

Integrating the liberal arts into the body of knowledge for civil engineering systems engineers

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ABSTRACT

The paper outlines the case for a body of knowledge for civil engineering systems engineers to include, alongside its primary focus on engineering and technology, supplementary strands from the liberal arts. A case is made for future thought leaders in civil engineering systems to be exposed to a body of knowledge that goes well beyond current UK engineering undergraduate content, providing the formation for a lifetime career in the design, planning, development and administration of infrastructure and cities systems. This would equip systems engineers with empathy and understanding of the social, economic, governance, cultural, philosophical, historic and business context behind complex civil engineering systems, and enhance skills in analysis, synthesis, collaboration, leadership, and communication skills. A set of exemplar modules is provided to complement the engineering and technology content of post-graduate systems courses.

KEYWORDS: Systems engineers, systems, liberal arts, body of knowledge, civil engineering

At the interface of the liberal arts and engineering

Despite the liberal arts and engineering sciences (the latter as a sub-set of STEM) often being viewed and indeed promoted as distinct and incompatible routes to a tertiary level award, there is a long tradition of theory and praxis which has sought to blend the two curricula - for a number of purposes. From the earliest years, engineering courses in US institutions made space for the liberal arts. In 1867, one third of MIT's mechanical engineering programme consisted of languages and humanities (Florman, 1987). But the pressure to add technical content without increasing the programme duration, stimulated by the growth in the sophistication of engineering knowledge, steadily squeezed out liberal arts courses until leaders of the US engineering profession agreed to set a minimum of 12.5% liberal arts content for approved curricula. This was, and remains, significantly more than taught in their contemporary European engineering courses, although Florman regrets the progressive shift since the 1960s of the taught content within that 12.5% away from the 'great books' representing the cultural and philosophical achievements of civilisation, towards the more vocational subjects for engineers such as economics and social sciences.

In the UK and its 'dominions' in 1891, there were 42 educational establishments giving instruction in Civil Engineering approved by the Institution of Civil Engineers. In the syllabi provided, only one, the Glasgow and West of Scotland Technical College (a forerunner of Strathclyde University), mentions any liberal arts content. 'Besides the examination in the subjects of the first year's course, candidates have to pass an examination in either French or German, and in either Logic, English Literature or Political Economy, before they can be admitted to the final examination in the main subject of the department..' (ICE, 1891)¹

¹ It is interesting that in that same list, the University of Edinburgh core two-year lecture programme for its three-year engineering degree is described as "Systematic Engineering" – an early example of enlightened systems thinking?

To be admitted as a student member of the Institution of Civil Engineers in 1891 required a 'competent knowledge' of English Grammar and Composition as well as two of the optional subjects of Latin; Greek; French, German, Italian or any other modern language; Logic; Chemistry, Geology, Botany or any other branch of Physical Science. Apart from English, the liberal arts subjects were available but avoidable. Competence was measured by examination and the English paper included questions on the geography of the British Empire, the history of the United Kingdom, and on English literature, examples being: 'In what sense may English poetry be said to begin with Chaucer? Name native writers who lived long before him; name also some contemporary with him. Who was the next great English poet in order of time?'; and 'Give a clear outline of any one of Shakespeare's plays, and briefly discuss the leading characters in it.' One would be amazed to see questions such in an entry examination for an engineering institution today, but there is a view that defining only "STEM" subjects for aspiring engineers is too narrow and should be expanded to "STEAM" with Arts being added to Science, Technology, Engineering and Mathematics.

What is the right balance between formalised tertiary education and continuing professional development? Would it be enough for the liberal arts to be picked up in early, mid or even late career as CPD? There is after all a perceived pattern that engineering careers progress in phases where the body of knowledge required shifts from almost entirely technical in early years through to business and economics in middle tier positions, and finally as engineers encounter the challenges of leadership, ethical behaviour and the complexities of human interaction, they wish they had studied more literature, history and philosophy (Florman, 1987). Or, acknowledging those phases, is there a better way to anticipate and prepare for these gradual changes in emphasis? Is there a better way to engineer an education for life?

