength and weakness based on a list of competencies being sought.

The structure of the event is such that an individual can identify why he/she had probably not made the interview shortlist, or fell short of expectations at an interview/assessment centre. The assessment centre provides an excellent avenue for such evaluations to be made; the AFBE aims to provide real-life challenges to the candidates in order to assess their decision-making abilities under pressure. Candidates gain practice in interview/assessment centre strategies. They also understand potential shortfalls when faced with a real assessment centre activity.

Networking is one of the most important and effective career development tools that an individual can use throughout their professional career. Networking is a skill that can be learned and refined throughout an individual's career.

Transition provides opportunities to engineering students to meet and interact with industry professionals and experts with emphasis on BME engineers in senior positions within the in engineering sector. As role models, these experts will be able to exchange their knowledge and talk about their experiences and pathways to success in their respective industries. Employability skills as students embark on careers are also promoted at these events.

AFBE Scotland has successfully run Transition events at various venues in Aberdeen. So far, over 200 students and entry-level professionals have had the opportunity to be part of this preparatory process, which has yielded positive results for some of the attendees in terms of interview invitations and securing jobs. Transition has therefore become a popular event amongst university students in Aberdeen, as it provides a confidence boost to prospective interview candidates and it is hoped by the AFBE that Transition will be yet another phenomenal export from Aberdeen to other parts of the UK.

4 Summary

There is a great need to address diversity and sustainability challenges in Engineering by promoting engineering to people from underrepresented communities in the UK. There is limited research information on the current situation of BME engineering graduates which is reflected in the difficulty in finding ethnic diversity data post-university graduation. In addition diversity in engineering senior/middle management level is bereft of BMEs individuals (Refer to Fig. 1). Further study is required to determine career progression of potential young BME engineers after graduation.

Engineering graduates need to be "industry ready" not just in terms of technical abilities but also business skills (such as communication, team work etc.). Exposure of university students and graduates to industry at an early stage can enhance their aspiration and improve their preparedness for the industry.

Transition addresses the lack of understanding and information on what being an Engineer entails in real terms by providing role models (at professional levels). Giving university students access to role models within their chosen disciplines and ultimately aiding engineering university students to make the transition into the engineering industry.

The beneficiaries of Transition include university engineering students who are encouraged to gain a sense of belonging in the industry and made aware of ways of accessing job opportunities and being entrepreneurial within the industry. Transition encourages these students to look beyond conventional notions of possibility by showcasing examples of engineers from ethnic communities who have been successful in their roles.

The benefits of Transitions are not limited to the university students but also the industry professionals and experts involved. It allows the industry to engage with communities and understand what the intrinsic barriers are for these communities to enter and work within Engineering.

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Use of Industrial SME Based Problem Based Learning to Promote and Embed Professional and Enterprising Skills

Plato Kapranos

Abstract In our rapidly changing world, the need for engineers has never been greater; even through the current economic downturn; companies in the United Kingdom cannot find enough local engineering applicants to fill their vacancies. That should be good news for the employability of our engineering graduates but it's not as simple as that, as more and more our engineering graduates have to differentiate themselves from the competition by demonstrating their transferable skills; this in general is true for other countries of the EU, US, Canada and Australia and to a lesser extent for China and the Asian subcontinent where personal connections still play a major role in finding employment. In the Centre of Doctoral Training (CDT) in Advanced Metallics, jointly run by the Universities of Sheffield and Manchester, a coordinated effort has taken place in the design of a Diploma in Personal and Professional Skills that CDT cohorts of students undertake in parallel with their PhD studies. This Diploma involves the cultivation of a multitude of skills that professional engineers use on their daily tasks such as communication, networking, leadership, project management, time management, problem solving, arranging and facilitating meetings, dealing with conflict, or Health and Safety issues, protection of Intellectual Property, ethical issues, to name but a few. In the process of embedding some of these skills to the professional conscience of our CDT students, we have devised with the help of industrial partners a Problem Based Learning (PBL) experience in the form of a two week long exercise at participating SMEs. During this time, the groups of students have to deal and solve 'real problems' set by the participating SMEs, under realistic conditions and strict time deadlines. The students are given little support by the academic staff and as much information as required by their SME counterparts and quickly learn the value and use of good communication, networking, group task allocation, time and project management, as they set out to deliver solutions to the problems posed. The students act as 'consultants' to the SME companies over the period of two weeks, at the end of which they deliver their solutions to the scrutiny of academic supervisors,

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SME managers and their peers, in the form of a formal report and presentations. Over the last three years that we have delivered the SME PBL exercise, we have seen increased motivation on the part of the students, development of professional attitudes towards their task, and the practical use of the transferable skills that the Diploma sets out to deliver. A harmonious synoptic learning experience appears to have developed through this exercise bringing together the embedding of transferable skills in a clearly identifiable contextual situation that generates engagement and motivation for the students and satisfaction and confirmation to staff and industrial partners that the newly trained cohorts of engineers will have the skills so much sought after by the UK industry.

Keywords PBL · Transferrable · Enterprising and professional skills

1 Introduction

One thing that can be said with certainty about today's world is that it is in a state of constant flux and that the rate of change around us is rapid and steeply accelerating; almost exponentially. We can say that the only thing that is constant is change itself. This is nothing new of course, over 2500 years ago the Greek philosopher Heraclitus observed that '*Everything flows and nothing remains the same*' ('Τὰ πάντα ρεῖ καὶ οὐδὲν μένει'), but what has dramatically changed since is the rate of change.

So how are we to educate our engineering students (although I will direct my approach to engineering but clearly there are parallels for all disciplines) not only to be able to cope with rapid change but to thrive with it; use it as a source and a springboard for innovation and progress? The Accreditation Board of Engineering and Technology (ABET) defines engineering as follows: "Engineering is the profession in which a knowledge of the mathematical or physical sciences gained by study, experience and practice is applied with judgement to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind".[1] Clearly, then the starting point is and remains that as countless students before them, today's and tomorrow's engineering graduates not only will have to grasp the basic tenets of science and engineering, which unless something very dramatic occurs will not change in the foreseeable future, but unlike previous generations they will have to have a much more acute sense of flexibility of mind and approach, combined with resilience and passion to 'get the job done'.

Engineers use their analytical skills, their imagination and creative problem solving capacity to invent, design, and make things that work for us or make

[1] http://users.ece.utexas.edu/~holmes/Teaching/EE302/Slides/UnitOne/sld002.htm (12/11/2015).

existing things work better. Although engineers have independent minds, they work in teams that endeavour to change the world we live into something better for all of us. We have to remember that engineers operate not only in a world of rapidly changing knowledge but also knowledge that is incomplete. They make decisions that affect all of us and their social responsibility is well enshrined in the Canons, Rules and Regulations of their various engineering societies. We have to ponder on the question posed by the Education and Training within the European Union in Round 1: Promoting excellence and innovation "Future Priorities of the ET 2020 Strategic Framework for European Cooperation in Education and Training and Synergies with Youth Policy", Do we need 'knowledge retainers' or 'knowledge harvesters' (people who collate up to date information as and when required)? Do we need people who can 'talk about' innovation or do we need people who can 'do'?.[2]

I believe traditional methods of educating our students will not be able by themselves to cope with adequately equipping our students to deal with the vast and rapidly occurring technological and knowledge changes, explosion in information availability, the increasing nature of multidisciplinary approaches to problem solving, Globalization of the market economy and the cultural awareness it implies, environmental issues, ethical issues and issues of social responsibility, which inevitably will affect existing business structures, to name just a few of the challenges facing them. There can be no doubt that in engineering, technical knowledge and understanding of the underlying scientific principles are of the outmost importance to our graduates, however, it is also plainly clear that these must be supplemented by 'skills' that are transferable to different contexts, skills that provide them with the flexibility of mind to adapt and apply their basic technical and scientific knowledge as appropriate to the various situations they will face in their careers. We need to deliver graduates that not only think like professionals, but act like professionals and the SME PBL exercise provides the platform for exactly that. Knowledge is the main tool in the professional engineer's tool box; but transferable skills are the extra tools needed to manipulate knowledge in order to meet specific goals. Goals are influenced by attitudes and our future professionals must be imbued by the 'right' attitudes during their years of training. Over the years our engineers have been trained to create things that make the world better for all of us. However, they must also be made aware of the business side of what they create; how their creations are marketed, sold, who are the customers, who drives development, how do the products they design get from design idea to the market place, how the operation is financed, how products are costed, etc.

This changing curriculum will also need changes in training of the educators who will be asked to impart these skills, or to change attitudes and behaviour of students, and traditional lecturing might not be the best way forward; tacit knowledge can best be transmitted through instruction, not by the book. Thankfully, there is no need to

[2] http://www.euroclio.eu/new/index.php/news/1247-association/4099-european-education-training-youth-forum (12/11/2015).

reinvent the wheel, a number of pedagogical approaches have been developed over the years such as team based learning, problem based learning, action and experiential learning, peer learning, to name a few; all part and parcel of enterprise education as more fully outlined by Colin Jones in his paper on 'Enterprise education: revisiting Whitehead to satisfy Gibbs' (Jones 2006). Also, once one starts delving deeper in the teaching and learning aspects of their work finds that different students learn in different ways (Kapranos 2010), classroom dynamics, motivation (learning psychology), assessment, feedback, grading, also affect the process. Surely we cannot expect a lecturer of engineering to know about this stuff? It is not untypical to think that 'I was taught by lecturers and that is the way I will teach my students, I don't have time for all this epistemological jargon'.

I am happy to report that the situation is being addressed and that every new lecturer has to undergo educational training, CiLT (Certificate in Learning and Teaching) as part of becoming a lecturer; until recently, lecturing was one of the few professions that did not demand a formal instruction or training for its new practitioners, newcomers to the profession had to learn by themselves through trial and error or by taking someone else's notes and ploughing-on regardless.

2 Centres of Doctoral Training

2.1 CDT Teaching and Learning Philosophy

In designing the Diploma in Personal and Professional Skills we had to go through the conventional process for developing any new course, i.e. identification of clear objectives in the form of deliverables that could be assessed, and devise appropriate feedback loops that are aligned with these objectives. We had to also align the pedagogical methods and tools that would be used in delivering the objectives, the assessment and the feedback, such as multi-based and student based learning, action learning, peer learning, continuous assessments, personal portfolios, mini-research projects, public engagement tasks, working in the community and other Outreach activities, the image of Science and Engineering in the Media, etc. We tried to provide flexibility in the delivery approach, assessment as well as feedback in a way that we satisfied the educational quality demands and regulations for the provision of a Diploma set by the relevant educational authorities and enforced by our external examiner.

