Australasian Journal of Engineering Education

Emerging learning environments in engineering education

Abstract

Three major challenges, sustainability, the fourth industrial revolution, and employability, will require new types of engineering programs, to help students develop skills in cross-disciplinarity, complexity, and contextual understanding. Future engineering students should be able to understand the needs for technological solutions in context, with sustainable solutions. The engineering graduates should be able to act in complex and chaotic situations.

The question is how engineering institutions are responding now and how they should respond in the future. This article analyses the general responses from engineering education over the last 20 years. These responses are student-centred learning, integration of theory and practice, digital and online learning, and the definition of professional competencies. Examples are given of institutions that are already applying several of these components in the curriculum.

On the long-term horizon, more personalised curriculum models are emerging based on students developing and documenting their own learning and career trajectories, as a part of a lifelong learning strategy.

Introduction – Sustainability, Automation, Employability

There are several challenges for the future development of engineering education. The first challenge is sustainability and climate change all over the world. For the 17 Sustainable Development Goals (SDGs) formulated by the UN, engineering and technologies are of vital importance for the future of the globe (UNESCO, 2017) in at least 12 areas of need – poverty; hunger; health; water and sanitation; energy; employment and economic growth; industry, innovation and infrastructure; sustainable cities and communities; responsible production and consumption; climate action; life below water; and on land. Engineering education is vital in humanitarian, social and economic development and engineering education has to prepare graduates to respond to these numerous sustainability challenges.

The second challenge is the fourth industrial revolution which is on the political and industrial agenda, involving widespread integration of technologies such as automation, the Internet of Things (IoT), artificial intelligence (AI), robotics, advanced materials, additive manufacturing, multidimensional printing, bio-, nano-, and neuro-technologies, and virtual and augmented realities (Lorenz, Rüßmann, Strack, Lueth, & Bolle, 2015; Schwab, 2016). The Boston Consulting Group's focus on industrial production emphasises that the interaction between technologies, such as IoT, robotics, augmented reality, and AI, are all necessary for efficient and automated production (Lorenz et al., 2015). Engineering has not, traditionally, been taught in this integrative manner.

If engineering education should be exemplary and match Industry 4.0's needs and the SDGs, increased interdisciplinary collaboration across a number of existing programs and disciplines is required. As the Boston Consulting Group has indicated, the success of Industry 4.0 depends on the *interaction* and *integration* of technologies in the production of goods and services (Lorenz et al. 2015). At the university level, this will involve collaboration among computer science, data analytics, robotics, automation, production, management, electronics, and materials, as necessary elements in the education of engineers.

Both the SDGs and industry 4.0 have re-strengthened the need for interdisciplinarity as a set of key skills, including systems thinking and design thinking. Empowerment and human values are also key elements in future development, and Schwab argues that "the future should be designed by and for humans and that technologies should treat values as a feature, not as a 'bug'" (Schwab 2016: 592). Schwab also finds that the impact of technology depends on how we apply it and how we let it influence society. This might be a very technology-optimistic approach in the sense that it assumes that we are able to control the application of technology and foresee the impact on society. From a more technology-critical approach, one may say that this is certainly a question of how the societal values and how sustainability will be integrated into the development and application of technology (Christensen S., Delahousse B., Didier C., Meganck M., & (eds), 2018; Domenic Grasso & Burkins, 2009).

The third challenge, the employability and innovation competencies, including entrepreneurship and design thinking, has been on the agenda for some years, but is still unimplemented in many engineering programs. The gap between engineering education and work readiness still exists; integration of theory and practice through a focus on employability and collaboration with industry, using internships, partnership projects and learning labs, are partial solutions to that challenge (Yorke & Knight, 2006). The growing use of various forms of problem/project-based learning is another mechanism, to be discussed later.

These three challenges call for increased emphasis on social responsibility, integration of societal context and interdisciplinarity, combined with digital and generic skills. Responses to these three challenges from engineering education are essential for students to learn the fast-changing, specific skills needed for jobs in a workplace replete with tools of automation.

From an educational research point of view, this is not new, as reports for years have called for new knowledge and skills of various kinds. The OECD is one of the international political organisations calling for more adequate *skills and training systems* encompassing lifelong learning and continuing training, digital skills, *generic skills* (such as literacy, numeracy, and problem-solving for the whole population), and *interdisciplinarity* across research institutions, teams, and departments – private and public – to enable interdisciplinary education and research (OECD, 2017).

But, how do we educate our engineers to take an interdisciplinary, systems approach, including sustainability and human values? Even if the needs for change in the educational system are formulated at a general political level and are specified by many private company organisations, in which directions should engineering education head in the future, and what will these directions involve?

Emerging Trends

This article aims to identify the emerging trends for the future of engineering education, beginning with existing practices. Basically, the future is a result of the decisions that we have made in the past. These decisions have led to existing practices, embodied in curriculum models, teaching and assessment methods, trends and discourses.

Emergence is a key idea – a phenomenon, whereby structures, patterns, and behaviours become visible by types of interactions among smaller elements (Goldstein, 1999; Sawyer, 2001, 2005). Visually, it is like starlings creating the “black sun”, making all kinds of different formations, where each starling is just one element in the patterns that emerge. Similarly, patterns emerge in engineering education, that can give a hint towards the direction of engineering education in the future.

Another way of interpreting the concept of emergence is related to strategic foresight methodology, which identifies short- and long-term horizons (Lustig, 2017). In our case, the short-term horizon contains the current trends of today, or the espoused theory of existing practice, based on prevailing assumptions. This includes obvious best practice and well-defined good practice in a complicated domain. Laboratory practice in engineering classes could be seen as an example of accepted good practice in traditional programs.

The short-term horizon might be a series of fading trends, although we might not see the decrease in importance for some time. (Lectures are probably a fading trend.) There are elements of these good practices that we will want to maintain, e.g., technical competence in selected engineering fundamentals.

The long-term horizon is the shape of the future, which is not yet really clear. Pockets of the future will be visible; however, there may not yet be well-defined and accepted, good practice. The long term can take various directions and might be best described through a set of scenarios. In between the short- and long-term horizons, there are emergent mid-term trends that bridge the two.

In this article, we will start out by conceptualising the technological and societal trends, followed by a review of existing responses from engineering educators over the last 20 years. We will connect the existing trends with the emergence of new, integrated programs, which point the way towards likely future practice.

Complexities and systems

The three challenges described in the introduction result in ever-increasing complexity for technology and engineering projects, and complexity can be seen as an already-existing trend in the requirement for new competencies. For example, the Washington Accord and ABET both call for competencies like complex problem solving and design of systems (International Engineering Alliance, 2017).

The introduction of renewable energy is an example of a complex systems problem. Small and large-scale renewable energy systems cause complex control issues for the larger electricity network. The spectacular failure of the grid in South Australia following the 2016 thunderstorm shows how difficult it can be to balance supply with load under extreme conditions (ABC (Aust. Broadcasting Corp.), 2016). Engineers need to be able to identify the critical performance measures for a system, not just for a single component.