The dominant narrative about exposure to the liberal arts being a necessary precursor to continuing professional development has been largely replaced by one which highlights the interconnectedness of the systems engineers' design and build and the collaboration imperative which characterises contemporary engineering praxis. Reflection on the relative strengths and weaknesses of a STEM education compared with a liberal arts one in an engineering career context has, perhaps predictably, identified frailties in engineering curricula (Lucky, 2018) and led to calls to provide young engineers with a more liberal education which might imbue them with a more secure underpinning for lifelong learning and professional development (Sample, 1988). A re-discovery of the significance of the interplay between knowing and doing has done much to catalyse progressive thinking on how engineering relates to the arts and humanities (Blockley, 2020). The contemporaneous view that engineers are most satisfied by 'complex, technical problem-solving and the opportunity to work with stimulating colleagues and to make a meaningful contribution to society' (Griggs and Manning, 1985) still rings true today, as does the consequential deduction that to make a meaningful contribution to society requires engineers to have a broad understanding and empathy with society's future socio-cultural as well as its techno-economic and environmental needs and aspirations. So, should STEM become STEAM?

Opinion that many of the skills needed by engineers can be attained outside of a science based curriculum has recently been verified by evidence that students on liberal arts programmes are able to develop engineering professional competencies without detailed engagement with the engineering sciences (Bell *et al.*, 2019). The specifics of how hybrid programmes might be best designed has likewise been the subject of debate and contention as educators deliberate the details of where the emphases should be, what constitutes 'core' in an integrated curriculum, how, when, and with what content should the non-science learning be provided, and whether combined programmes of study might be viewed as 'engineering lite' by students, academics, and employers (Jackson, 2015). For accredited programmes, that debate must also involve the representative bodies of the engineering profession, perceived by many as the greatest challenge to progressive change. But the growing acceptance of accreditation bodies within the 21st Century that sustainability should be a core undergraduate component for civil engineering courses is evidence of progressive institutional thinking.

The search for unifying principles or approaches which can be used to frame such seemingly disparate topics has led to the harnessing of Design Thinking as a paradigm through which creativity and innovation serve as the (discipline-agnostic) yardsticks of value (Rossmann, 2017) and others where design problems explore creativity, compromise, complexity, confidence and confusion as a continuous thread running through an engineering curriculum (Stratford, 2016). Example programmes can now be found at major US colleges (e.g. Amherst, Wellesley) and universities (e.g. MIT, Cornell), and although the Florman of 1987 may have seen this as reclassification of pure liberal arts, there is a growing evidence base of examples where the goals of a liberal arts programme can be achieved while at the same time fulfilling the fundamentals of a traditional engineering course of study (Bucciarelli and Drew, 2015). Recent interest in the wedding of liberal arts with engineering has not been limited to the USA and has, for example, catalysed interest and commentary in Europe, significantly at the University of Aalborg in Denmark (Christensen, 2015) which has produced some of the continent's major thinkers on the relationship between engineered systems and society.

Although these ideas and initiatives have applied many descriptive labels to the end product - 'more rounded', 'renaissance', 'eclectic', 'boundary spanning' 'integrative', 'interdisciplinary'² - there are two acquired aptitudes that underlie all of them; awareness of how different branches of science generate knowledge and make claims to the veracity of the understandings they generate, and the ability to work productively with stakeholders from different perspectives and disciplinary traditions. The first of these requires engagement with the fields of epistemology and philosophy of science whilst the second requires the acquisition of a suite of transferable skills such as problem structuring, collaborative working, and effective communication across the boundaries of (e.g.) specialisms and culture. The following paragraphs pursue this agenda in the context of the contributions that engineers are making to the urgent task of transitioning our cities to be more sustainable and resilient.

² We deliberately avoid systematic use of some of the alternative epithets applied to the 'rounded' scientist or engineer, perhaps the most egregious of which is 'Renaissance Engineer' - the primary examples of which (e.g. da Vinci) often finished little of what they started and were (hugely talented) eclectics rather than integrators.

Designing and delivering future infrastructure and cities

The past fifty years have witnessed dramatic growth in the size and population of cities resulting in significant challenges for urban planners and infrastructure providers. Today's cities are now home to the majority of the world's population, jobs, and GDP and by 2050, the UN estimates that the global urban population will increase by 2.5 billion to constitute 66% of the world's population. Cities attract the talent and investment to drive the next wave of economic and social development around the world. However, they have also experienced weakening links between economic growth, employment and social progress which push an increasing proportion of the population out of the labour market or towards low-skilled and low-wage service sector jobs, thereby fuelling widening income disparities.