Bauman (2012) in his book 'On Education', likens the delivery of education to an intelligent missile well reflecting the position we espouse regarding the need for curriculum flexibility. In the rapidly changing world we live in, knowledge is quite a 'fluid' commodity and rapidly goes out of date. The new generation of students is well adapted to their world of rapid change and we need to take into account that they have a stake and a say on their learning, and should be able to decide on what knowledge they consider as useful for them to keep or dispose of as they see fit. In recognising the contribution of students to their learning experience, especially where the embedding of transferable skills is concerned, we see the Diploma in Personal & Professional Skills as an educational experiment that provides the flexibility to engage with a variety of pedagogies and it is precisely this flexibility of approach that provides the excitement of discovery of the unexpected, the eureka moment when unexpected links are formed with what was previously thought of as unrelated.

Of course we need the destination, the target, the objective, but if they could be tempered with the flexibility to allow us to look for the unexpected, to see and take on new opportunities and deliver value, to be more creative, then we are on the way to deliver the critical, enterprising, free thinking leaders needed by tomorrow's UK industry.

Clearly, as with any experiment, there are risks involved and care must be taken to appreciate as to what might be the reaction of students to the move away from traditional methods of teaching and assessing them. That can be achieved through good upfront communication on questions of why this is being done, and the establishment of a culture of trust, collaboration and understanding, it is not 'us' and 'them', we are co-travellers and this is an exciting trip. Making the students to personalise the process will make them more engaged and intrinsically motivated; to absolutely invaluable components for learning.

We want our students to be engaged, and by engaged we mean that they really care about what they are learning, that not only they want to learn but they are excited and eager to learn, i.e. they are driven to learn, they are highly motivated. Barkley (2010) in her book Student Engagement Techniques states that engaged students exceed expectations, they go beyond what is required, and they devote enthusiastically their hearts and minds to the learning process. They try to make meaning of what they are learning, they are using higher-order thinking skills when analysing information or solve problems. Edgerton (1997) proposes that "to really understand an idea students must carry out a variety of performances involving the idea". Students can know about engineering by reading books or attending lectures about engineering, but to really understand engineering, they have to engage with the tasks performed by engineers. Therefore, learning by doing is a must, hence the ample use of Project Based Learning, Collaborative Learning, Active Learning, and Experiential Learning activities are used throughout the duration of the 4 year CDT training. It is the combination of Motivation and Active Learning that forms the basis of student engagement, Barkley, also suggests that engagement is the product of two basic elements, Motivation and Active Learning and that for engagement to take place, both elements must be present. She proceeds to take this model further by proposing that these two elements when working and interacting in synergy provide a continuum of ever increasing intensity which has the form of a double helix (Barkley 2010).

The current educational literature for engineering is awash with what skills are required of the engineers of today and the future and without going into details it suffices to say that not only they must be highly versed technically and scientifically, but most of all they must be dynamic, flexible, resilient with strong analytical skills, practical ingenuity, creativity, good communication skills, business and management mastery, leadership, high ethical standards, professionalism and a drive for lifelong learning (Kellogg et al. 2005; Dym 2008; McMasters and Cummings 2004; Education 2012; Leitch 2006; Vitae 2009; Whitehead 1929). That is a tough ask from anybody but we do believe that if one is a 'Professional', it is bound to strive for such characteristics as part of his professionalism. Professionalism is much more than just acquiring specific skills and subject knowledge; it is a state of mind, a way of thinking and living. The Diploma in Personal and Professional Skills was developed to form part of the overall CDT training aims to achieve the creation of the academically sound, ethically minded, Professional Leaders of tomorrow's UK industries.

2.2 On the Shoulders of Giants

In setting up the idea of the CDT Diploma in Personal and Professional Skills we decided that we need to deliver critical thinking enterprising individuals equipped to handle the challenges that real life employment will throw at them when they graduate. To do that, they need to be prepared to think like professionals do, they need to assimilate both theoretical and practical knowledge and be open minded enough to apply it in different contexts. At least we have to create for them a microcosm of 'real-life' experiences that will allow them occasionally to experience failure in a constructive manner and provide them with the setting to learn from such failures. Plato said that "*a text is a poor substitute for what really counts, that is the living exchange between different people*" and Whitehead concurs with "... *there is only one subject matter for education, and that is Life in all its manifestations*".

Our drive is shape our students into individuals that act and think professionally. We want them to be driven motivated individuals that want to make and deliver change, we want them to take leadership and responsibility in shaping the future industries of our country and moving its economic base forward through the application of their ideas into valuable products. "Predicting might be difficult, especially about the future" as Niels Bohr said, but we don't want our students to predict the future which is difficult, we want them to shape it and that is feasible.

These are all high ideals and look good on paper but we feel that a start has been made and although the expectations are high, we feel quietly confident that this step in the right direction is just the beginning of a process, a process to develop and deliver good quality enterprising, imaginative, creating students, with skills, knowledge and inventiveness, able to think critically and differently. This is not a simple task; as Whitehead (1929) aptly states "*Education is the acquisition of the art of the utilization of knowledge. This is an art very difficult to impart*".

So where do we start? Your library or the internet; the list is endless: Bandura, Baume, Bloom, Broughton, Dewey, Elton, Felder, Fisher, Flavell, Hannon, Hilgard, Kegan, Kolb, Perry, Piaget, Race, Schon, and Whitehead, to name but a few. There is a plethora of material available for anyone who wants to improve their educational approach to Teaching and Learning.

3 Developing the Professional Engineer

Engineers are professionals who apply their knowledge and skills to the benefit of humanity. They make things that 'work' and make things 'work better'. They consider the available facts and they make decisions based on scientific as well as ethical principles. Being professional and acting professionally must be the state of mind of any practicing engineer. Clearly we must impart to our engineering students certain knowledge and specific skills that are necessary for them to practice their chosen profession but we must whenever possible to create the appropriate learning environments and situations that reflect engineering as it is practice in the 'real world', that way we can ensure that not only our students can mature as professionals but they will gain the necessary confidence they will need to practice once they graduate.

"How can we create the educational environments where students learn about engineering with interest and enthusiasm?" asks Prof. Dym (2008). One answer can be by 'engaging students in evaluating and solving real problems, where they have to seek, identify and collect relevant information, work as part of a team, generate possible solutions and use their knowledge and skills to reason, justify, defend and communicate their choices in order to convince their peers of the value of their proposals, i.e. what in fact happens in professional practice'. By setting contextualised challenges that are relevant to their studies and their future careers, we are achieving a number of objectives and we hit a number of targets such as practice of professionalism, application of knowledge, application and practice of transferrable skills such as teamwork, communication, and their assessment. By using a Problem Based Learning (PBL) approach where students are given full responsibility for their actions, we are naturally nurturing their professionalism. Employing real PBL situations provides the active learning excitement which drives the motivation that forms the basis of the engagement continuum proposed by Barkley (2010) and bridges the gap between theory and application and academic education and professional practice.

After a number of iterations in developing the structure of the CDT Diploma in Personal and Professional Skills we embedded the SME PBL exercise in year of their CDT studies in order to provide a forum that the students can practice and internalise the skills they have been developing consciously and subconsciously over the course of their studies. Involving SMEs that were willing to contribute their problems as challenges to our groups of students is another step in the process of making our students to become independent thinkers and develop as professionals. We have varied our approach over the past three years in relation as to how much guidance we give the students prior to tackling these industrially based 'real' problems from the absolute minimum, "here is the problem, you have two weeks to provide solutions", to allocating a day of seminars on discussing "effectuation, creativity, enterprise and the use of a Project Canvas" in order to prime them on what might be relevant to their task.

It is important that students quickly recognise that there are deadlines involved and therefore group dynamics are established equally quickly, and that project planning, time management, networking, clear communication lines are established. The issue of leadership also surfaces as different groups take different paths in approaching their problems. Another key interaction is communication with members of their host SMEs, as well as their academic tutors in acquiring the necessary resources and any additional information that will assist them in their tasks. It has been very easy to see that students become very engaged in the process and focus in completing their task within the imposed deadlines, and the fact that there is an element of completion between the groups throws an extra motive in the mix. Students are quick to realise the interdependencies involved in this process and sort out what is expected, what resources are needed and where to find them, what information is required and where and how to find it, analysed it and use it appropriately. The theoretical discussions about ‘team work’, ‘Bruce Tuckman’s Team-development model and Belbin’s team roles’ become real issues to be dealt with and no longer abstract concepts, Networking is fully utilised, Self-Motivation and Team-Motivation must be maintained, Problem Solving techniques find their place, Project Management skills are employed, Creativity tools are displayed and appropriately chosen, the realities of Conflict Resolution and Negotiating at different levels become part of the reality of the experience, establishing and maintaining clear lines of Communication at all times, and finally, selection and use of appropriate Presentation Skills, all forming core part of the Diploma in Personal and Professional Skills are put in full use and by osmosis become assimilated into the students conscience.

Of course the PBL approach taken as part of achieving the professionalism espoused by the CDT Diploma is not new, Dym and his colleagues (2005) at Mudd College have made extensive use of PBL using real design projects as central part of the activities of engineering students to give them a flavour of what engineers actually do. This is not surprising if we consider the experiential learning cycle as proposed by Kolb (1984) as a fairly accurate representation of how real-life engineering projects are accomplished. Brereton (1999) also demonstrates that the “learning of engineering fundamentals is promoted through activities that involve continuously translating between hardware and abstract representations”, indicating that convergent-divergent thinking naturally takes place in contextual hands-on projects. Wang and his co-authors (2005) provide more support evidence with their findings that engineering professionalism, attitudes and skills can be developed through active learning and problem based learning, as students are exposed to engineering practices that help them to become mature independent learners with developed problem solving skills. Real-life PBL projects tackled under conditions representative of professional working, with real deadlines and responsibilities help students to acquire critical cognitive and professional skills as these projects are by their nature complex and interdisciplinary (Steinemann 2003). The work undertaken under the SME project banner pays little regard to traditional engineering teaching but instead provides the students with the environment with a balance between systematic methodology and disorderly openness, where they can exploit original innovative thinking, creative problem solving, and of course learn from mistakes and failure (Barak and Goffer 2002).

Completing the learning process we have to carefully consider assessment, feedback and reflection; a lot of useful information is available on these available for download by a number of authors (Zijlstra-Shaw et al. 2011; Cajander et al. 2011; Gibbs 2009; Schon 1987).

4 Conclusions

Using PBL learning exercises with SMEs engages students with current and real problems to be solved. This provides the very attractive combination of motivation and engagement for learning to take place. Actively engaged, enthusiastic students testing their knowledge against real problems, under conditions faced by engineers in their daily professional practice and delivering tangible results, successfully links the philosophy behind the CDT Diploma. Students consider the experience very valuable, academic staff see justification in the curricular flexible approach to learning paying dividends, external examiner is happy that the targets set are demonstrably being met, and industrial partners are reassured that the skills they want from our graduates are being embedded and practically used as part of their studies. The long run benefits will be felt few years down the line as are delivering the next generation of technically competent, motivated engineers with professional attitudes and skills that have been gained through engineering practice; the future leaders of our industries as envisaged by the CDT programme objectives. Beware that SME based PBL is an emotionally charged process that provides ample opportunities for the students to experience momentary perspectives conducive to learning and creativity as learning is an intrinsically emotional business (Claxton 1999; Ray 2013).