The design of transport systems for a large city is another good example. It is one thing to teach civil engineers to design and construct a road; it is quite another thing to decide where highways and public transport should be built for a city of five million people, considering expected growth to 8 million people over the next 20-50 years.

Similarly, the acknowledged success of Apple's iPod was that it was part of a larger system of music delivery. The iPod was the interface to music rather than a gadget in its own right. This system required understanding at the user level – what we would now think of as the user experience, made up of interactions with the device itself and also music selection, purchase, rating, sharing, and so on. All of this required Apple to negotiate with music executives in order to make their music available through iTunes. This kind of system requires a broad range of skills, including business and societal values as well as software engineering, interface design and stakeholder engagement.

Graduates need human skills, as well as technical understanding and systems-level insights that will be required in their new workplaces. Innovative solutions will be required that genuinely meet customer, client, and community requirements.

From Simplicity to Complexity, from Disciplinary to Cross-disciplinary

The Cynefin framework, Figure 1 (Snowden & Boone, 2007) is a useful way of understanding the complexities involved. Situations are divided into simple, complicated, complex, chaotic and disorder.

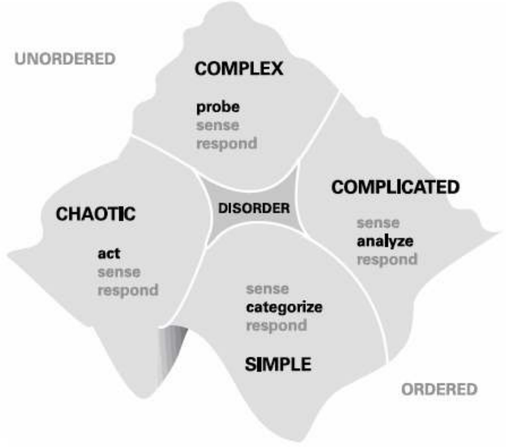

Figure 1: The Cynefin framework (Snowden & Boone, 2007)

In the *simple* category, system behaviour is well understood. Best practice has been defined and can be implemented. Practitioners should act as follows: sense, *categorise*, and respond. Engineering fundamentals fall into this category. A student recognises a familiar problem (sense), categorises it as "flow in a pipe", for instance, and responds by applying the right formula from fluid mechanics. Many exam questions are of this kind.

Similarly, much research addresses defining behaviour that can be well understood, for example, how a column buckles under a load or how a material behaves under fatigue. Much of this understanding is captured in engineering codes of practice. This domain is also easily amenable to computerisation, as has been achieved in the last 40 years, in areas such as structural engineering, computational fluid dynamics and multi physics programs, e.g. COMSOL and ANSYS. These packages have become the basis of a more recent trend to digital engineering and digital twins as a means to predict future performance of complicated engineered systems (Aurecon, 2019).

The *complicated* domain requires *expert* behaviour, where there are multiple right answers. Design of a bridge or a mobile phone falls in this category. Behaviour should include: sense, *analyse*, and respond. It is no longer a case of quickly identifying the right formula but first identifying (sensing) all the design requirements before *analysing* them in order to synthesise a solution. Students need practice in these kinds of complicated situations to develop these design skills. Student design projects can fit in this category, e.g. design a process to convert solar thermal energy into cooling for air conditioning.

Systems engineering provides a structured framework for this kind of work, providing a set of well-defined procedures that can simplify the *complicated* situation (INCOSE, no date). The sequence of design units in engineering programs addresses this capability to varying degrees, depending on discipline and institution. Students learn to deal with complicated scenarios and to create designs that satisfy the system requirements.

Complex situations are the domain of *emergence* of competencies: *probe*, sense, and respond. It is not clear whether there is a good solution to a problem or opportunity. Complex problems fit what (Rittel & Webber, 1973) called 'wicked problems'. These authors defined characteristics of such problems as: there is no definitive formulation of the problem and the chosen formulation shapes the nature of solutions that are considered; there is no best solution, just better or worse; there is no stopping rule (is the problem solved?); every attempted solution counts significantly and will disturb the system; there are innumerable solutions; every wicked problem is a symptom of another, bigger problem.

Designing transport systems for large cities is a complex, wicked problem. No matter how much modelling is conducted, every new motorway or public transport route is a new experiment. It may or may not work the way it was designed because people may or may not choose to use it. There is no stopping; the problem is never solved; cities just keep growing. Different routes and innovations have their own benefits and side-effects. Which one should be built first?

In some systems, a good outcome will emerge unintended. For instance, the text message service we take for granted on our mobile phones was a simple add-on to the original design. For many young people, text messages, and other forms of instant messaging, are their main form of communication with their friends; voice calls are so last century. This could not have been predicted by the original mobile phone designers.

Student projects can also provide opportunities for complexity and emergence. A bridge project can easily be rethought as a river-crossing project, allowing new solutions, such as a tunnel or ferry, to be considered. The bridge form could also be emergent – multi-span beams or cable-stayed beams, for instance. This is low order complexity, but it gives students an experience that solutions can emerge from the team and in consultation with the stakeholders. A key question is always: *What problem are we solving?*

Our educational systems also show complex characteristics. Every student is different, with different backgrounds, motivations, and expectations of their future career and life directions. Collectively, student cohorts constantly change due to the impact of technology and many social factors, in ways that we categorise as Gen-X, -Y, and -Z. Our professions are changing; the problems that graduates face are changing; the body of knowledge is changing. Professions are rapidly remade through new, emergent challenges and capabilities.

Chaotic situations, beyond the complex domain, are often the result of disaster, whether natural or manmade. Action is required to stabilise the situation before methods from the complex, complicated, and simple domains can be applied. These are likely not the kinds of topics that fall within an engineering degree, except in engineering ethics, which is often studied within the context of past engineering disasters. Students need to be able to learn from these past disasters to ensure similar things do not happen again, such as the Challenger disaster (Presidential Commission, 1986) and the VW faked emissions scandal (Veksler, 2017).

We need engineering curricula that include complexity and the complicated. Many current models, based on simplicity (the obvious) – e.g. learning fluid mechanics, solid mechanics, thermodynamics – are useful, but are only part of the skill set required. Students also need the opportunity to design a bridge or a Wi-Fi network or a racing car or a transport system.

Complicated design tasks take students beyond the simple application of scientific formulas and provide the opportunity to learn integrating competencies across discipline boundaries, integrating the societal context, values, and sustainable system competencies. There are multiple good answers, and students need to be able to seek a good match between stakeholder requirements and the proposed solution. Stakeholder requirements extend well beyond technical sufficiency.

The best student projects also offer glimpses of complexity. Open-ended projects allow student groups to take projects in their own direction. A robotics group might begin to explore locomotion in a robot and end up creating a bipedal walking robot (over several semesters). The final solution is not predictable, with constant adjustment of intended learning outcomes.

Complexity is expressed in both the curriculum and in the learning environment. Students, at the start of their studies, rarely know where they will be employed in the future or what they need to know when they get there. However, as time goes by, a sense of purpose *emerges*. Students should have the opportunity to become active learners, shaping their future careers by engaging in real situations and seeking solutions. Initially, this needs to include *complicated* situations using *simple* engineering fundamentals.