Major cities commonly cite infrastructure planning, financing, and implementation among the most pressing issues they face. In addition to shaping how citizens live, work, and play, infrastructure decisions also influence cities' resource use, climate impact, resilience to shocks, and long-term sustainability. Cities rely upon increasingly complex infrastructure systems that underpin the delivery of basic services and support the wellbeing and security of urban communities. These systems are beset by a number of pressures (e.g. growing populations, economic growth, increasing urbanization, deteriorating legacy assets, pandemics, and extreme climate events) which need to be managed whilst simultaneously anticipating future needs and making best use of emerging science and technology to improve the quality, reliability, affordability, and resilience of services. A McKinsey study in June 2016 estimated that US\$3.3 trillion needs to be invested in global infrastructure each year to 2030 in order to support current urban growth rates.

The form and function of future cities will be shaped by a range of ambitions, challenges and opportunities, including;

- Pervasive ICT with omnipresent real-time monitoring and information
- Decarbonised transport systems which make use of electric / hydrogen fuelled vehicles
- Cooperative and collectivist values which underpin new models of shared ownership
- Multi-scale mechanisms for resource recovery and recycling
- Smart grids and appliances for energy and water
- Autonomous conveyance systems
- Social aspirations for environmentally-friendly, safe, secure and culturally inspiring cities
- Intelligent infrastructure systems (supported by advances in the Internet of Things)
- A changing climate and other global risks and events

Professionals charged with imagining, planning, designing, building, and operating elements of the urban environment require new skill sets and understandings if they are to meet these challenges. At post-graduate level they will need to be adept at not only applying engineering and management competencies but also understanding how multi-disciplinary and multi-stakeholder collaborations and alliances can be best assembled to deliver innovative solutions. They will be expected to be able to appropriately exploit scientific discoveries, advances in technology, new business models, and emerging behaviours to the benefit of urban populations. A new breed of civil engineer is needed who can exploit

emerging opportunities in the information and knowledge economy and balance these with an appreciation of business, financial, and operational risks and the impact of solutions on poor, disabled or otherwise disadvantaged populations. The interconnectedness and, in some cases, interdependence of urban landscape elements (e.g. water & energy) will require professionals with a broad understanding across multiple infrastructure systems (Jowitt, 2004). As green infrastructure and urban agriculture becomes a more common feature of our cities, these experts will require knowledge in the environmental sciences and in the complex relationships between cities and their hinterland. The 2020 pandemic has revealed new insights into the resilience of cities that may prompt greater appreciation of the importance of understanding the holistic system of cities and their multiple supporting and synergistic networks.

Doctoral level training provides an essential development opportunity for those wishing to advance their career in the area of future infrastructure and cities. However, as expertise and proficiency is achieved so breadth as well as depth of understanding becomes important. Awareness of, and the ability to interpret and manipulate the central tenets of theories and allied methods is a critical tool in the search for accommodation between different perspectives or approaches. An understanding of the nature of problems, how we might acquire knowledge about the world, the strengths and weaknesses of different forms of enquiry, and the knitting together of knowledge to support action constitute transformatory competences that convert cooperation (working together for independent ends) into collaboration (working together for common ends).

Whilst it is never too early to be exposed to the fundamentals of epistemology or the challenges and rewards of collective endeavour, there is a sense in which the ability to understand and extract practical value from them depends on experiencing or at least understanding what it is to be part of a discipline or to have expertise. This professional confidence and self-awareness will regulate the point in their career at which students (in the broadest sense) should be looking to acquire broad interdisciplinary skill sets. Importantly, movement in both directions should be encouraged so that graduates from the arts and humanities can transition to (perhaps specially designed) post-graduate engineering programmes. Systems engineers cannot of course study all the liberal arts. Just as hospitals do in triage, choices must be made. The following section discusses twelve of the most promising topic areas that could complement a systems engineer's formation by drawing on the liberal arts.

A Body of Knowledge for Civil Engineering Systems

With a primary focus on engineering and technology, programmes should offer supplementary strands from the liberal arts on the social, economic, governance, cultural and business context of civil engineering systems and afford opportunities to acquire and refine analysis, synthesis, collaboration, leadership, and communication skills. We do not propose the following as a necessarily adequate collection of additional understandings and skills but offer a set of example topics which post-graduate training could include.