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Giving Enterprising Engineers a Business Edge

Peter Harrington

Abstract This presentation draws upon a decade of research and development of a business simulation game designed to engage learners in an authentic learning experience. Since 2006, undergraduate and postgraduate students at most UK universities have been using 'SimVenture', business simulation software, designed to develop business, entrepreneurship and enterprise skills. The simulation allows students to create and run a virtual company and deal with all the decisions and necessary consequences associated with the learning experience. SimVenture is extensively supported by multimedia-rich learning resources which caters for all learning styles and levels. Educators can use the software in a number of engaging ways such as traditional in-class activities during tutorial/seminars, blended learning or within a flipped classroom setting. The case study considers the value and relevance of using 'Serious Games' to engage engineers and draws on available research data to examine the impact this approach to learning has had on peoples' ability and desire to acquire business, enterprise and employability skills. The presentation also references how the simulation has been used to develop management and leadership skills of engineers working in the Asian Telecoms sector as well as their reaction to using a business simulation. This contextual comparative information is provided to help evidence the impact of the simulation as a professional development tool. The presenter, Peter Harrington, is a serial entrepreneur with a deep interest in education. He first started in business immediately after graduation in 1989 and has been researching and supporting the development of simulation tools for the past 15 years. Since the simulation is now used in over 40 countries, Peter is a regular traveller.

Keywords Authentic learning · Serious games · Entrepreneurship · Blended and flipped learning

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1 Introduction

According to the Futurelab Report prepared by Ulicsak and Wright (2010) entitled ‘Games in Education: Serious Games’ “digital games, including simulations and virtual worlds, have the potential to be an important teaching tool because they are interactive, engaging and immersive activities.” However, the overall use of game technology in teaching remains relatively low even though there is increasing research (Freeman et al. 2014) and evidence that traditional, ‘industrial age’ approaches to teaching and lecturing alone are insufficient to meet the needs of the digital native student. There is also evidence that blended approaches to teaching and learning are growing in popularity although it is far from being the accepted status quo.

Wikipedia defines a Serious Game as “simulations of real-world events or processes designed for the purpose of solving a problem. Although serious games can be entertaining, their main purpose is to train or educate users, though it may have other purposes, such as marketing or advertisement.”

Within the military, health service and aviation sectors, the use of simulations to train professionals to develop skills and understanding within a risk free environment has grown significantly and in line with technological advancements. And that growth appears set to continue. In a 2012 BBC interview, David Owens (Senior Director, Flight Crew Training Policy—Airbus) said that the number of industry simulators (900) globally is set to double, such is the demand for simulation training. The story is similar for healthcare and Universities like the Stanford School of Medicine[1] has created its own dedicated simulation centre in anesthesiology, intensive care, emergency medicine and other clinical settings. Writing about Patient Safety and Quality, Durham and Alden (2008) draw on wide experience and research to highlight the value and benefits of using simulations to train nurses so that they are better able and prepared to manage risk properly in a live event. The body of evidence is sufficient to conclude that simulators used in risk-based industries do improve performance and as a consequence the ongoing investment in such resources is considered worthwhile.

Whilst it is outside the scope of this paper to delve further into the specific benefits of using simulations in different industries, it is important to examine the principle of allowing people to learn from authentic experiential practice when preparing to undertake the risk pursuit of starting in business.

2 High Diving into Business

Since 2010 (and as part of my own research into the purpose and value of simulations) I have been asking groups of people from all over the world, would they be prepared to dive off a 10 m board into a diving pool. The number of people

[1]Stanford School of Medicine Simulation Center. http://med.stanford.edu/VAsimulator/.

prepared to take on the task is consistent (approximately 1:25). But when I tell the whole group that they have no choice, they have to dive off a 10 m diving board within the next 8 hours things change; I ask how participants want to prepare. In little time, people within each group agree that they want to practice diving at lower levels and gradually build up the necessary skills and confidence to complete the task. In other words, people want to be able to break down the main task into a series of simulated minor tasks where the risks are minimised.

This visual analogy of high diving emerged as part of a presentation/research toolkit following 7 years work into the importance and value of using a business simulator to help people understand what it was like to start and/or run a business. The reason for this is because globally, there is little evidence that business start-up and survival rates are improving (unlike performance in the healthcare, military and aviation sectors). For example, UK data released by Experian (November 2011) showed that a record 70 % of start-up business are failing within 36 months of being launched. Interestingly, there is little evidence that would be start-ups have been, or are, exposed in an authentic manner to the risks of running a business before the event actually happens for real. The predominant training method to support people starting in business has involved traditional didactic 'chalk and talk' methods and use of business planning modules and/or courses. Research indicates that this situation has arisen because training has typically been led by the availability of public funding, top-down policy decisions and tried and tested teaching methods rather than the absolute need for the improvement of performance and results.

Back in 2000, when my research started to examine whether a simulation could improve peoples' ability to start and run a business, Gordon Brown was Chancellor of the Exchequer and each of the 10 operational Regional Development Agencies (RDA) in England and Wales published a Regional Economic Strategy (RES). A repeated priority theme of each RES was the importance of increasing the business start-up as well as survival rates in order to stimulate and sustain economic growth. With access to a surplus budget and keen to see the UK economy competing with the Far East, Central Government as well as RDA monies were made available to schools, colleges and universities to foster the wider teaching of enterprise and entrepreneurship. Whether the funding made any impact on start-up and survival levels remains unclear. However, the growing culture of enterprise and entrepreneurship was critical to the decision to invest £250k in the creation of a new business simulation that allowed people to create and run a company and learn through success as well as failure.

3 Building 'SimVenture'

SimVenture is a 'Serious Game' allowing people to start and run a virtual company for up to 3 simulated years. Taking 4 years to build and tested in schools, colleges, universities as well as with budding entrepreneurs, the Windows-based software first launched in 2006 and is now used in 40+ countries. SimVenture is most popular within Higher Education environments and is used at undergraduate as well as postgraduate levels. Whilst there are a number of other simulations on the market, the clear majority are either focused on larger-scale corporate business (e.g. Marketplace) or simulate a single subject (e.g. Markstrat). When SimVenture was launched in 2006 there were only 2 other commercially available simulations that focused on small business including: The Small Business Game and The Enterprise Game (Pixelearning). At the time of writing this situation is unchanged (Diagrams 1 and 2).

Research undertaken by Venture Simulations (2002–2006) with academics and teachers into the development of a new simulation (SimVenture) highlighted 3 key simulation design principles that needed to work in harmony for the product to be 'fit for purpose'. Primarily, people wanted a simulation that provided an authentic learning experience so that what happened within the learning resource reflected the realities of starting a business, self-employment and the world of work. This authentic aspect would turn 'the game' into a 'Serious Game'. For the record, creating an authentic experience meant the design team had to model financial, time, skill, stress and tiredness levels every time a decision was taken within the simulation. This layer of important complexity added significant costs and time to the design of the product. But if a simulation doesn't reflect reality, what is its purpose?

The second principle was to create a simulation that engaged people in their own personal learning so they wanted to learn rather than felt they had to learn. Research by people including Jones et al. (2011) repeatedly demonstrates that the effective

Diagram 1 SimVenture home page

Diagram 2 SimVenture menu page

teaching of entrepreneurship 'requires people to act and deal with consequences'. Designing an engaging simulation meant drawing users into the learning experience so they felt emotionally involved and attached to their virtual business. Much has been written about the importance of engaging learners in experiential learning (e.g. Mason and Arshed 2013) particularly in higher education now that information is everywhere and the audience is made up almost entirely of digital natives.

Finally, since academics are typically time poor, the new technology had to be sustainable within any teaching environment and thus release the person who was typically at the front of the class from being the centre of attention. This meant designing a simulation that allowed students to learn how to use the simulation themselves and at a time to suit. It also meant including features such as 'Save and Load' so people could access their 'game' at a time to suit, as well as a 'History' function so people could review the details of decisions made and how a business had been run.

4 SimVenture Impact

Since 2008, a number of independent research studies have been completed and published by UK Universities into the impact of SimVenture as a learning and teaching resource. Universities completing research include: Leeds Beckett University, Leeds University, Southampton Solent University, Edinburgh Napier University, The University of Huddersfield and the University of West London.

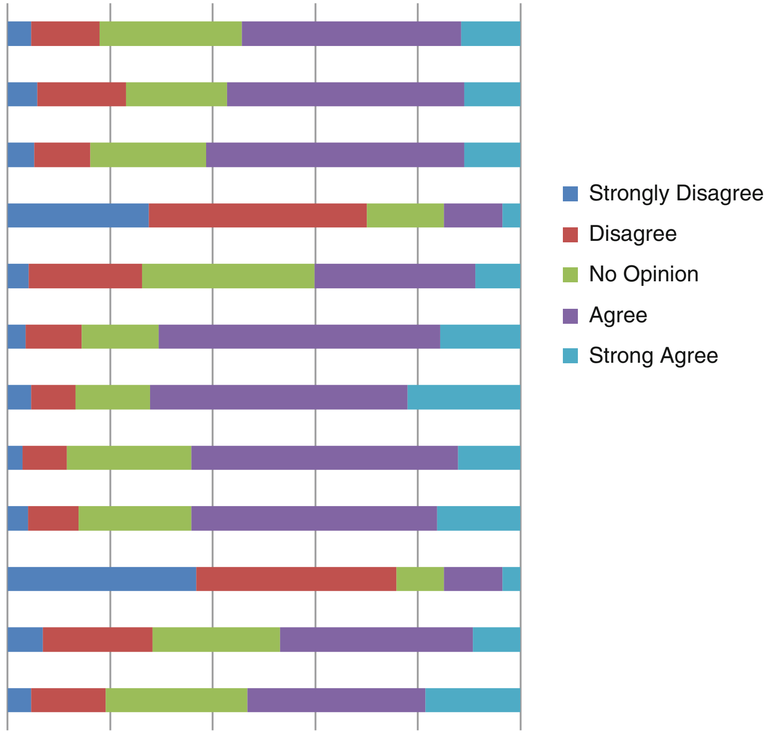

Diagram 3 SimVenture impact survey results (2010) sample 213 students

Wherever possible, these research reports are published within the Resource Library of the SimVenture website www.simventure.co.uk so findings can be shared. To complement this body of work, Venture Simulations has also carried out its own student impact research using on-line surveys (2009 and 2010). Research results have consistently demonstrated a number of important impacts on student learning.