However, as time goes by, students must be made aware of the *complex* situation in which they find themselves – to develop themselves and the competencies they will need for their intended careers. They need to act by *sensing* their emerging future career direction, *probing* for learning situations that align with their interests, and *responding* by seeking new learning opportunities in the following semester.

The point is that it is not a question of whether students *should* learn simple, complicated, and complex knowledge that prepares them for an emerging chaos; it is that they *must* learn all these aspects and the curriculum should be organised to encompass all aspects. To educate students for the future, they should have the possibility to learn both single disciplines and cross-disciplinarity as well as both the simple and complicated technical knowledge and skills and the complexity involving understanding of context, systems, sustainability, and values (Figure 2).

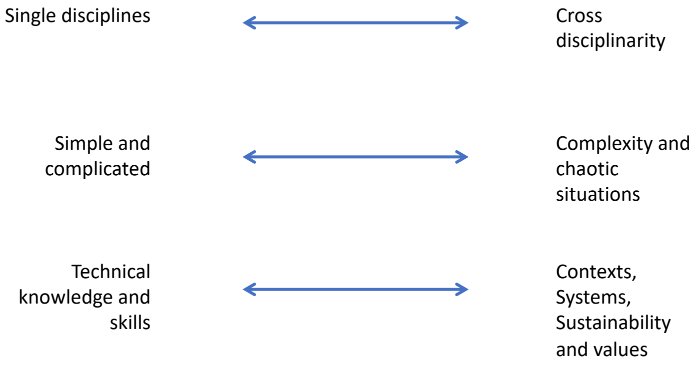

Figure 2: Content dimensions in development of future engineering education

This increases the requirement for new types of integrated curricula as this cannot be added onto the curriculum without creating overload (Fogarty & Pete, 2009). Therefore, the need for more systemic curriculum models has emerged in order to secure progress throughout education. Where most curriculum development has taken place as an add-on strategy in single modules or subjects, systemic integration strategies are needed to plan for both poles in the dimensions of Figure 2. To learn single disciplines, the simple, complicated, and technical knowledge can be achieved within single modules. However, to learn cross-disciplinarity, complexity, systems, and sustainability, requires a much more coordinated and integrated curriculum, crossing the traditional boundaries of single modules and disciplines.

Existing responses from engineering education

How are institutions responding to these challenges, and what emerging trends can be identified for learning methodologies? As general trends, there are four types of responses which may be combined in the curriculum in different ways: 1) student-centred learning, 2) contextual and practice-based learning, 3) digital learning and 4) professional competencies. Each of these responses are short-term emergence as they already represent existing practices, however mostly in “pockets” of the curriculum and mostly at a single course[1] level.

---

[1] By course, we mean subject or unit, a component of an engineering program.

These four trends are based on literature review and the authors' long experiences within the field as trends are combined to broader categories that are emerging from short-term to expected long-term trends.

Student-centred learning

The last 30 years have seen the emergence of new *student-centred learning methods*, such as active learning, collaborative learning, team-based learning, design-based learning, inquiry-based learning, and problem- and project-based learning (PBL). There are many more different student-centred learning concepts than the ones mentioned, so it can be hard to cover all aspects as the application of the learning concepts might also differ to a great degree in practice. For example, active learning is a broad category that covers a wide range of different learning activities, ranging from action-oriented lectures through cooperative and collaborative learning, leading to problem-based projects as the highest level of student activity (M. Prince, 2004; M. J. Prince & Felder, 2006).

The overall trend is that there is a clear move away from the traditional academic curriculum, where the academic lectures the students, to a much more engaging and involving curriculum, where students influence the direction of their learning within a given academic framework, e.g. (UTS, 2015). The political system in some countries and the accreditation bodies have supported this trend through changes of accreditation criteria, moving from a focus on inputs (academic content) to a focus on outputs in the form of learning (International Engineering Alliance, 2017).

Student-centred learning is a well-researched area. Studies on active learning, inquiry-based learning, design-based learning, and challenge-based learning show positive effects on learning outcomes (Atman et al., 2007; M. Prince, 2004; M. J. Prince & Felder, 2006; Roselli & Brophy, 2006; Yadav, Subedi, Lundeberg, & Bunting, 2011). These results demonstrate that involving students in the decisions on their own learning process has a positive effect on their learning.

Problem- and project-based learning (PBL) are commonly proposed solutions in engineering education as a response to a requirement for more complex (and complicated) learning. Also, the PBL approaches have proven successful, and it is no longer a question of whether PBL is working or not, but the questions now concern the quality of PBL implementation, because the practice of PBL varies tremendously by including both problem-based and project-based learning with many variations of these two educational approaches (Savin-Baden, 2015).

Despite the variations in practice, the philosophy and learning principles are basically the same, and, in the general PBL literature, results indicate increased motivation for learning, decreasing drop-out rates, and increased competence development (Dochy, Segers, Van den Bossche, & Gijbels, 2003; Strobel & van Barneveld, 2009). Increasing knowledge retention is another field where PBL seems to have an impact (Norman & Schmidt, 2000; Strobel & van Barneveld, 2009). Furthermore, PBL has been seen as a way to bridge the gap between engineering education and engineering work and developing professional competencies (Anette Kolmos & Koretke, 2017; Lamb et al., 2010; Royal Academy of Engineering, 2007).

Most often, the implementation of PBL often begins in an existing single subject or course. Problems in the projects are mostly formulated within the academic (technical) context, and this is what many authors characterise as course-based PBL (Ahern, 2010; Gavin, 2011; R Hadgraft, 2017; A. Kolmos, 2017; Nedic, Nafalski, & Machotka, 2010; Popov, 2003; Roselli & Brophy, 2006; Thomas, 2000). The course-based PBL has its limitations in achieving more complex learning; however, these academic-initiated projects may be very useful in helping students to understand and resolve *complicated* issues.

Course based projects are different from projects in a more systemically oriented curriculum, which has the possibilities of organising projects of various sizes and types of problems and learning outcomes. Problems can range from academic- and theoretically initiated projects to projects initiated by different societal and industry actors with more authentic problems. Most often, this is some kind of student project in collaboration with a company or a member of the broader community, or it is a project identified and formulated by students themselves.

Motivation rises with student-initiated projects, where students identify problems and have a high degree of influence on the direction of the project. Motivation is a key ingredient in learning, and it is rather important that students actually learn how their own motivation can be increased and how they learn in the best way (P. R. Brown, McCord, Matusovich, & Kajfez, 2015; Benoît Galand, Raucent, & Frenay, 2010; Roger Hadgraft, Francis, Lawson, & Araci, 2018).

Contextual Practice

Along with the trend of student-centred learning, there is a trend of *contextual, practice-related learning*, where students have elements in the curriculum related to later work situations, including internships, industry projects, entrepreneurship, and innovation hubs. Externally initiated projects are often very hard to control in an academic curriculum, as the problems might lead in a different direction than first anticipated. Research indicates that student motivation increases when working with company projects, as students experience these learning situations as more authentic and exciting, because there is an identifiable customer (Benoit Galand, Bourgeois, & Frenay, 2005; Zhou, Kolmos, & Nielsen, 2012).

