



COMPLEX SYSTEMS

Knowledge resource: The real world is a complex system

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Topic: The importance of teaching and learning about complex systems.

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Learning and teaching resources:

- [Glossary](#): This article refers to many concepts and terms which are more fully described and explained in this companion resource.
- [Ask an MIT Professor: What Is System Thinking and Why Is It Important?](#) – by MIT xPRO on September 14th, 2022
- *What is a Complex System?* (2025) by James Ladyman and Karoline Wiesner: [An overview from Bristol University \(with James Lambert\) here](#), or [the full book published by Yale University Press on JSTOR](#) (which should be accessible via your institution).

Who is this article for?: This article should be read by educators at all levels in higher education who are seeking an overall perspective on teaching approaches for integrating complex systems in engineering education.

Related INCOSE Competencies: Toolkit resources are designed to be applicable to any engineering discipline, but educators might find it useful to understand their alignment to competencies outlined by the International Council on Systems Engineering (INCOSE). The [INCOSE Competency Framework](#) provides a set of 37 competencies for Systems Engineering within a tailorable framework that provides guidance for practitioners and stakeholders to identify knowledge, skills, abilities and behaviours crucial to Systems Engineering effectiveness. [A free spreadsheet version](#) of the framework can be downloaded. This resource relates to the **Systems Thinking** and **Critical Thinking** INCOSE competencies.

AHEP mapping: This resource addresses several of the themes from the UK's Accreditation of Higher Education Programmes fourth edition (AHEP4): **Analytical Tools and Techniques** (critical to the ability to model and solve problems), and **Integrated / Systems Approach** (essential to the solution of broadly-defined problems).

Premise:

We live in a complex world. Complexity is a key challenge, captured in leadership terms by the VUCA framework: volatile, uncertain, complex and ambiguous (Lanucha 2024). Engineers have the privilege of creating products and processes for humans to use in this landscape. Each of these likely has numerous parts which interact, as well as interacting with the environment, people, and needing to meet a host of safety, quality, sustainability, ethics, and financial obligations. Traditionally, engineers analyse problems by breaking them down into simple parts. This helps understanding and makes calculations feasible, but it's easy to lose understanding of the whole system. Any change can easily create a problem elsewhere. From a technical viewpoint, engineers need to understand this interconnectedness in order for their creations to work. In a wider sense, 'systems thinking' is a skill central to engineering quality and management techniques, which seek to rationalise the complexity of entire organisations and their ever-changing market pressures.

The case for understanding systems:

Systems is perhaps one of the most misunderstood words in engineering. It is often found combined with mathematical modelling or control – topics often perceived as challenging – and is used in other fields like Computer Science, where tools and models are different. In all cases, the idea revolves around a group of interacting or interrelated elements which form a unified whole. Those elements can be physical or information, hardware or software, or any combination of mechanical, electrical, and other engineering domains. Thinking in terms of systems can therefore be thought of as a *holistic* approach.

The Engineering Council UK's AHEP criteria include a systems approach: C/M6 – “Apply an integrated or systems approach to the solution of complex problems.” Several other AHEP criteria also reference complexity and complex problems, which they define as having “no obvious solution and may involve wide-ranging or conflicting technical issues and/or user needs that can be addressed through creativity and the resourceful application of engineering science. The Systems Thinking Alliance (2025) gives a broader definition of complexity as referring to “the condition of systems, objects, phenomena, or concepts that are challenging to understand, explain, or manage due to their intricate and interconnected nature. It involves multiple elements or factors that interact in unpredictable ways, often requiring significant information, time, or coordinated efforts to address.” For these, there is no ‘one-size-fits-all solution’ (Ellis 2025). This is the reality that engineers need to manage by understanding the potential effects on all parts of the system.

In order to analyse, engineers dissect complexity into manageable components, and educators teach these simple components before moving onto more complex systems. For example, students initially learn basic electrical components, simple beams, rigid bodies, etc. before bringing these together in case studies, and then moving onto topics like mechatronic systems. Historically, engineers specialised on graduation, perhaps becoming a stress engineer or fluid dynamicist in dedicated offices and functional teams.

A design decision by one team could have unintended consequences for another, as well as additional uncertainty. The advent of cross-functional project and 'matrix' organisations mitigated against this, and companies have moved towards attribute teams which can consider the balance of behaviour. Even so, some uncertainty remains in the form of assumptions in calculations, changes in material properties with temperature or stress, or small variations in composition and manufacturing tolerances, which can all accumulate. Any parts which are bought 'off-the-shelf' or made by other companies under license must be carefully specified. Relationships can be nonlinear – or even chaotic – and contain feedback loops which can amplify changes (Kastens et al 2009). This all increases the risk of a product's comfort, performance, and safety being impacted in ways that weren't anticipated. Any problem that doesn't come to light until the testing phase – late in the design process – represents costly redesigns and delays. In the unlikely event that a problem isn't captured during testing either, the outcome could be disastrous.

Systems engineers will bring the product together and establish these complex behaviours through models and testing. Identifying potential problems early in the design phase can save significant money and facilitate better designs. This can be challenging, especially for systems using novel materials or operating in extreme environments, which aren't accurately captured by standard calculations. Models may be linearised, neglect external forcing, or be derived for an assumed air density or ambient temperature which may not be valid. In recent decades, the engineering industry has moved towards model-based design and virtual prototyping, facilitated by advances in computer tools. These are increasingly sophisticated, but models still need to be built by engineers with an appreciation of complexity and the mechanisms by which a problem could arise. As humans develop new materials and technologies, and explore the limits of what is possible, engineering techniques and calculations need constant revision, and software tools are frequently updated to facilitate this.

That holistic view of problems has benefits outside of designing engineering artefacts. The manufacturing process is itself a complex system with potentially long supply chains. As is the organisation, which is comprised of numerous people operating in a landscape of financial pressures, employment law, politics and culture. Quality guru William Deming's *14 Points for Management* (Deming 2018) can be viewed as a systems approach to handling this complexity, by breaking down barriers between departments and instigating continuous improvement. Once a product is produced, it exists in a wider world and continues to interact with it. From a sustainability viewpoint, this can be the user and surrounding community, the environmental impact over a product's lifecycle, and the financial markets which dictate whether a product is viable. It can also be the social, political, and legal landscapes: these can place direct constraints in the forms of laws governing safety and emissions (such as the UK's legally binding target of net zero by 2050), or through embargos, tariffs, and subsidies. Each country has its own regulations, which can necessitate multiple variations of a product: a good example is cars, which need to be produced in both left- and right-hand drive, satisfy varying safety and emissions regulations, and cater for differing personal and cultural preferences for size, noise, usage and driving styles. Even when not legislated, a company might choose to support fair trade, lead the way in sustainable practices, or refuse to do business with suppliers or regimes they find objectionable – potentially making this a key part of their brand.

An engineer's ability to appreciate and understand the wider social and business landscape is a reason why finance and management consultancy companies can often be seen recruiting engineers at student careers fairs. The Sainsbury Management Fellowship (SMF) scheme notably develops UK engineers as industry leaders, and fellows have made a major contribution to the UK's economic prosperity (RAEng 2025).

Conclusions:

Complex systems are the "real world" that engineers attempt to understand and design for. They are complicated, interconnected, changing, and uncertain. The well-known part of engineering is analysis: breaking systems into understandable parts. There needs to be a parallel operation where those parts are assembled or integrated into a whole, and that whole interacts with everything around it. This is where unforeseen problems can occur. Systems models and a holistic systems thinking approach can mitigate this risk. A systems approach and ability to manage complexity is a key skill for engineers, and positions them well for other fields like management.

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