As part of the 2010 Venture Simulations impact research,[2] respondents were asked to determine their agreement with a number of impact statements (see Diagram 3). The findings help to highlight the effect of the simulation in terms of students' resultant ability and desire to acquire business, enterprise and employability skills. For example, over 70 % of respondents agreed or strongly agreed that they were better able to link theory and practice; Over 70 % agreed that they developed a better grasp of business as a subject; and nearly 60 % agreed that they learnt more quickly.

[2]Venture Simulations Ltd summary student impact study of SimVenture as a learning resource. http://simventure.co.uk/sites/default/files/ResearchExecutiveSummary.pdf.

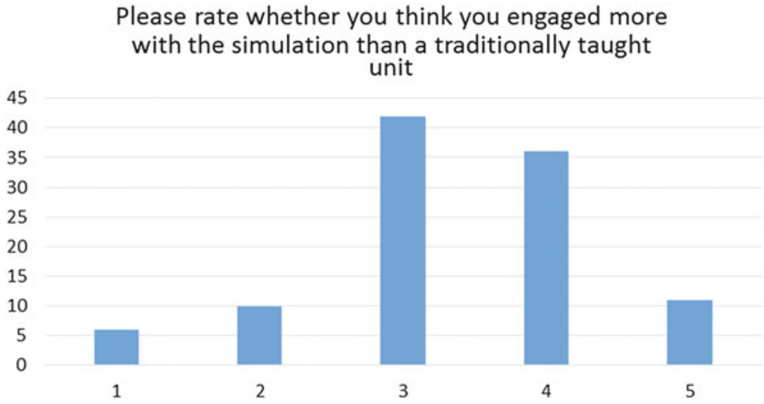

Diagram 4 Southampton Solent University business student research (2013)

Linked to these impact findings are the results to a larger survey carried out at Southampton Solent University by Senior Lecturer, Lesley Strachan.[3] As part of the survey. Students were asked about their level of engagement when using the business simulation; the findings shown in Diagram 4 evidence the fact that people were significantly more engaged with the simulation compared to the traditionally taught methods within the Unit.

These two sample findings are provided to highlight how SimVenture has made an impact and further results are available within the full reports provided on the website.

Extent to which respondents agreed with the statement (see Diagrams 3 and 4).

5 Business Simulations, Engineering and Higher Education

Whilst SimVenture was originally designed for use within Higher Education and Entrepreneurship-based classes, there has been increasing evidence of its use within Engineering Departments. Loughborough and Birmingham Universities were among the first to start using the software (2009) and since 2010 SimVenture has been used at a number of other institutional Engineering departments including Cambridge University (Centre for Technology Management).

Client research has consistently shown that academics want to provide engineers with practical business experience as part of their undergraduate or postgraduate degree so they are equipped with important employability skills when seeking

[3]Evaluating the impact of SimVenture at Southampton Solent University, Lesley, Strachan. http://simventure.co.uk/sites/default/files/SimVenture%20Employability%20Research.pdf.

work. This desire to provide business skills is supported by Nathan Baker,[4] Director of Engineering Knowledge at the Institution of Civil Engineers. Nathan recognises that: “Many engineers within organisations may have the necessary engineering skills and qualifications but over time they are promoted to positions which demand much greater business acumen, which they may not necessarily have.” As a consequence, he believes, it is important to be able to provide business training to engineers at a time and in a format that meets their learning needs and requirements.

Whilst traditional Engineering degrees do not typically include a business-based component, it seems the simulation provides a valuable experiential learning opportunity and thus ‘bridge’ into the subject. At the same time, since SimVenture allows students to develop their skills as individuals as well as in groups (peer to peer learning opportunities are high and valuable knowledge and understanding is thus shared). That said, to date no formal Engineering Student-based SimVenture research data has been collated and so it’s not possible to comment with any accuracy on the real impact the software is having on learning.

6 Business Simulations, Engineering and Corporate Training

As part of the presentation content, Peter Harrington will refer to the use of the simulation as a training resource used by engineers working for a large Telecoms company based in the Far East. Over recent years the company had typically relied on case studies to support teaching and training, but there was a belief that a new active approach would better help engineers to develop their business and strategic thinking ability.

In total, 30 engineers (who were in the company’s Executive Talent Development Programme) were selected to be part of the course which was designed to run in Bandung (Indonesia). The course sought to provide delegates with a strategic mind-set of what it takes to run a large organisation. Since the company believed managers were susceptible to silo thinking, they wanted to take people out of their own specialist areas and put them in charge of all business disciplines within a smaller virtual company. Ngiam Tee Woh, who observed the training, noticed how delegates gradually realised that success wasn’t just about sales, marketing, finance or operational matters. People discovered that to be successful they had to think strategically about all areas of business and work closely as a team.

Asked about the most effective part of the training, Ngiam Tee Woh said: “Getting delegates involved in group discussions about the decisions they had made, and would be making, was very beneficial because they lived through the

[4]Nathan Baker, Director of Knowledge at the Institution of Civil Engineers. http://www.nce.co.uk/news/ice/new-knowledge-transfer-director-joins-ice-in-november/8670116.article.

experience in a safe learning environment. Delegates were able to experiment with a combination of decisions and discover for themselves what worked. Listening to peoples' reflections also showed how much people had learnt."

7 Conclusion and Summary

The traditional view of learning within higher education places the student in a passive receiver role. Meanwhile, the 'sage on the stage' is the sole provider of information and the central focus of attention. But today's digital native learners work in a world where information is everywhere and available almost instantly. At the same time, globalisation, greater competition for students and advancing technologies are all issues that are nudging and perhaps forcing educational institutions to rethink how learning is delivered.

The business simulation 'SimVenture' is one example of recently developed technology that has been used to engage learners in a world where the student is at the heart of his/her own learning. Reflecting the way in which authentic simulators are widely used in other industries such as aviation, the health sector and the military, students learn by making decisions and dealing with consequences—but all within a safe environment.

To engage learners, SimVenture was designed to reflect reality as closely as possible so that the lessons learned within the simulated environment could be used later by the student to help them into work and to understand the world of business (and not just as a means to pass a course). As a result, the software has become popular in higher education institutions around the world and is also used within corporate training environments.

Impact research studies completed since 2009 (9 and 10) have demonstrated the impact and value of the simulation as a learning tool, particularly within business and entrepreneurship-based courses. More latterly, the simulation has been used as a tool to help engineering undergraduates and postgraduates learn about business in a manner that suited their own learning styles.

As the Paper's author, I'm of the belief that simulations have a powerful, important and growing role to play in business and engineering education, especially as digital native student expectations increase and employers place greater emphasis on the need for connected (rather than silo) thinking and deeper levels of subject understanding. It is perhaps surprising that simulations are not used more widely to support the teaching of business and entrepreneurship, but if academics are not making sufficient demands, should we be surprised by the lack of quality supply? Another critical issue to consider is the fast-paced change of technology and the cost of building and marketing new simulations. Given the multi-billion pound demand value of the consumer games industry, why should companies be making efforts to design innovative technology in order to supply the much smaller and less lucrative sector inhabited by educational institutions?

But the case to create innovative simulation technologies is growing. As Freeman et al. report (2), the demand to provide active and blended learning approaches to an increasingly market led education economy is only set to increase. Education institutions that provide what students want and find ways to increase learning engagement and efficiencies are surely more likely to thrive? And as this truth gains greater acceptance amongst academics, so it will have consequences for institutions that fail to change at sufficient speed or fail to change at all.

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Leading the Way to Enterprising Futures: A Response to the Engineering Skills Gap

Holly Nicholson and Gary C. Wood

Abstract This paper describes and demonstrates the value of the Sheffield Engineering Leadership Academy (SELA), in the Faculty of Engineering, University of Sheffield, UK, in responding to the widely recognised skills gap amongst engineering graduates. The unique and ambitious programme prepares a select group of undergraduate students with the skills and confidence to become engineering leaders of tomorrow, who can create positive change in industry and research. It brings together an international cohort of students from a range of engineering disciplines, supported by a network of industry experts, academic colleagues, enterprise educators and engineering alumni, who deliver training, coaching and leadership preparation to the students. Over two years, the students benefit from training, development and mentoring opportunities in enterprise, innovation, business and project management, all contextualised within engineering. Following an initial skills bootcamp, the students complete two separate year-long inter-disciplinary collaborative projects, and undertake two placements in industry or research. Enterprise skills are embedded into the programme, with students facing authentic challenges that require them to generate new ideas and proactively realise them to provide solutions. Students must be resourceful and confident to strategically take advantage of opportunities to create positive outcomes, whilst recognising and working within constraints, facing and managing risk and uncertainty, and dealing with change.

Keywords Engineering · Enterprise · Leadership · Skills gap · Training

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1 Introduction

The UK is facing a skills gap in engineering, including a lack of leadership skills in engineering graduates. Although technically gifted, graduates are often not equipped to take on the world of business or to quickly assume leadership roles in an increasingly competitive global market (IET 2014). The University of Sheffield's Faculty of Engineering is responding to this issue with the implementation of a unique and ambitious co-curricular programme for undergraduate students. The Sheffield Engineering Leadership Academy (SELA), launched in September 2014, prepares students with the skills and confidence to become engineering leaders of tomorrow, who can create positive change in industry and research.

Through a rigorous and highly competitive selection process, including written applications and interviews, up to twenty students enter the SELA programme at the start of their second year of undergraduate study. Over the two-year programme, they make connections between their learning, industry and research, through exposure to industry experts, academic colleagues, enterprise educators and engineering alumni. SELA students complete two separate year-long projects that develop their ability respond to authentic problems, and to provide creative solutions by generating new ideas and proactively realising them. The students must be resourceful and strategically take advantage of opportunities to create positive outcomes, whilst recognising and working within constraints, facing and managing risk and uncertainty, and dealing with change.

In addition, two industry or research placements enable the students to apply, test and extend their learning in real-world contexts, and to benefit from the mentoring, guidance and experience of colleagues in professional environments.

This paper describes the SELA programme and its aims in detail, and it is organised as follows. The next section presents the backdrop and the impetus for SELA; Sect. 3 gives an overview of the structure and organisation of the programme before Sect. 4 discusses the advantages and benefits of the programme. In the final section, attention turns to the future sustainability of the programme.

2 Background

For many years, a skills gap has been recognised amongst engineering graduates. The Institution of Engineering and Technology's Skills and Demand in Industry Annual Report 2014 highlights a gap for the ninth consecutive year (IET 2014). Fifty-four percent of employers surveyed by the IET reported that graduates' skills fell short of their expectations, with a lack of practical experience, leadership skills and technical expertise being particular issues. Phillips (2014) observes, on the basis of interviews with industry, that engineering degree programmes tend to emphasise subject knowledge at the expense of developing students' skills, attitudes and experience. This is particularly concerning, since the IET's survey reports a decline in the number of employers intending to train existing staff (14 %, compared with 20 % in 2013), with a third of companies indicating that they will instead prioritise recruiting apprentices and graduates. And these two surveys are not alone in painting a negative picture of engineering graduates' readiness for the workplace; even a quick literature search reveals dozens of recent articles reporting the issue (see, for example, Wellington et al. 2002; Patil 2005; Radcliffe 2005; Nair et al. 2009).