Collaboration with companies can be shaped in various ways, from an informant or case level where students go out to observe practices, to real collaboration and partnership where students are working on solving identified problems in the company. These are exactly the kinds of projects that give students a sense of the complex domain in which solutions emerge through engaging with the problem in all its real-world complexity.

This trend also encompasses internships, where students are out in placements for periods in their study in order to let students get an understanding of the complex-problem situations in which they will engage at work, e.g. (UTS, 2019). Normally, internships are regulated, or at least encouraged, at a political level and in many countries there has been a pendulum swaying from a dominant academic curriculum to a more practice-related curriculum – also named as academic and employability drifts (Christensen & Erno-Kjolhede, 2011).

Internships are, surprisingly, not well-researched from the point of view of learning outcomes. During the last 30 years, the literature mainly describes development projects and recommendations for how to improve the learning in internships as there are mixed experiences from the perspectives of the students, the academics and the industry partners. There are positive outcomes such as increased understanding of future work and application of academic knowledge, which adds motivation for academic learning. However, there are also negative comments highlighting the often poor connection between academic learning and engineering practice, sometimes caused by a lack of effective facilitation of the learning in the workplace (Henriksen, 2013; Linn, Howard, & Miller, 2004). Therefore, many of the development projects focus on new guides for company employees facilitating the trainee or guides to academic staff on how to facilitate the reflection on practice and its relationship to academic knowledge (Heitmann, 2005).

Digital learning

Digital learning (including the flipped classroom) is the third teaching and learning methodology. This trend has roots back to distance learning in the 80s, and earlier, but it has taken totally different shape during the last 15 years. Digital learning today is to be found in blended learning strategies (Beetham & Sharpe, 2013; Buus, 2016). Digitalisation is more than offering online learning platforms and environments like Blackboard or Moodle; it is using new technologies for learning, such as augmented reality, 3-D visualisation, etc (Buus, 2016). It is also a key support for active, student-centred learning.

The digital learning that has been developed is a new way to present the scientific content, applying new media instead of the lecture, supported by the paper-published textbook. The university movement of massive open online courses (MOOCs) pushed the online and digital learning forward in engineering education, although MOOCs are mostly a distance learning system. However, today, many lecturers will find that their students will join a MOOC within their subject area (usually at another, more prestigious university) to complement the lecture part or actually to replace lectures (Liyanagunawardena, Adams, & Williams, 2013).

During the last 10 years, the flipped classroom has dominated the online learning approach in on-campus education. The flipped classroom combines “digital learning” and “on-campus” learning, with elements of active learning, in order to engage students in the classroom. The online part is normally a structured preparation part, such as videos, quizzes, reading, or a collaborative activity before the classroom – so, instead of starting out with presenting the theory and then letting the students work on assignments, it is flipped to let students start by watching a video on the content before they come to class. The class is much more dominated by learning activities, where there are facilitated activities to prepare them for assignments (Bishop & Verleger, 2013; Jenkins et al., 2017; Reidsema, Kavanagh, Hadgraft, & Smith, 2017).

The flipped classroom, as a student-centred learning model, is a response to the most widespread teaching and learning methodology in engineering education, which is instructional textbook learning organised as lectures, tutorials, and laboratories, combined with solving small exercises. This way of learning is traditionally initiated and organised by the teacher in a classroom or lecture hall.

Research indicates that lectures are not the most efficient learning method; lectures originates from a point in history where there were no books for students, and the lecturer therefore read the book to the students (Bligh, 1972; Hanford, 2012). However, even if the practice of lectures today might have changed significantly, and the lecturer is not reading the book but trying to explain the book and engaging students in problem-solving exercises, particularly in flipped classrooms, it often corresponds to the lower levels of Bloom's taxonomy and from the Cynefin framework to the *simple* aspects in discipline subjects, where rule-following works.

Professional competencies

Another emergent trend in engineering education is the growing importance of the integrated learning of *professional competencies*. This is a 21st century response to the employability challenge and is still an emergent response from some engineering institutions, but it is on the long-term horizon, and it will involve new competencies from engineering students, through meta-learning, to be able to identify and develop their own competencies in a personalised way (Goldberg, Somerville, & Whitney, 2014; Domenico Grasso & Burkins, 2010; Bart Johnson & Ulseth, 2016; Turns, Sattler, Yasuhara, Borgford-Parnell, & Atman, 2014).

Even if students work in collaborative learning environments, it is each individual's responsibility to construct their own *learning trajectory*, which may include various *blended learning communities*. For each of these communities, the individual will participate in collaborative activities, but the individual will have to integrate their learning in a personal way, to suit their career intentions. The interaction between creating individual learning trajectories and participating in collaborative community activities or collaborative projects will increase and become a new, emerging trend. Portfolios will play a key role in this process, helping students to articulate their learning to themselves, their academic mentors, and to future employers at a job interview.

In summary, the four emerging trends are (i) a shift from teacher-centred to student-centred, active learning, (ii) more engagement in contextual engineering practice, (iii) the use of digital learning tools, and (iv) personalised learning, evidenced through portfolios. What curriculum models are now emerging that embrace these trends?

Future Curriculum Models

Each of these pedagogical trends has been applied in engineering education all over the world with various levels of success and various degrees of integration into the curriculum. But as an overarching trend, there has definitely been a move from teacher-driven to much more of a student-driven learning environment and an emerging trend is a tendency to start developing curricula at a system level, which involves coordinating all the curriculum elements. This is quite difficult and challenging and usually needs outside assistance for most teaching teams.

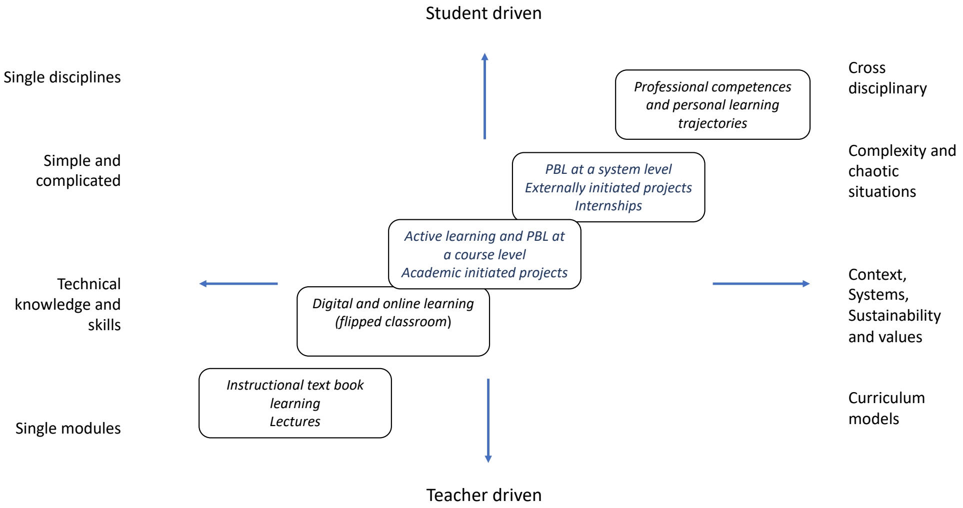

Figure 3: Combined dimensions of short term emergence in engineering education

Figure 3 sums up the evolution of educational responses from lectures and text books (box, bottom left) to personal development of professional competencies (box, top right). There is a shift from teacher driven to student driven (vertical axis).