Understanding the past; engineering foresight from hindsight – ‘Those who cannot remember the past are condemned to repeat it’ (Santayana, 1905). A knowledge of the history of civil engineering, of the systems domain, and of the successes and failures of key

strategic decisions will provide real world case studies to reveal the value of learning from the past. Taking the long view of engineering developments and comparing past approaches in the context of today's knowledge, will enable a critical re-evaluation of the changing validity of drivers for change, and form a rich source of references to inform current systems-based problem solving. Understanding a historian's approach to sources and research gives the systems engineer the research skills to acquire a broader perspective.

Systems thinking and practice - The ability to appreciate different viewpoints and understand problems holistically enables professionals to better appreciate system dynamics and the impacts of n order dependencies. Critical and reflective thinking skills and an appreciative inquiry-based approach helps challenge what appears to be a 'given' constraint or policy-based limitation, identifying and challenging any assumptions. Useful competencies in this context include the use of rich pictures, system mapping, soft systems methods, systems dynamics / causal loop diagrams, and dependency modelling.

Imagining plausible future infrastructure and city systems - Competent engineers will need to work with others to generate well-formed yet still plastic visions of how our cities and infrastructure might look in the mid and far future. Understanding how volatility, uncertainty, and complexity shape how the future becomes and is perceived provides a grounding for exploring the interplay between the physical (e.g. disruptive technologies and changing urban form) and social dimensions of the city space.

The mechanisms and standards that govern the built environment - Cities don't just happen; their physical evolution is partially governed by planning laws, building codes, regulatory imperatives etc.. The paramount reason for acquiring a more than passing acquaintance with these legal obligations, and perhaps more importantly the reasons for their existence, is to be able to challenge their suitability for new circumstances. Innovations in processes and standards can be as stimulating to the realisation of desirable futures as new technologies.

Data science for decision-makers – engineering programmes in all sectors increasingly include digital components. Programme delivery relies on ever-growing quantities of heterogeneous data. The concept of 'Digital Twin' is increasingly employed, with varying degrees of precision. Systems engineers must have knowledge of the key concepts and ideas from data science and data management and how these relate to decision-making processes. This requires a blending of organisational theory, science, technology, and rhetoric, to empower systems engineers to manage governance challenges across formal and informal settings.

Socially responsible innovation - Engineers are a natural connection point between science and society in that they deploy knowledge in the service of humanity. This (albeit implicit) public service imperative brings both responsibility and significant opportunity - and engineers are perhaps not always fully appreciative of the influence that they can wield to ensure that solutions meet a reforming and progressive social agenda. For example, greater awareness of the interplay between risks and responsibilities for community based utilities provision can open up new models for citizen engagement with, and commitment to, novel solutions.

Financing urban futures - The path dependencies created by urban form are sustained over centuries, driving a complex and constantly shifting distribution of costs and benefits across sectors and communities. Arguably the biggest impediment to achieving and scaling infrastructure investments which support non-traditional forms of value such as climate adaptation is financing. Innovative blended funding solutions which can alleviate the financial burden on the public sector by accessing private sector resources are playing an increasingly important role here. Well-rounded solutions will be sensitive to these cost - benefit dynamics across time and space.

Stakeholders and governance – Engineering programmes require robust systems for accountability, peer review and stakeholder management. The people skills and empathy to understand stakeholder perspectives, often conflicting with aspects of the programme aims and objectives, are essential. Delivering a programme with multiple stakeholders, and in highly regulated domains, demands a systems approach to navigate successfully these complex relationships and authorities.

Philosophies of Design for Infrastructure and Cities - The broader cultural contexts within which cities operate have greatly impacted the nature and functioning of the urban experience. The range of aesthetic, ethical, and functional expectations which are brought to bear on urban design and urban designers is vast. Engineers are not immune to the more abstract considerations which characterise such debates and need to be able to reflect on and make judgments about how the qualities of their solutions relate to, for example, public health outcomes, equality and justice, and environmental regeneration.

Leadership and Management – Successful programmes require capable and effective leaders. What we think influences what we do, and in turn, how we think influences what we think. These fundamental influences are central to the subject of philosophy. On the premise that successful leaders need to think well to act well, and that they should also create a climate of thinking that supports successful outcomes, systems thinkers need a deeper understanding of thought and thinking, and to be given the opportunity to test this against real world programme challenges and experiences.