It is thus more important than ever that higher education equips students not only with technical and subject knowledge, but also with enterprise skills, including collaboration, team-working, and leadership skills. It goes without saying that engineering graduates—indeed, graduates of any discipline—must have sound knowledge of their subject area, including an understanding of theory and technical skills. But applying such knowledge to provide products and solutions for customers, and to benefit society, requires enterprise capability and an entrepreneurial attitude, often combined with interdisciplinary collaboration in project teams, where strong leadership is essential to success. The recognised lack of leadership skills amongst graduates is therefore a serious problem that requires urgent attention. If engineering graduates can be equipped not only with exceptional technical skills, but also with the skills, attitudes and experience to be effective leaders, they will be able to lead successful organisations and projects earlier in their careers, and help to close the skills gap.

A challenge in solving this problem is that teaching academics, whilst educating students with technical knowledge, are often not well placed to provide enterprise training that will enable students to develop the capabilities to be effective future leaders. There is thus a need to identify and implement new approaches, changing the student experience and academic programmes in order to address the demands that graduates will face as they move into the workplace.

One new approach, and perhaps the most widely known leadership programme for engineering students, is the Gordon-MIT Leadership Program (GEL), established in 2007. This co-curricular programme provides leadership development for engineering students at MIT, who apply and are selected to join a GEL cohort alongside their studies. The two-year programme supplements students' academic learning by equipping them with values, attitudes and skills to empower them as effective future leaders. The training is based on the Four Capabilities Leadership Model, also devised at MIT (Ancona et al. 2007). This model describes four tenets of leadership:

1. **Sensemaking**: analysing and understanding the industrial or research context of an activity, and constantly monitoring and interpreting changes within it.
2. **Relating**: building relationships and support networks through listening to others' viewpoints, and explaining one's own ideas and point of view.
3. **Visioning**: imagining future possibilities and potential, and communicating these in ways that inspire others to want to share in their realisation.
4. **Inventing**: finding and implementing new solutions and approaches to overcome problems and to realise visions and ideas.

Significantly, the Four Capabilities Model dismisses the idea of a ‘complete leader,’ an individual with equal skill in all four areas, and recognises instead that leaders need to be adaptive and recognise their own strengths and weaknesses. In this way, they are able to draw effectively on the skills and knowledge of those around them. This is particularly important in engineering contexts, where solutions often depend on interdisciplinary collaboration and the combination of technical expertise across teams.

GEL develops students’ skills across the Four Capabilities through short courses on leadership theory, group activities, leadership labs and internships, all contextualised within engineering and supported by mentors from industry. In recognition of the idea of all leaders being incomplete, there is an emphasis on individual reflection and goal setting, to foster attitudes of personal development and a personal recognition of strengths and weaknesses, and a concomitant need to draw on the skills and knowledge of others.

Despite the success of GEL at MIT, with 120 students completing the programme each year and a developing network of alumni who continue to support the development of the programme and its students, until recently, similar opportunities have not been available to students in the UK.

3 Structure and Organisation

It was against this backdrop that SELA was launched in September 2014, as the first co-curricular leadership programme offered by a UK university and covering all the engineering disciplines. The programme was initiated following recognition by the Faculty of Engineering that in the UK, leadership training opportunities are provided for almost every demographic—from school children to professionals—with the exception of undergraduate students (O’Sullivan 2011).

To develop the University of Sheffield’s response to this gap in provision, a SELA Management Board was established, consisting of three academic staff from the Faculty of Engineering and two staff from University of Sheffield Enterprise (USE). USE is a central University department that develops and implements an enterprise education strategy across academic departments, to support development of enterprise capabilities in students. This is achieved by providing training directly to students and professional development opportunities to academic staff at the University to enable them to deliver contextualised enterprise education within their own subject discipline. The Faculty of Engineering’s collaboration with USE thus draws in expert enterprise educators, to contribute to the development and delivery of the SELA programme and enable students’ subject training to be supplemented with the soft skills identified as lacking in graduates.

The Management Board worked with Blueprint Talent Group (Chicago, USA, http://www.blueprinttalent.com) to develop seven foundational attributes of SELA. These state that students should:

- be enterprising—proactively taking advantages of opportunities to create positive change;
- have good judgement—be willing to make decisions involving risk and uncertainty;
- be technically gifted—understand and apply technical knowledge, especially beyond an academic setting;
- be inspiring—create and communicate a purposeful, compelling and/or transformational vision that influences others;
- be flexible—manage and adapt to change, embracing alternative perspectives;
- be self-aware and undertake self-improvement—identify and understand personal strengths and weaknesses, and be prepared to continue proactively learning through setting new individual goals; and
- have personal vision—hold long-term ambitions, inspired and shaped by personal values.

These attributes guided the development of the SELA curriculum and provided the criteria upon which to select students into the Academy. Students are inducted into the programme through a bootcamp, and over the subsequent two years, work continuously on inter-disciplinary, multi-faceted group projects alongside attending lectures and workshops with guest speakers and facilitators. Each of these aspects of the programme is discussed in detail below.

3.1 Selection

The SELA attributes form the basis of a comprehensive selection process for students wishing to join the programme. This process is specifically designed to ensure that students are not judged solely on educational achievement, but on each student's aptitude and potential as an effective future leader. All first year undergraduate students in the faculty (approximately 1200 students) are invited to apply for the programme, with the first step in the selection process being an online application form. The form comprises questions about personal achievements and aspirations as well as competency-based questions, to measure students' personal vision alongside their existing enterprise skills and experience. Applicants who demonstrate capabilities in these areas are offered two-stage interviews, comprising an informal conversation and a pitch-style presentation, followed by questioning, with Board members. Up to twenty of the students interviewed are selected for the cohort each year. The first cohort was selected in spring 2014, and the range of factors considered in assessing applicants successfully led to the recruitment of a diverse group, comprising international, mature, and female students.

3.2 Bootcamp

After selection, the first event in the SELA calendar is the bootcamp, which is the introductory weekend for SELA students. The residential weekend takes place in a setting outside the University, to fully immerse the cohort in the experience, and to instil a sense of prestige and significance. The bootcamp is the first opportunity for the students to meet each other, the Board members and mentors, and to learn more about how the SELA programme works. The residential nature of the event allows students to network with each other and the mentors informally, as well as working together more formally in team activities. This is important, given that students are drawn from different disciplines across the Faculty, and so many have not previously met each other.

Through the bootcamp, the cohort is engaged in an intensive two-day programme of activities, which provide the foundations for SELA by: introducing students to the possibilities of what they can achieve; initiating working relationships; and beginning the development of leadership skills and approaches that the students build upon throughout the rest of the programme. The workshops at the first bootcamp were delivered by experienced facilitators from USE, and focus on activities such as recognising working styles and drivers, in which students consider their own and others' approaches to work; how teams function and what makes for effective teamwork; and problem solving. Other sessions focus on negotiation, in which students investigate approaches to making a deal; decision making, for which a mock pressurised situation is established and students have to assimilate information quickly and effectively to agree on an outcome; and lateral thinking, which introduces students to tools and techniques including de Bono's Thinking Hats (de Bono 1985), to help them explore problems from different perspectives. There is a strong emphasis on team-work throughout the weekend, with students establishing efficient working relationships from the outset, and students are encouraged to take a reflective, self-evaluative approach from the beginning, enabling expectation management and helping the cohort to make the most of each activity.

Throughout the bootcamp, SELA students also receive valuable input from mentors, who are experienced engineers, intrapreneurs and entrepreneurs from both academia and industry. These individuals are chosen by the Board to give the students a more experienced perspective on problems, and to inspire and encourage the cohort over the weekend.

3.3 Lectures and Workshops

In the two academic years following the bootcamp, SELA students attend a series of lectures from guest speakers, designed to inspire them with the possibilities of what they can achieve, and offer insights into leadership challenges and successes from their careers. Each speaker brings a new perspective, giving the cohort a comprehensive appreciation of the many opportunities offered by a career in engineering or manufacturing, and a way to begin relating their skills development to real-life engineering contexts. For example, an academic from the University shared her experience of leading an interdisciplinary research team and the importance of finding a team who are equally passionate about what they do, whilst a graduate engineer on the Sigma leadership programme at BAE Systems spoke about leading by example and not being afraid to ask for help. Speakers have also highlighted the importance of body language, of developing confidence, and of creating new personal challenges and goals. Through these insightful testimonies, the SELA cohort has been reminded of the SELA foundational attributes of inspiring others, having a vision for the future and being self-aware.

In addition to the guest lectures, a series of workshops and talks offers a plethora of techniques and information to help guide the SELA cohort through the planning stages of the group project (see Sect. 3.4, below) and reinforce learning from the bootcamp. Workshops are delivered by experts in their field, drawn from across and outside the University, and in the last academic year have included project management, networking and social media, which develop transferable skills.

3.4 Group Project

Two separate one-year-long projects are a key mechanism through which the cohort experience on-the-job learning in leadership, team membership and enterprise, and have the opportunity to put into practice their learning from the bootcamp and the workshops and guest lectures. The projects are intentionally broadly defined with briefs that lack specific detail, in order that the cohort must collectively pool their resources to engage in the process of sensemaking (see Sect. 2, above). They are required to draw on their existing knowledge, both as individuals and as a cohort, to identify information needs and respond to them with both literature-based research, and through the process of relating. This requires the students to draw on existing networks and to create new ones through the programme, utilising those networks to seek advice and guidance before interpreting and applying that new knowledge in the context of the project challenge. Visioning and inventing are then required in order to scope, develop, document and deliver a project plan and respond to the challenge by providing a solution.

The first year challenge for the inaugural cohort is to deliver the bootcamp for the 2015 intake, and to do so from a starting point of a zero budget. This project is intentionally not an engineering-related challenge, to enable students to work together regardless of their engineering discipline, whilst honing team-working skills and experiencing true collaboration towards a deliverable goal: the success of the project, rather than the achievement of a particular grade. This project also enables students to identify their own strengths and weaknesses, to learn how they work in and contribute to a team, and to share their individual knowledge and skills for the benefit of the project as a whole.

The second year project builds on these skills, allowing the students to contextualise them within engineering, as they tackle an engineering grand challenge. The use of a grand challenge draws on the subject knowledge of all the students in the cohort, enabling them to put into practice learning from their degree programmes, and to apply that technical knowledge alongside input from their peers, to contribute to solving a problem. Thus, the cohort further refines the leadership skills developed through the first project and learns how to apply that training in an authentic engineering context. Leadership is required in order to co-ordinate the efforts of both discipline-specific sub-teams, and the drawing together of those sub-teams to provide the whole solution.