In the horizontal dimension, new models of learning have shifted from single modules to whole-of-curriculum models, from single disciplines (the simple and the complicated, with technological knowledge and skills taught in single modules) to integrated curricula based on complicated and sometimes complex problems. Digital and online learning is being applied in a student driven way; however mostly it is a digitalisation of content combined with some active learning.

Active learning and PBL at a course level is placed in the middle. This is normally the academic initiated projects and with learning outcomes within the disciplines, whereas PBL at a system level plus externally initiated projects calls for an open approach to identify and solve problems.

The professional competencies and personal learning trajectory go beyond complexity, cross disciplinary, context, sustainability and curriculum models as these competencies concern how to participate in complex problem identification and solving, which will require team work and collaborative knowledge construction. That element also goes beyond the university curriculum as it points at competencies for lifelong learning.

So, in shaping new educational models, it is clear that several factors must be included to address the challenges of today. First, there needs to be opportunity for students to operate at simple, complicated, and complex levels. Much of the simple knowledge, e.g., learning fluid mechanics, is steadily moving online. Students will *demonstrate* mastery online as well. With this knowledge, students can also design complicated systems, such as an urban storm-water systems. A complex scenario, using this and other disciplinary knowledge, would be the assessment of flooding in a coastal city due to combined rising sea levels and increasing rainfall intensities.

Complex situations, as well as complicated ones, inevitably push students to consider *multidisciplinary* perspectives. Flooding in cities due to climate change is not just a challenge for hydraulic engineers. It is an issue faced in urban planning, law, social work, architecture, etc. Such projects should run across the university rather than within a single discipline or faculty.

This, then, impacts our curriculum models. Timetables must allow students from different faculties to work together on such projects. A first step is to create university-wide electives in which all students can enrol and participate. A next step is curriculum models made up of (mostly) project opportunities. Students undertake some simple and complicated models to build technical capability and then engage in more complex ones to build cross-disciplinary capabilities.

These projects combine the development of several competencies – technical ones as well as social/environmental skills, such as communication, teamwork, ethics, and sustainability. The third category of skills includes design and problem solving. This is a generic capability, common to many design disciplines, including engineering. It is probably best known as design thinking, a process with typical steps of empathise, define, ideate, prototype, and test (T. Brown, 2008). Design has been further formalised as systems engineering (Shamieh, 2011).

It is clear that the curriculum must extend beyond traditional academic objectivity. Problems in the world are complex, with many differing points of view. Students must develop the skill to understand problems in context, to seek multiple perspectives, and to grapple with different value systems. Students need skills to deal with subjectivity as well as objectivity. Finally, the curriculum must facilitate students to create their own learning trajectories in blended learning communities, which will become an important future competence.

Emerging Models of Integrated Learning Environments for Complexity

There are numerous examples of curricula changes at a system level combining the different new pedagogical elements in various ways. Three examples of recent curricula are considered here to show mid-horizon emerging trends.

The first example is a way to move to an integrated curriculum in a large, research-oriented university, and the following two cases are completely new programs.

The **University College London** (UCL) Engineering Faculty has recently introduced their Integrated Engineering Program (Graham, 2018). This program dedicates one week in five to an integrated project. UCL has three ten-week terms, so each of these is divided into two five-week sprints, made up of four weeks of teaching followed by a one-week project.

The benefit of such a change process is that much of the teaching can remain fairly traditional, even if it is now technology enhanced. Each academic discipline has to consider how the project might integrate the term’s topics. For instance, a building design project could include structural engineering, foundation engineering, some transport (parking) concepts, as well as estimation of quantities, cost estimation, construction scheduling, and project management. Students quickly see the connections between the separate modules they learn – hence, the title of Integrated Engineering.

This is, potentially, not too disruptive to the teaching team (other than the loss of two weeks of the term), and it paves the way for rethinking the five-week module as an integrated project. Now that the project has been defined, as above, could the students learn the contributing knowledge online or in a mix of online and drop-in classes over that five-week period?

There are two new Australian programs that have used this idea of the integrated project as the basic module of program design.

Charles Sturt University (CSU), in New South Wales, commenced their new Engineering program in 2016 (Lindsay & Morgan, 2016). In a radical departure from most programs, students take three project-oriented semesters in which they learn as required; students use half their time on projects and half their time on online modules (Ulseth & Johnson, 2015). The academic staff have assembled the Tree of Knowledge in civil engineering, so that students can complete online modules as required. These initial semesters build the basic competencies for practice (Engineers Australia, 2017). Students then take four one-year work placements to develop breadth and depth in their chosen discipline.

Students have the option of summer school to undertake projects at the university, where their current employer might not be able to provide the right kinds of experience. For instance, a local authority employer can provide plenty of experience in road design and maintenance as well as in storm-water design but may be unable to provide direct experience in structural design. A student at such an authority could spend a few weeks back at the university in the summer to boost his/her structural capability.

Swinburne University in Melbourne has a similar approach, except that students do all their projects at the university. Each project runs over six weeks, working with an industry sponsor. Students also study modules when required, defined by the Swinburne Wheel of Competencies (Daniel & Mann, 2017). The learning environment operates like an engineering company, with students inducted into the workplace with normal health and safety protocols and also expected to undertake pro bono work according to “company policy”. This approach balances the need for a “real-world” approach with a structured academic environment – particularly useful for students in their first year.

The three examples above are pockets of future curricula. The key elements are *integrated learning* at a systemic level through projects in all of the examples, together with just-in-time, *online learning* in the latter two examples. A third element is the use of portfolios to help students to connect their project work to their long-term career aspirations (Lawson et al., 2015).

Iron Range is another excellent example of such integrated practice, where engineering students work on company projects and continuously reflect on their own learning (B. Johnson, Ulseth, Smith, & Fox, 2015; Ulseth & Johnson, 2015).

At many institutions, the reflection, development and articulation of professional competencies were identified as key ingredients in helping students to grapple with the emergent nature of their careers. As they progress, they become more skilled at selecting projects that build the competencies for the kinds of employment that they envisage for themselves, including self-employment in a start-up. The institutions listed above are just some of the examples combining the four short-term emerging elements. Other institutions have also moved towards a whole-of-education model.

Ruth Graham has recently analysed some of these new educational models and proposed that there are actually two types of institutions: those with new programs and those with a change of existing programs (Graham, 2012, 2017). The group of institutions with the most extensive student-centred learning models include the new civil engineering program at Charles Sturt University in Australia and the new engineering program at Iron Range, Minnesota, USA.