Research methods for change – Systems engineers must be able to communicate effectively and present persuasive arguments that draw on evidence to make compelling recommendations. Research methods are a required core skill and an understanding of the methods and approaches appropriate to the generic topics most likely to be encountered in practice will be invaluable. Coaching on the practical aspects of preparing and writing of evidence-based reports in the context of uncertainty and change is almost certainly applicable to every real world assignment.

Reflection

The ability to provide such a comprehensive body of knowledge will require conventional educational organisational boundaries to be broken and silo-thinking to be challenged. It may well require multi-institution collaboration to provide the necessary breadth and incentive. Challenge focused national research initiatives provide a concrete opportunity to provide these ancillary, but vital, skill sets and several such bodies in the UK (e.g. the Henry

Royce Institute and the Rosalind Franklin Institute) have launched germane training initiatives. Yet others (e.g. UK Collaboratorium for Research in Infrastructure and Cities) have linked these skill sets to the role which transdisciplinarity should play in the structuring and solving of urban transition challenges (Leach and Rogers, 2020). Such ambitions may also require new educational structures that force the traditional academic boundaries to be breached, as the Edinburgh Futures Institute is doing with the Centre for Future Infrastructure's MSc in Leading Major Programmes involving the schools of engineering, philosophy, psychology and language sciences, business, and informatics.

We are, of course, never fully formed as professionals and we are confronted with hard choices when it comes to training budgets and the time we have available to enhance our education. The overlaying of a liberal arts sensitivity to post-graduate engineering training can be achieved in a variety of ways but all will rely as much on the inquisitiveness and aspirations of engineers as on curricula and learning outcomes. The liberal arts imbue a compassion for ignorance and an awareness that there is more than one way to experience, describe, and appreciate the physical world we encounter. So, for example, a common interest amongst engineering and specific liberal arts topics in the particulars of circumstance and situation have been recognised (e.g. Dias, 2014). However, despite these similarities in problem framing, little has been done to exploit the underlying value of non-engineering disciplinary toolsets in teaching curricula.

Ted Wurman, the creator of the TED conferences, has summed up this empathic take on understanding through a simple challenge; 'As you learn about something, try to remember what it is like not to know. This will add immeasurably to your ability to explain things to other people.' Importantly, this perspective does not focus on negotiation and consensus building to generate an ideal communal view balanced precariously between the needs and desires of multiple constituencies. It rather encourages us to engage with the unfamiliar and make bolder efforts to help others refine their knowledge. The liberal arts could be seen as taking engineers out of their comfort zone; replacing the certainties of physical science and mathematics with the ambiguities of meaning and impression. However, it is only by embracing the equivocality of the urban experience that engineers will be able to create supportive, resilient, and sustainable environments for our communities - and there's nobody better placed to do it!

Summary

A case is made for future thought leaders in civil engineering systems to be exposed to a body of knowledge that goes well beyond current UK engineering undergraduate content, providing the formation for a lifetime career in the design, planning, development and administration of infrastructure and cities systems. This body of knowledge integrates the liberal arts with engineering content and is expected to provide the educational formation for practitioners to acquire the habit of learning that will be further developed through career-long CPD. It draws on history, philosophy, law, economics, socio-political studies, creative thinking, data science, informatics, behavioural science, psychology, ethics and organisational theory. In addition to sector specific learning (water, energy, transport, buildings, resource efficiency and resilience), programmes might cover;

- Understanding the past - engineering foresight from hindsight
- Systems thinking and practice
- Imagining plausible future infrastructure and cities systems
- The mechanisms and standards that govern the built environment
- Data science for decision-makers
- Socially responsible innovation – the ethics of technology
- Financing urban futures
- Stakeholders and governance
- Advanced asset management techniques
- Philosophies of Design for Infrastructure and Cities
- Leadership and Management
- Research methods for change

Such learning and praxis agendas would equip the civil engineering systems professional with practical sector specific skills complemented by an understanding of the interdisciplinary skill sets required for a broader perspective.

However, it is difficult to make predictions, especially about the future (Anon) and the pace of change. whilst greater now than it has ever been before, will never be as slow as this again, so the relevance and appropriateness of any postulated body of knowledge for civil engineering systems must be seen as a temporary conceit, to be constantly challenged, reviewed and improved, true to the systems thinking tenet of learning from feedback and experience.

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Anon. Old Danish proverb. Author unknown. Many later variations attributed – eg Niels Bohr, Sam Goldwyn, Yogi Berra, Mark Twain

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