3.5 Placements in Industry or Research

Complementing the term-time programme of events and projects are two summer placements which the students are required to apply for, secure and undertake in areas of research or industry that interest them. These placements are included in the programme to provide an opportunity for students to apply their learning in a real-life workplace context, as they take up roles in project teams providing real-life solutions. The opportunity to work in such environments also provides an opportunity for students to build personal networks and to benefit from the insight of colleagues already working in areas that the SELA student might consider as future career opportunities.

4 Benefits and Advantages

The SELA programme is designed to enable students to learn experientially. It allows the students to face authentic engineering challenges and to apply their subject knowledge whilst practising and developing the skills and attributes demanded by industry. Thus, the major anticipated benefit of the programme is that it provides a mechanism for students to develop the skills that have been recognised as lacking in graduates by industry for at least the last decade. Although the programme is currently supporting its first cohort of students, and therefore the benefits to industry cannot yet be measured, it is hoped that SELA graduates will be equipped with skills and attributes that will enable them to progress to senior positions in engineering more quickly than might otherwise be the case.

In order to empower students to recognise and respond to opportunities, the development of enterprise skills is an integral part of the programme. University of Sheffield Enterprise identifies five enterprise capabilities, and the SELA programme provides students with the opportunity to develop all of these:

- **Authentic problem enquiry and response**. Throughout the programme, and particularly in the group projects and placements, students have the opportunity to investigate and respond to authentic and true real-world problems using a variety of methods. In so doing, they face and work within authentic constraints, and negotiate barriers. In the first year group project, for instance, students have to consider multiple approaches to delivering the bootcamp. They have to recognise the limitation of a zero budget and attempt to overcome this problem with fundraising, having established costings to deliver their ideal bootcamp. Further iterations of that plan become necessary as funders make specific requests in return for financial support, and to respond to funding shortfalls.
- **Innovation and creativity**. In the workshops and group projects, students must demonstrate creativity, generating and critiquing new ideas and solutions. In the grand challenge of the second year project, for example, students are required to solve a real-world problem by applying their knowledge creatively. Similarly, in constructing the bootcamp as their first project, students have the freedom to create their own curriculum for the new cohort, responding to their own cohort's feedback on their experience of the initial bootcamp run by the SELA Board.
- **Risk-taking**. Good judgement is developed in SELA students by exposing them to calculated risk-taking, as they apply their engineering knowledge in new situations, use common sense, and analyse available information to make decisions. The reflective approach woven throughout the programme ensures that students assess risks and identify opportunities for future improvement as they learn from mistakes and failure whilst developing self-confidence. The students also experience operating within an uncertain environment. This begins with the bootcamp, where students are brought together and thrown into challenges, having never met each other before. Securing funding for the bootcamp is a further example of the students facing and dealing with uncertainty, since they have to begin putting in place plans for the event before it is clear whether or not they will raise the required level of funding to deliver those plans without modification. Thus, the students are likely to need to also demonstrate flexibility and a willingness to respond to change.
- **Taking action**. Delivering solutions to the project challenges, contributing to work undertaken on placement, and responding to the smaller-scale problems presented in workshops requires the SELA students to demonstrate leadership capabilities and a willingness to take action. They must be pro-active in identifying opportunities and acting on them as they build networks, make connections, and draw on support from others in making their ideas happen. Current and future SELA members can draw on this network to seek advice, funding and summer placements. The summer placements are one good example of where students demonstrate and develop skills in taking action. Self-awareness and being prepared to continue learning will help students to make the most of the placements, whilst searching for and securing the placement initially requires a proactive approach, self-confidence and personal vision from the students, as well as a drive to achieve it. Students who do not succeed at first in securing a

placement learn a valuable lesson in coping with failure, and have to be tenacious in continuing to strive for their goals.

- **True collaboration**. Students have to work in groups throughout the programme, recognising the strengths and weaknesses of others, and operating professionally to move beyond the typical student groupwork project. Recognising working styles and drivers is key to the students' development of strong working relationships and empathetic conflict resolution skills. In the second year project, for example, students must draw on the engineering knowledge of different members of the cohort, since a multi-disciplinary team is necessary to provide a solution. Furthermore, as the students recognise the myth of the 'complete leader', they must collaborate in sharing their skills, and see that the strength of the team is greater than the sum of its parts.

The benefits of the SELA students developing these skills extend to other students in the Faculty who are not selected or do not apply to join the cohort. Engineering courses at the University of Sheffield frequently engage students in group projects, both as part of the curriculum and on a co-curricular basis. SELA students have the opportunity to volunteer as team leaders in these projects, improving their leadership skills in a different context and group of people. Leading by example in this way, SELA students can also pass on their skills and learning from the SELA programme to other students, actively encouraging team members to take roles that will develop their own leadership skills. Notably, 'Engineering You're Hired' is a faculty-wide initiative in which all second year undergraduate students participate, to develop team-working skills during a week-long inter-disciplinary project. This is an opportunity for SELA members to practice and develop their leadership skills with students who have not been exposed to such training and experiences, and to reflect on how much they have learnt from the programme.

5 Future Sustainability

At the time of writing, SELA has been operational for only seven months. In this time, the inaugural cohort has been inducted into the programme through a successful bootcamp. That cohort has welcomed inspirational speakers on a variety of topics, and has succeeded in establishing itself as a functional team, working towards clear and achievable self-set goals. The 2014 cohort will deliver the bootcamp for the next cohort in September, kick-starting the involvement of that new group of students in the programme. The first cohort will continue their development through engagement with the second, engineering-related group project, the continuing workshops and seminars, and the summer placements. With a collective SELA body of around forty students, in the next year the groups will be able to learn from each other, expand their collective network and set bigger targets which can be achieved to a higher standard.

The SELA programme is offering a unique and thorough enterprise and engineering education to prepare participating students with the skills and training to take on the challenges of industry, filling the leadership skills gap in the engineering sector whilst building a framework and network that will continue to address this gap by developing students and alumni into the future. Upon graduating from university, SELA members are expected to enter engineering and manufacturing jobs or take positions in research projects, and will be capable of taking on higher levels of responsibility than the average graduate, rising faster through the ranks of leadership, and spreading their skills and knowledge, continually learning and improving, and effecting positive change.

SELA has funding for research projects to run for five years, but it is expected that SELA will last for much longer, if not become a permanent offer from the Faculty of Engineering at the University of Sheffield. Once a critical mass of alumni is reached, the programme will become self-supporting, with an extensive network of industrial partners and a wealth of experience to draw upon for mentors, guest speakers and facilitators. As the skills gap closes, SELA students' skills development can be accelerated even more, through contact with young leaders in research and industry who are themselves graduates of the programme. SELA graduates will thus contribute to the SELA vision of a graduate body helping undergraduates achieve their goals and bridging the skills gap in industry by providing work-ready, enterprising graduates, prepared to take on the challenges of leadership in engineering.

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Encouraging Technology Entrepreneurship for All

Simon Mosey

Abstract Drawing upon contemporary research, this paper observes a significant increase in the supply and demand for technology entrepreneurship education. Specific case examples are considered highlighting how engineers and scientists can learn technology entrepreneurship through creatively deploying research breakthroughs to address industrial and societal challenges. The relative merits of different methodological approaches to evaluate the impact of such educational approaches upon skills development and subsequent career destinations are discussed. Finally a case study is presented demonstrating how technology entrepreneurship can be supported on an unprecedented scale using novel online learning tools.

Keywords Technology · Entrepreneurship · Education · Online

1 Introduction

This paper highlights an increased need for technology entrepreneurship education defined as 'learning how to commercialise a new discovery to address an industrial or societal challenge.' Historically this type of activity was the preserve of the research and development divisions of large corporations (Royal Academy of Engineering 2012). However, consecutive waves of disruptive technologies have eroded the capability of such institutions to manage this process effectively. The breakthroughs in materials science, biotechnology, information technology and electronics have wrought disruption across industries in unpredictable and complex ways (Tidd and Bessant 2013). As a response to this change, the educational demand from engineers and scientists has shifted away from general technology

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management education such as that historically provided by corporate training and business school MBAs. This has been replaced by a demand for technology entrepreneurship education typically provided within incubator or accelerator environments (Feld 2012). Not only has the education environment changed but also the course content and pedagogical methods. Didactic and case based teaching has been augmented by entrepreneurial boot camps where lecturers are replace by inspirational speakers and historical case studies replaced by 'live cases.' Here engineers and scientists are encouraged to work in cross disciplinary teams with business, legal and finance experts in an iterative, experimental learning format combining fast failure with mentoring and expert guidance (Binks et al. 2006).

This paper reflects upon this shift and seeks to highlight case exemplars of good practice from across Europe. It then addresses a fundamental shortfall in the lack of systematic evidence of the efficacy of these contemporary teaching and learning practices. Evidence is presented of different evaluation methods including student feedback of changes in self efficacy and entrepreneurial intentions. Building from a critique of the rigour of such approaches, the relative merits of the different approaches to evaluate entrepreneurial skills development are considered. A longitudinal case evaluation is presented highlighting the potential longer term impacts of entrepreneurial boot camps upon the aspirations and destinations of participating scientists and engineers. The paper concludes with an introduction to one approach to scaling such pedogogy using online tools. Here the potential benefits of virtual teams and more effective use of scarce expert resources are posited.

2 From Technology Management Education to Technology Entrepreneurship Education

Clarysse et al. (2009) argue that the management and enterprise educational needs of engineers and scientists can be categorised by considering skills deficits and context of application. Using these categories they built a descriptive framework as shown in Fig. 1. Here they propose that the features by which educational offers vary can be positioned using two axes. First, they propose a skills provision axis ranging from general to specific skills. Second, they argue for an educational aims axis ranging from a focus upon individual career development to meeting an industry level need for more innovation and entrepreneurship. This builds a framework of four quadrants as shown below.