Interestingly, both of these institutions are in the geographical periphery (in regional areas, away from the main cities). The same has been the case with several of the 1970s reform universities in Europe, such as Aalborg, Roskilde, and Maastricht Universities, as they were simultaneously new regional universities while enacting radically new pedagogical models (some form of problem-based learning). The advantage of being a newcomer on the periphery is that there are not so many institutionalised academic traditions to address in the development process of a new institution.

However, change of engineering education also happens at geographical centres, even though these institutions often have long historical roots. Examples include University College London (above) and also MIT, which is about to integrate projects, linking the various discipline courses in a progression mode (NEET, 2019). The change is, however, often more limited in the degree to which student-centred learning can be progressed, given the natural conservatism of high-prestige universities.

All these institutions serve as living labs for future engineering education, where it is possible to see and experience other curriculum systems and, importantly, to research the outcome of these new institutions. The systemic approach is important because research on educational change clearly indicates that only *integrated systemic change* will be sustained in the longer term (Graham, 2012). Change in isolated elements in the curriculum is unlikely to be sustained if lecturers change or system requirements create restrictions, e.g. perceived resource constraints for project-based learning (Fullan, 2007; Graham, 2012; Thomas, 2000).

Discussion and perspectives

This article has identified the emerging trends for the future of engineering curricula in response to the three main challenges: sustainability, the fourth industrial revolution, and graduate employability.

Four short term emerging trends have been identified: student-centred (personalised) learning, experiential learning (integration of practice), digital and online learning, and, finally, professional competencies.

These elements are already combined in various ways by institutions, and there is a clear trend in curriculum planning, shifting the focus from modifying single courses to designing whole curricula, as described in the examples above.

There are four competencies that are critical to these changes: complexity, systems thinking, interdisciplinarity, and new curriculum models.

Learning how to handle *complexity*, both in terms of subject knowledge, competencies and collaborative skills, is an emerging requirement. In order to educate students for that purpose, engineering education needs a more *systemic* approach. Learning complexity will be difficult within the existing boundaries of the individual disciplines, as complexity can be characterised by embracing dichotomies like disciplinary/interdisciplinary knowledge, theories/practices, contextual/abstract understanding, individual/collaborative knowledge construction, subjective/objective knowledge, and academia/corporate collaboration. Learning to handle these dimensions will require learning situations that encourage students to experience these dilemmas and to seek solutions.

This is one of the reasons that externally initiated projects might provide a better platform for learning complexity than academic-initiated projects with theoretical problems. Understanding of complexity derives from the dilemmas and the choices that are made in applying academic knowledge to contextual, real-world challenges.

However, there is still a need for learning both the *simple* and *complicated* aspects of engineering practice and, indeed, also learning how to analyse and solve complex and even chaotic problems.

What can be observed is that lecturers are applying more active-learning methodologies and that online learning has become a part of a “traditional lecture” via the flipped classroom. These trends are short-term trends and already in practice. There are mid-term emerging trends, such as application of more personalised, student-centred learning methodologies, where more time in the curriculum is allocated for students’ project work, and these projects are becoming more complex in collaboration with external stakeholders. This will give students the opportunity to learn how to deal with complexity and chaos. When more time in the schedule is allocated for student-driven projects, it will involve a more systemic and holistic re-thinking of the coherence of the curriculum.

In order to provide a learning environment where students do have a chance of learning complexity, engineering education has to be organised in a more systemic way. Most engineering curricula are organised by courses/modules/units/disciplines, where a certain number of credits are compulsory/mandatory, and the rest of the credits are electives. The different courses normally have pre-requisites, and by that, an implicit progression is woven into the study.

Most lecturers are concerned about their own courses and might be less concerned about how the various courses are related to each other in a system, to produce the final, holistic graduate outcomes. This has the implication that it is the students who have to build their own comprehensive understanding of their discipline and that the professors do not necessarily contribute much to the construction of this holistic understanding. For most universities of today, active learning will be applied, and some of the courses will have an emphasis on students working on projects. However, the holistic development of graduate capabilities is, often missing.

This traditional single-course approach is slowly changing, and there is a new trend emerging, where the engineering curriculum is approached as a system. This trend originates from the early European reform universities from the 60s and 70s, which were established with a new pedagogy. Also, the CDIO community has advocated for a much more integrated and holistic curriculum (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014). The CDIO syllabus covers learning outcomes, including professional skills, as an integrated part of the curriculum. CDIO proposes 12 standards that, altogether, encompass several organisational levels in engineering education (REF?).

With the new industrial developments, there are new expectations for engineering knowledge, skills, and competencies with a much broader approach, including values, ethics, social responsibility, and sustainability, alongside the existing technological knowledge. Especially as IoT transforms engineers' use of technology, the required competency profiles will change. Mastering the level of technical calculations will be (mostly has been) taken over by technology itself. What will be left is to be able to understand the social, environmental and economic requirements for each new development of technology and its application.

However, engineering institutions might be falling behind in re-thinking the entire curriculum for educating students to handle complex situations. Most commonly, changes are made at the single course level which leads to a lack of alignment between the technological and societal developments and responses from the educational system.

The relation between the individual and collaborative dimension is intertwined in this process. Complexity will require more resources than individuals can provide – it will require a systems approach with teams of individuals in a shared and mutual process of cognitive understanding and development. The identity of the individual will be challenged in the sense that there will be a shift in the focus from satisfaction of individual contribution to satisfaction of collaborative contributions. This involves a new way of understanding oneself as a professional, involved in several parallel projects, as is often the case in the workplace, and it is what computer-supported collaborative learning and networked-based learning communities address with new individualised learning trajectories mimicking the kinds of knowledge management systems common in large organisations. (Maynard et al., 2012; Rongbutsri, Ryberg, & Zander, 2012; Ryberg, Davidsen, & Hodgson, 2016).

And where will we see engineering education go from here? There are no clear conclusions on that – and surely engineering education will take various courses. However, there will be issues that will have to be addressed.

On the long-term horizon, the combination of personal learning trajectories, professional competencies, and complexity will become the dominant trend. There is a need for lifelong education, and universities will collaborate with companies, including publishers, in solving this challenge. The educational system will not only have to re-think the content of the curriculum and its function as educator of new professionals but, indeed, to combine engineering education with continuing education in formal and informal learning communities. Single engineers will become much more responsible for their own personal learning paths, and they will need to learn how to organise and construct their individual learning growth within combined collaborative learning communities.

Access to new knowledge is growing with MOOCs and other online learning and this trend will increase. However, having online tutorials does not automatically lead to learning and capacity building. Students need to create the competencies of lifelong learning individually as well as at a community level. Learning how to learn collaboratively and individually by critical reflection on the combined elements in the learning process such as experience, experiment, theory, societal values, and future-orientation is a complicated process. Students will need to develop their self-awareness, together with systems thinking, normative and anticipatory thinking (REF to UNESCO SDG report). They will need both to imagine different possible scenarios as solutions to present challenges and imagine their own development of competencies.