2.1 Technology Management Education for Career Development

The first, (bottom left) quadrant is where generic management skill development is integrated with a focus upon individual career development. This is traditionally

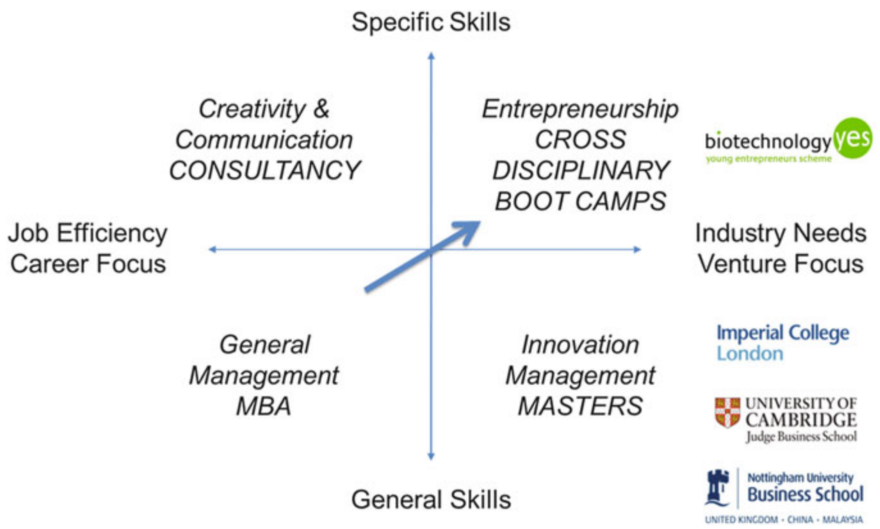


Fig. 1 Supply of management and enterprise education for engineers and scientists (Adapted from Clarysse et al. 2009)

where business schools offered open programmes such as MBAs. Such programmes have a long pedigree of helping engineers build their general management skills and thereby climb up the corporate career ladder. However such programmes are suffering from fierce competition due to the increase in providers and an awareness that general management training as provided by most business schools is becoming detached from the contemporary needs of corporate employers (Starkey et al. 2004).

By contrast, quadrant 2 (top left) integrates specific skills development, such as creativity training, with a similar aim of individual career development. Such programs are increasingly prevalent within blue chip organizations, to meet the need for more creative employees that can work more effectively across the organisation. Such an offer is rarely provided by Business Schools due to a capability gap in this area. Clarysse et al. (2009) observed organisations such as Rolls Royce and Alcatel employing consultants to provide such training.

2.2 *Technology Entrepreneurship Education for Industry Needs*

In the third (lower left) quadrant, we see the integration of generic skills together with industry specific aims. These are exemplified by the developments at the Cambridge MIT Institute. From 2000 to 2001 the Cambridge-MIT Institute aimed to transfer the cross disciplinary capability observed at MIT over to Cambridge to more effectively enact the practice of innovation. As a result, they redesigned some of the MPhil degrees at Cambridge to inculcate a more cross disciplinary approach to teaching and learning.

They built a suite of one year master's-level degrees aimed at scientists and engineers wishing to be more innovative. To cater for this emerging group, Cambridge offered new degrees in contemporary technology areas ranging from sustainable energy and nanotechnology through to biotechnology. These introduce students to the technological breakthroughs aiming to be absorbed by specific industry sectors and they all share a core management module in technology and innovation to better understand the commercialisation of that knowledge within existing organisations.

This lower left quadrant has seen a significant increase in providers with notable UK examples being the University of Nottingham creating MScs in Electrical and Electronic Engineering and Entrepreneurship, Sustainable Energy and Entrepreneurship and Computer Science and Entrepreneurship in 2005 and Imperial College Business School launching an MSc in Innovation and Entrepreneurship in 2012.

The final quadrant (top left) highlights the most novel area of specific skills provision to encourage greater levels of technology entrepreneurship. Binks et al. (2006) proposed that the most effective pedagogic models for developing such entrepreneurial skills was through integrative learning. Only through a combination of theoretical instruction from academics, practical coaching from industry experts and reflection upon entrepreneurial activity could such skills be effectively developed and delivered on a scalable basis. They considered how best to deliver such integrative learning for scientists and technologists. They concluded that entrepreneurial boot camps where participants enact the process of identifying, evaluating and presenting a commercialisation proposal for a novel technology to potential investors to be a highly effective educational method.

Within the UK this has been one of the fastest growing areas of training provision supported by research councils and corporate sponsors. For instance one of the longest running schemes is the Biotechnology Young Entrepreneurs Scheme (YES), an entrepreneurial boot camp for postgraduate life scientists, chemists and chemical engineers. The Haydn Green Institute for Innovation and Entrepreneurship (HGI) has worked closely with the Biotechnology and Biological Sciences Research Council (BBSRC) since 1995 to manage and deliver Biotechnology YES. A new growth plan was agreed in 2005 that introduced content and pedagogical additions based upon HGI research (see Wright et al. 2004; Mosey et al. 2006; Mosey and Wright 2007). This allowed for the scheme to grow and yet retain the rich learning experience enjoyed through small cohorts. The scheme pioneered the use of opportunity identification training, introduced peer reviewed investment pitches for all participants and provided interaction on a large scale with industrialists and equity financiers as mentors and judges across the whole cohort.

As a result, annual participation in the scheme grew from under 200 in 2005 to more than 400 in 2011. In total, more than 4500 academic researchers took part between 1998 and 2014. Expansion into other academic disciplines ensued with a variant for environmental scientists initiated in 2006 (with the Natural Environment Research Council) and two further schemes launched in 2009 to bring this unique delivery model to the engineering and sustainability research communities (with the Engineering and Physical Sciences Research Council).

This growth was further accelerated through wider (industry) partnerships: a bespoke competition was held for microbial and plant scientists at Syngenta's Jealotts Hill research site in 2011. Here participants were tasked with addressing bespoke industry specific challenges using breakthrough technologies. Similarly, a competition for biomedical scientists was launched at GlaxoSmithKline's Bio incubator in Stevenage in 2012, together with the Medical Research Council and Welcome Trust. The CEO of the Bio incubator explained the added value of hosting the competition on industrial sites:

> I've seen many times the value and benefit young entrepreneurs can derive from being exposed to an incubator and seeing for themselves what can be achieved away from academic research. It is a highly networked atmosphere they are not traditionally exposed to early in their careers – a space where early start-ups develop and grow. It's a whole new world which provides a real-life focus.
>
> Martino Picardo, CEO of GSK Bio Incubator, 2012[1]

This continued expansion has been highly endorsed by the UK Government:

> I would like to congratulate all the participants of the Biotechnology and Environment YES competitions on their success. Scientists who are able to combine their expertise with an understanding of business are a very precious resource. By learning how to translate research into wider successes, they can help ensure their work delivers the maximum benefits to society and the economy. I am impressed that the participants are taking the opportunity to develop their skills and knowledge at this early stage of their careers - it suggests a bright future for the commercialisation of UK research.
>
> David Willetts, Minister for Universities and Science, 2011[2]

In terms of supply and demand the trend in the UK seems to be towards industry and venture focussed skills development, with a particular emphasis upon technology entrepreneurship. The demand side appears driven by the disruptive nature of technology developments in ICT, biotechnology and cleantech that can not be easily absorbed within current industry business paradigms (Royal Academy of Engineering 2012). However regarding the supply side there is a relative lack of evidence of the impact of these contemporary forms of technology entrepreneurship education.

[1]http://www.bbsrc.ac.uk/news/people-skills-training/2013/130502-f-enter-now-for-biotechnology-yes/.

[2]http://impact.ref.ac.uk/CaseStudies/CaseStudy.aspx?Id=28495.

3 Evaluating the Impact of Technology Entrepreneurship Education

There is an emerging body of evidence for the impact of the upper left quadrant type technology entrepreneurship education, the entrepreneurial boot camp. The most frequently cited form of evidence is student feedback and there is a healthy debate regarding the validity of such an approach. In summary, numerous constructs have been tested and validated to capture students views of their self efficacy and entrepreneurial intentions before and after taking boot camp type courses (Souitaris et al. 2007). However the relationship between self efficacy, intentions and entrepreneurial action is complex and context specific (Mosey et al. 2007). Moreover, some authors argue that a decrease in self efficacy and entreprenurial intentions of students following a boot camp experience is a positive validation of the impact of the course as it has therefore given students a more realistic appreciation of the challenges inherent in the practice of entrepreneurship.

3.1 Evaluating Entrepreneurial Skills Development

DeTienne and Chandler (2004) take a different approach. They argue that capturing an increase in students capability to identify new business opportunities is a more reliable measure of the impact of technology entrepreneurship education. They developed before and after tests where students are asked to identify new business ideas within a short time period. Experts subsequently categorised both the number of innovative ideas and the quality of those ideas and in this way any increase in capability as a result of the course can be isolated.

Munoz et al. (2011) built upon this approach by also asking students to pictorially represent their understanding of the process of entrepreneurship before and after taking the course. Building upon the work of Zuboff (1988) and Clarkson (2008) these visual representations were analysed for evidence that the students had enhanced their understanding of how entrepreneurship works in practice. There was a remarkably correlation between those students that increased their capabilities to identify new business opportunities through taking the course and those who showed a significant change in their visual representation of entrepreneurship. Figures 2 and 3 below show visualisations drawn by Christopher, a students who did not develop his entrepreneurial capabilities during the course. Here it is clear that there is also a corresponding lack of change in his representation of the practice of entrepreneurship.

By contrast, Figs. 4 and 5 show the visualisations of Michael, a student who significantly increased his capability of identifying new business opportunities through taking the course. Here we can see a corresponding change in his understanding of the practice of entrepreneurship through the changes in drawings.

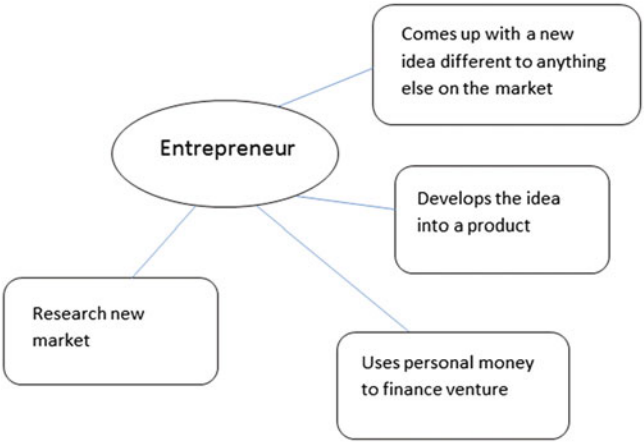
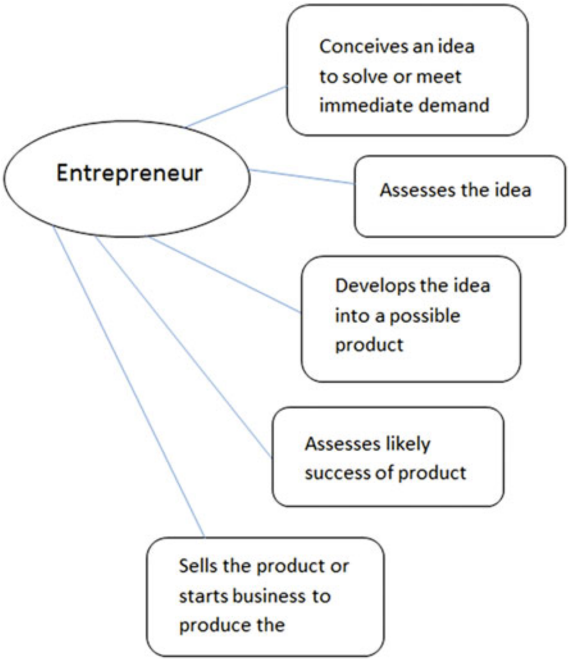


Fig. 2 Christopher, first interview. Student who did not develop his entrepreneurial capabilities during the course

Fig. 3 Christopher, second interview. Student who did not develop his entrepreneurial capabilities during the course



However it still remains to be seen whether this increase in capability and understanding translates into entrepreneurial activity. In the following section we consider the Biotechnology YES scheme which has been established for a twenty year time period over which such outcomes can be realistically evaluated.

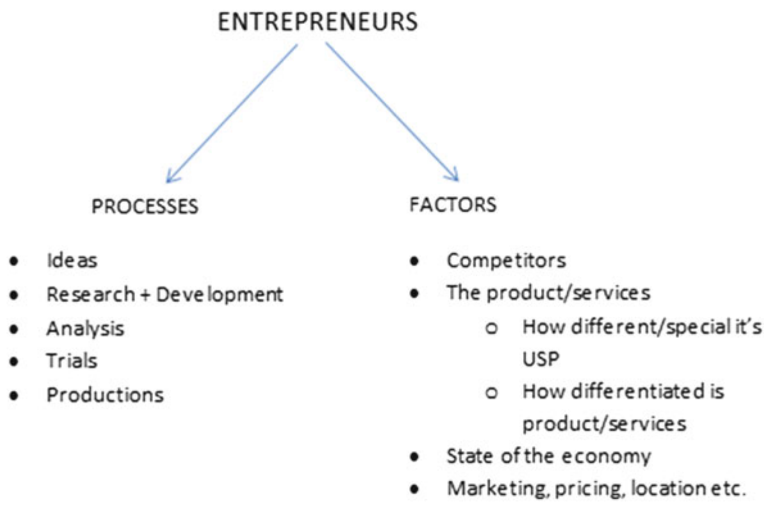


Fig. 4 Michael, first interview. Student who developed his entrepreneurial capabilities during the course

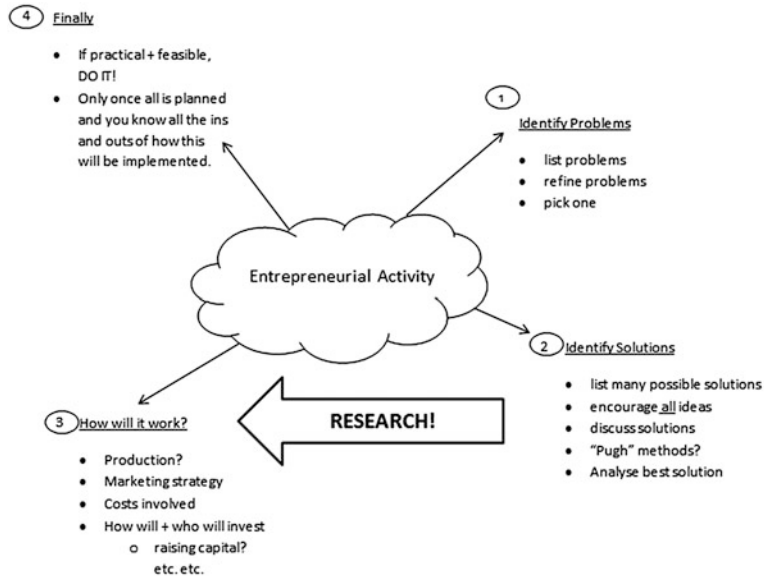


Fig. 5 Michael, second interview. Student who developed his entrepreneurial capabilities during the course

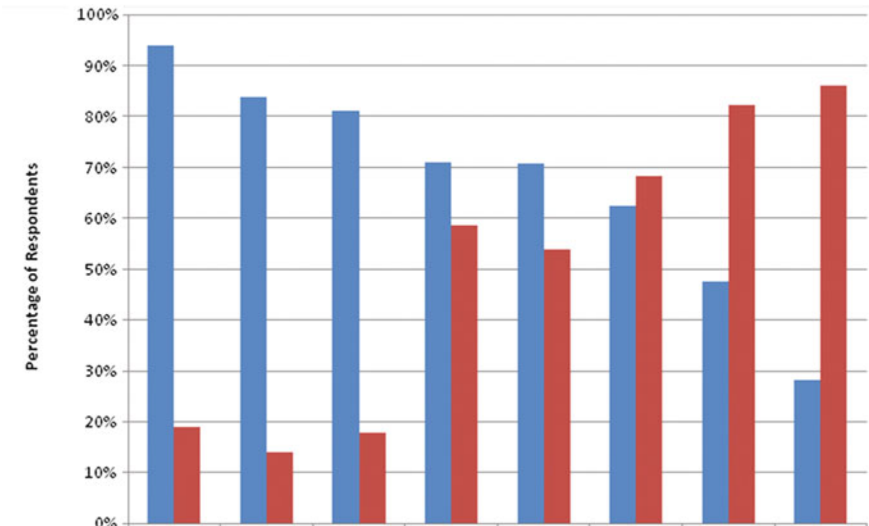
3.2 Evaluating Skills Development and Subsequent Careers Destinations

Webb (2010) conducted an independent review of the Biotechnology YES scheme, commissioned by the BBSRC. They reported that:

Biotechnology YES participants were found to develop a different set of skills than those developed through taking a Ph.D. Specifically commercialisation knowledge, financial awareness and the ability to communicate in a commercial setting were all increased as illustrated in Fig. 6.

Reinforcing the work of Munoz et al. (2011), the participant feedback on completion of the programme presented a common consensus regarding their view of skills developed as a result of participation. They stated that they developed skills in financial awareness, team working, management, verbal communication, and time management within a commercial context. For example:

> I thought the YES experience was excellent. Perhaps my opinion of the course is slightly biased because our team performed well in the competition, but I have taken many varied skills away from the course. The commercial aspect of science is still one that is poorly understood within my faculty and this course gives a great insight into the business world for an emerging scientist/manager/entrepreneur.
>
> Participant, 2009 (see Footnote 2)



	Commercial knowledge and awareness	Financial awareness	Communication in a commercial setting	Management skills	Team working	Interpersonal skills	Time management	Written communication
Biotechnology YES	94%	84%	81%	71%	71%	63%	48%	28%
PhD	19%	14%	18%	59%	54%	68%	82%	86%

Fig. 6 Reported skills development of participating in Biotechnology YES versus those gained from studying for a Ph.D. (Adapted from Webb 2010)

In terms of the longer term impact, Biotechnology YES was found to have a significant impact upon the career aspirations of participants by developing a greater awareness of employment opportunities outside academia and enhancing the propensity to set up their own business. A higher proportion of participants were employed within industry than those researchers that did not participate and Biotechnology YES had a consistent fit with UK and international entrepreneurship and innovation policy.

The evaluation also found that former participants highlighted substantial career and business impacts attributed partly to YES. These ranged from:

> salary uplifts of up to 25 % and 5-60 % of business success being attributed to YES. The financial benefits ranged from £5 k p.a. of self-employed turnover to £200 k of investment funding and, from one business alone, potential licensing income of £3 M. [Webb 2010, page 62]

Despite this strong evidence of impact, there still remains a significant constraint upon the widespread delivery of such programmes. Clarysse et al. (2009) argued this to be a shortage of human capital, a lack of academics and industrialists that have the experience, capability and credibility to deliver such programmes. Mosey et al. (2006) qualified this more specifically as a shortfall in individuals that have the experience to span the different networks of academe and industry.

However, a new development at the University of Nottingham could help address this limitation. Academics at the Haydn Green Institute working together with an entrepreneurial education software provider have developed an online version of the entrepreneurial boot camp experience. This has been successfully deployed with undergraduate students working in virtual teams across the university. The outcomes are summarised in the case study below and although at an early stage this system offers a possible solution to a significant constraint to offering technology entrepreneurship to all.

3.3 Case Study of Using Online Learning for a Cross Campus Entrepreneurial Boot Camp

The Undergraduate Ingenuity Prize is an annual entrepreneurship competition open to students at The University of Nottingham. Participants attend a training boot camp which aims to help them prepare an entry for the competition by taking them through the Ingenuity Process to identify a societal or industrial problem and potentially discover a technological solution. The result of this process may form the basis of their business plan for submission as an entry into the competition. 2015 was the first time that Ingenuity Online, an online version of the teaching and learning approach, had been used at the boot camp for participants.

98 students took part from 28 schools across the University. Roughly half of the students had a business idea that they were bringing to the boot camp versus half without an existing idea. The role of the Ingenuity Process was to help those

students without a business idea to identify an opportunity to develop one and to help those with existing ideas to break them down and ascertain whether there is a demand for their product or service and if their idea is the best possible/most innovative solution to their identified problem.

During the boot camp, the teams were led through the three stages of the Ingenuity Process (Kirkham et al. 2009) using Ingenuity Online. Team members used laptops and mobile devices to access the software and set up their own challenge to work through. Each team was also allocated an external business mentor who accessed their teams' challenges and gave guidance during the process. The mentors gave a mixture of face-to-face support and also took the time to step away from their teams and mentor them solely via the software.

3.4 The Impact of Using Ingenuity Online Learning Tools

The software was seen to encourage users to input a large volume of ideas which are sorted into categories before one is chosen to develop as a solution to the identified problem. In this case, the solution that will be developed forms the student's business plan. The nature of using an online platform to capture ideas is that the students input their ideas by typing them in, rather than having to voice them to the group. This seemed to encourage more ideas to be solicited as there was less pressure on team members to explain or justify an idea. The idea is typed in and participants quickly move on to the next thought. Groups contributing collaboratively in this manner also removed the need for a team spokesperson. This in turn allowed less vocal team members to input just as many ideas as those who are more outgoing.

The boot camp teams were encouraged to come up with more and more ideas against the number generated by their peers. The element of competition within the room encouraged participants to throw more ideas into the mix which gave them a richer pool of possibilities from which to glean a solution. The students were able to re-visit their ideas saved in their challenge within the software and receive additional input from mentors before they submitted their entry to the competition. This had not been possible in previous years when support was limited solely to the boot camp session.

Following the boot camp event, 28 teams submitted a business plan to the competition. Compared to previous years these entries were more cross disciplinary, cross cultural and global in outlook. For example they included overseas projects creating sustainable micro economies in Malawi as well as building recreation spaces in India's overpopulated cities. We also observed highly innovative products that aim to improve sports therapy treatments through to a novel patentable paint packaging product.

4 Conclusion

This paper presents a broad view of the increasing supply and demand for technology entrepreneurship training for engineers and scientists. By considering different evaluation methods it demonstrates that entrepreneurial boot camp pedagogical techniques where students work on commercialising novel technologies together with expert mentors can be highly effective in terms of skills development and encouraging entrepreneurial careers destinations. It highlights a human capital constraint in terms of expanding these programmes and concludes that online learning tools offer potentially novel extensions to the method that require further consideration and experimentation.

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