References

ABC (Aust. Broadcasting Corp.). (2016). SA power outage: How did it happen? *ABC News.* Retrieved from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwiyl4fymt_eAhVHVH0KHRL6D34QFjABegQIBRAB&url=http%3A%2F%2Fwww.abc.net.au%2Fnews%2F2016-09-28%2Fsa-power-outage-explainer%2F7886090&usg=AOvVaw0oODaEfX5LIArZij42jy0H

Ahern, A. A. (2010). A case study: Problem-based learning for civil engineering students in transportation courses. *European Journal of Engineering Education, 35*(1), 109-116. doi:10.1080/03043790903497328

Atman, C. J., Adams, R. S., Cardella, M. E., Turns, J., Mosborg, S., & Saleem, J. (2007). Engineering design processes: A comparison of students and expert practitioners. *Journal of Engineering Education, 96*(4), 359-379.

Aurecon. (2019). What is digital engineering? Retrieved from https://www.aurecongroup.com/expertise/digital-engineering-and-advisory/defining-digital-engineering

Beetham, H., & Sharpe, R. (2013). *Rethinking pedagogy for a digital age: Designing for 21st century learning*: routledge.

Bishop, J. L., & Verleger, M. A. (2013). *The flipped classroom: A survey of the research.* Paper presented at the ASEE national conference proceedings, Atlanta, GA.

Bligh, D. A. (1972). *What's The Use of Lectures?* Harmondsworth, Middlesex: Penguin Books Ltd.

Brown, P. R., McCord, R. E., Matusovich, H. M., & Kajfez, R. L. (2015). The use of motivation theory in engineering education research: a systematic review of literature. *European Journal of Engineering Education, 40*, 186-205. doi:10.1080/03043797.2014.941339

Brown, T. (2008). Design Thinking. *Harvard Business Review*(June).

Buus, L. (2016). From Website to Moodle in a Blended Learning Context. *International Journal of Web-Based Learning and Teaching Technologies, 11*(1), 51-64. doi:10.4018/IJWLTT.2016010104

Christensen S., Delahousse B., Didier C., Meganck M., & (eds), M. M. (2018). *The Engineering-Business Nexus* (Vol. vol 32): Springer.

Christensen, S. H., & Erno-Kjolhede, E. (2011). Academic drift in Danish professional engineering education. Myth or reality? Opportunity or threat? *European Journal of Engineering Education, 36*(3), 285-299. doi:10.1080/03043797.2011.585225

Crawley, E. F., Malmqvist, J., Östlund, S., Brodeur, D. R., & Edström, K. (2014). The CDIO Approach. In *Rethinking Engineering Education* (pp. 11–45): Springer.

Daniel, S. A., & Mann, L. M. W. (2017). *Embedding social impact in engineering curriculum*. Paper presented at the 45th SEFI Conference, 18-21 September 2017, Azores, Portugal.

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and instruction, 13*(5), 533-568.

Engineers Australia. (2017). Stage 1 Competency Standard for Professional Engineer. Retrieved from https://www.engineersaustralia.org.au/sites/default/files/resource-files/2017-03/Stage%201%20Competency%20Standards.pdf

Fogarty, R. J., & Pete, B. M. (2009). *How to integrate the curricula*: Corwin Press.

Fullan, M. (2007). *The New Meaning of Educational Change, Fourth Edition* (4 edition ed.). New York: Teachers College Press.

Galand, B., Bourgeois, E., & Frenay, M. (2005). The impact of a PBL curriculum on students' motivation and self-regulation.

Galand, B., Raucent, B., & Frenay, M. (2010). Engineering students' self-regulation, study strategies, and motivational believes in traditional and problem-based curricula. *International Journal of Engineering Education, 26*(3), 523-534.

Gavin, K. (2011). Case study of a project-based learning course in civil engineering design. *European Journal of Engineering Education, 36*(6), 547-558. doi:10.1080/03043797.2011.624173

Goldberg, D. E., Somerville, M., & Whitney, C. (2014). *A whole new engineer: the coming revolution in engineering education*: ThreeJoy Douglas, MI, USA.

Goldstein, J. (1999). Emergence as a construct: History and issues. *Emergence, 1*(1), 49-72.

Graham, R. (2012). *Achieving excellence in engineering education: the ingredients of successful change*. Retrieved from

Graham, R. (2017). Phase 1 engineering education benchmarking study 2017.pdf.

Graham, R. (2018). *The global state of the art in engineering education*. Retrieved from United States of America: neet.mit.edu

Grasso, D., & Burkins, M. (2009). *Holistic Engineering Education: Beyond Technology*: Springer.

Grasso, D., & Burkins, M. (2010). *Holistic engineering education: Beyond technology*: Springer Science & Business Media.

Hadgraft, R. (2017). *Transforming Engineering Education: DESIGN must be the Core*. Paper presented at the SEFI Annual Conference 2017, Azores.

Hadgraft, R., Francis, B., Lawson, J., & Araci, J. T. (2018). *Summer Studios – Lessons from a 'small bet' in student-led learning*. Paper presented at the SEFI 2018, Copenhagen.

Hanford, E. (2012). The Problem with Lecturing. Retrieved from http://americanradioworks.publicradio.org/features/tomorrows-college/lectures/problem-with-lecturing.html

Heitmann, G. (2005). Challenges of engineering education and curriculum development in the context of the Bologna process. *European Journal of Engineering Education, 30*(4), 447-458.

Henriksen, L. B. (2013). *What did you learn in the real world today? : the case of practicum in university education*. @Ålborg: @Ålborg University Press.

INCOSE. (no date). What is Systems Engineering. Retrieved from https://www.incose.org/systems-engineering

International Engineering Alliance. (2017). Washington Accord. Retrieved from http://www.ieagreements.org/accords/washington/

Jenkins, M., Bokosmaty, R., Brown, M., Browne, C., Gao, Q., Hanson, J., & Kupatadze, K. (2017). Enhancing the design and analysis of flipped learning strategies. *Teaching & Learning Inquiry, 5*(1), 1-12.

Johnson, B., & Ulseth, R. (2016). *Development of professional competency through professional identity formation in a PBL curriculum.* Paper presented at the Frontiers in Education Conference (FIE), 2016 IEEE.

Johnson, B., Ulseth, R., Smith, C., & Fox, D. (2015). *The impacts of project based learning on self-directed learning and professional skill attainment: A comparison of project based learning to traditional engineering education.* Paper presented at the Proceedings - Frontiers in Education Conference, FIE.

Kolmos, A. (2017). From Course Based PBL to a Systemic PBL Approach. In A. Guerra, R. Ulseth, & A. Kolmos (Eds.), *PBL CURRICULUM STRATEGIES* (pp. 1-12). Holland: Sense Publishers.

Kolmos, A., & Koretke, R. B. (2017). *PROCEED-2-WORK Nyuddannede ingeniørers erfaring med overgang fra uddannelse til arbejdsliv*. Retrieved from

Lamb, F., Arlett, C., Dales, R., Ditchfield, B., Parkin, B., & Freng, W. W. (2010). *Engineering graduates for industry*. Retrieved from

Lawson, J., Hadgraft, R., Male, S., Shrestha, S., Lowe, D., Lemckert, C., . . . Lloyd, N. (2015). *Developing a national approach to eportfolios in Engineering and ICT*. Paper presented at the Australasian Association for Engineering Education Conference 2015, Torquay, VIC, Australia.

Lindsay, E., & Morgan, J. R. (2016). *The Charles Sturt University Model - Reflections on Fast Track Implementation*. Paper presented at the ASEE Annual Conference, New Orleans.

Linn, P. L., Howard, A., & Miller, E. (2004). *Handbook for research in cooperative education and internships*: Routledge.

Liyanagunawardena, T. R., Adams, A. A., & Williams, S. A. (2013). MOOCs: A systematic study of the published literature 2008-2012. *The International Review of Research in Open and Distributed Learning, 14*(3), 202-227.

Lorenz, M., Rüßmann, M., Strack, R., Lueth, K. L., & Bolle, M. (2015). Man and machine in Industry 4.0: How will technology transform the industrial workforce through 2025. Retrieved from https://www.bcg.com/publications/2015/technology-business-transformation-engineered-products-infrastructure-man-machine-industry-4.aspx

Lustig, P. (2017). *Strategic Foresight: Learning from the future* (Vol. 7): Triarchy Press. Kindle Edition.

Maynard, N., Kingdon, J., Ingram, G., Tadé, M., Shallcross, D. C., Dalvean, J., . . . Kavanagh, J. (2012). *Bringing Industry into the Classroom: Virtual Learning Environments for a New Generation.* Paper presented at the Proc. 8th Int. CDIO Conf.

Nedic, Z., Nafalski, A., & Machotka, J. (2010). Motivational project-based laboratory for a common first year electrical engineering course. *European Journal of Engineering Education, 35*(4), 379-392. doi:10.1080/03043797.2010.490579

Norman, G. R., & Schmidt, H. G. (2000). Effectiveness of problem-based learning curricula: Theory, practice and paper darts. *Medical education, 34*(9), 721-728.

OECD. (2017). *Meeting of the OECD Council at Ministerial Level Paris, 7-8 June*

ENABLING THE NEXT PRODUCTION REVOLUTION:

A SUMMARY OF MAIN MESSAGES AND POLICY LESSONS. Retrieved from Paris, 7-8 June 2017:

Popov, A. (2003). Final undergraduate project in engineering: Towards more efficient and effective tutorials. *European Journal of Engineering Education, 28*(1), 17-26. doi:10.1080/0304379021000055722

Presidential Commission. (1986). Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident. Retrieved from https://spaceflight.nasa.gov/outreach/SignificantIncidents/assets/rogers_commission_report.pdf

Prince, M. (2004). Does Active Learning Work? A Review of the Research. *Journal of Engineering Education, 93*(3), 223-231. doi:10.1002/j.2168-9830.2004.tb00809.x

Prince, M. J., & Felder, R. M. (2006). Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases. *Journal of Engineering Education, 95*(2), 123-138.

Reidsema, C., Kavanagh, L., Hadgraft, R., & Smith, N. (Eds.). (2017). *The Flipped Classroom: Practice and Practices in Higher Education*. Singapore: Springer.

Rittel, H. W., & Webber, M. M. (1973). Dilemmas In a General Theory of Planning. *Policy Sciences, 4*, 155-169.

Rongbutsri, N., Ryberg, T., & Zander, P.-O. (2012). *Personalized learning ecologies in problem and project based learning environments.* Paper presented at the Designs for Learning 2012, Proceedings of the 3rd International Conference Exploring Learning Environments.

Roselli, R. J., & Brophy, S. P. (2006). Effectiveness of Challenge-Based Instruction in Biomechanics. *Journal of Engineering Education, 95*(4), 311-324. doi:10.1002/j.2168-9830.2006.tb00906.x

Royal Academy of Engineering. (2007). Educating Engineers for the 21st Century. Retrieved from http://www.raeng.org.uk/news/publications/list/reports/Educating_Engineers_21st_Century.pdf

Ryberg, T., Davidsen, J., & Hodgson, V. (2016). *Problem and Project Based Learning in Hybrid Spaces: Nomads and Artisans.* Paper presented at the Proceedings of the 10th International Conference on Networked Learning 2016.

Savin-Baden, M. (2015). *Rethinking learning in an age of digital fluency : is being digitally tethered a new learning nexus?* Abingdon, Oxon ; New York, NY: Routledge.

Sawyer, R. K. (2001). Emergence in sociology: Contemporary philosophy of mind and some implications for sociological theory. *American journal of sociology, 107*(3), 551-585.

Sawyer, R. K. (2005). *Social emergence: Societies as complex systems*: Cambridge University Press.

Schwab, K. (2016). Shaping the Fourth Industrial Revolution. January 11, 2016. In.

Shamieh, C. (2011). *Systems Engineering for Dummies*. Hoboken, NJ: Wiley.

Snowden, D. J., & Boone, M. E. (2007). A Leader’s Framework for Decision Making. *Harvard Business Review*, 69-76.

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. *Interdisciplinary Journal of Problem-based Learning, 3*(1), 4.

Thomas, J. W. (2000). A review of research on project-based learning.

Turns, J. A., Sattler, B., Yasuhara, K., Borgford-Parnell, J., & Atman, C. J. (2014). *Integrating reflection into engineering education.* Paper presented at the Proceedings of the ASEE Annual Conference and Exposition. ACM.

Ulseth, R., & Johnson, B. (2015). *Iron Range Engineering PBL Experience.* Paper presented at the Project Approaches in Engineering Education, San Sebastian, Spain.

UNESCO. (2017). Sustainable Development Goals. Retrieved from http://en.unesco.org/sdgs

UTS. (2015). Learning.Futures - What is it exactly? Retrieved from https://www.uts.edu.au/sites/default/files/article/downloads/What-is-learning-futures.pdf

UTS. (2019). Internships. Retrieved from https://www.uts.edu.au/current-students/current-students-information-faculty-engineering-and-it/internships

Veksler, D. (2017). The Real Scandal Is the EPA's Diesel Policy, Not Volkswagen. Retrieved from https://fee.org/articles/the-real-scandal-is-the-epas-diesel-policy-not-volkswagen/

Yadav, A., Subedi, D., Lundeberg, M. A., & Bunting, C. F. (2011). Problem-based Learning: Influence on Students' Learning in an Electrical Engineering Course. *Journal of Engineering Education, 100*(2), 253-280. doi:10.1002/j.2168-9830.2011.tb00013.x

Yorke, M., & Knight, P. (2006). *Embedding employability into the curriculum* (Vol. 3): Higher Education Academy York.

Zhou, C., Kolmos, A., & Nielsen, J. F. D. (2012). A Problem and Project-Based Learning (PBL) Approach to Motivate Group Creativity in Engineering Education. *International Journal of Engineering Education, 28*(1), 3-16.