Interplays of humanism, cognitivism and behaviourism in design engineering
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Principal learning theories include behaviourism, humanism, cognitivism and constructivism. Each has held sway in education for a period and has contributed to our ability to develop and deploy evidence-based curriculums and learning environments. This chapter considers the contributions of these learning theories and their relevance to the design, engineering and hybrid domains, with a particular focus on the recently developed curriculum for an integrated masters in Design Engineering at Imperial College London.

Behaviourism suggests that learning, like all behaviours, are either reflexes produced in response to environmental stimuli (see, for example, Scales (2008)), or as a consequence of an individual's experience, especially influenced by positive reinforcement and punishment. This is dependent on an individual's motivational state, controlling stimuli and environmental factors. Proponents of behaviourism have developed their theories based on experiments with animals and humans, using repetition and reward or reinforcement as incentives. It has been repeatedly demonstrated that an animal can be taught to do a task if the animal has a clear motivating reason for doing it. For example a hungry cat in a maze will invest time and energy in finding a way out in order to get food (e.g. see Petty (2004)). Whether understanding is part of such processes has long been debated. Human learning is understood to be more complex, involving thinking, reasoning and social factors. Gilbert (2003) notes, “as we approach a learning situation, there is always a part of our brain that pops the question: ‘Do I need this learning in order to survive? Yes or no?’... if the answer is no, forget it.” These observations indicate the importance of the motivation for learning. An adult may ask whether an activity will help them in achieving a long term objective. If it will, then intrinsic motivating factors can kick in, and just as the animals in the experiments learned that there was a reward in getting the task right, so learners can be encouraged to achieve because the outcome is worth it, helping them achieve their long term goal.

Short term motivation strategies are also important. Gilbert (2003) suggests that “one of the differences between external and internal motivation can be found in the difference between rewards and celebrations.” Gilbert likens a reward to a bribe, providing only extrinsic motivation and a celebration to an achievement which helps provide intrinsic motivation.

Humanist theories of education involve consideration of the education and development of each person as a unique individual and their development with positive self-esteem (Scales (2008)). In humanist thinking a holistic approach is key with the cognitive, psychomotor and affective domains all interleaved. Learning is about a
balance of knowledge skills. A particular facet of the humanist approach to teaching is that learners should be encouraged to find their own personal goals to develop learner autonomy (Wilson (2009)), taking responsibility for their own learning. By taking responsibility for one’s own learning and engaging in self-reflection, it is possible for an individual to learn to be constructively critical of one’s own work and engage in a process of continuous improvement.

The cognitivist approach to learning involves the development of understanding by active learning, challenging and questioning, rather than just absorption of information in a passive environment. Cognitivism sees learning not as behaviour but a mental process. It is therefore individual and about acquiring knowledge and integrating it into a personal mental structure or schema. Proponents of cognitivism suggest that this leads to deep as opposed to surface learning. Deep learning involves understanding of a concept or issue and commitment of the learning to long term memory in a manner that it can be recalled and applied. Petty (2004) notes that learning occurs when an individual constructs their own meanings, usually from their prior learning and experience (see Bednar et al. (1992) and Ertmar and Newby (2013) for reviews of constructivism, sometimes considered to be a development from cognitivism). The learning is transformative as the individual is able to use this understanding to tackle different problems to those involved in the educational context and do useful tasks in the real world.

Bloom’s taxonomy (1956) is a key theory within the cognitivist school of learning. His classification defines knowledge, comprehension and application as low-order skills, and analysis, synthesis and evaluation, as the high-order skills. The low order skills do not demand much cognitive attention, while the higher order skills involve demonstration of functional knowledge and are where connections are made and deep learning occurs.

Experiential learning was first suggested by Dewey (1910) who devised a five stage reflective model encouraging thinking about answers in order to provoke reflection and as a result identify a solution. This was subsequently developed by Kolb (1984, 2014) into the experiential learning cycle. This learning theory suggests that the maxim you live and learn is only part of the story, and you are more likely to get caught up in a vicious circle than a learning cycle if you don’t take time to reflect on an experience. The stages of Kolb’s learning cycle are concrete experience, reflection on practice, abstract conceptualisation, and planning active experimentation. The teacher’s role is to set-up meaningful reflection and help support the skills to make this educationally useful. The cycle can be started at any point but should then be followed in sequence. Active experimentation, for example, encourages learning by trial and error and willingness to give something a go. This can help start the cycle all over again, never ceasing to reflect, continuously learning and improving and thus avoiding the harmful and recurring cycle of cause and effect.

We have had the privilege of developing a brand new curriculum for an MEng in design engineering. This has allowed for consideration of the merits of the humanist, cognitivist, constructivist and behaviourist pedagogic paradigms. Recent practice and evidence in engineering has favoured cognitivist, active-learning approaches. However there is value and best practice arising from each of the paradigms and we have embraced an interplay between humanism, cognitivism, constructivism and
behaviourism, with implementation of goal setting and active learning as well as training.

The domains of engineering and design are well established with many sub-categories, traditions and cultures of learning and progression into professional practice. Factors such as health and safety, reliability, ethics and financial considerations have led to regulation of aspects of the professions and this has resulted in the adoption of some common elements in syllabi across the world. Educational pathways and the interest base of individuals have combined to a bifurcation based on whether a candidate has skills in the sciences and mathematics or art and technology. This chapter argues that there is a need for practitioners who have skills in aesthetics, analysis and rationale, and therefore the case for a new type of education in design engineering, defined as the fusion of design thinking, engineering thinking and practice, within a culture of innovation and enterprise.

Recognising that there are no universally accepted definitions, the following statements provide an indication of what design and engineering are taken to encompass within the context of this chapter.

- Design is the process of conceiving, developing and realising products, artefacts, processes, systems, services and experiences with the aim of fulfilling identified or perceived needs or desires typically working within defined or negotiated constraints (Childs (2013)).
- Engineering is the application of scientific and mathematic principles in combination with professional and domain knowledge, in order to design, develop and deliver artefacts, products and systems to realise a societal, commercial or organisation requirement or opportunity (Childs (2013)).

These definitions illustrate considerable overlap between design and engineering, albeit acknowledging that engineering tends to involve quantitative analysis.

As noted in Robinson et al. (2004) a significant proportion of engineering education has roots in the enlightenment movements, the industrial revolution and the need to master scientific principles and manufacturing processes. Design however has a heritage in the master and apprentice model as well as vernacular traditions and design school traditions. The historical nature of both domains and the extent of worldwide activity have led to well-established approaches to learning and teaching with strong associated rationales. These encompass passive acquisition of materials, laboratory and workshop training, experimentation, goal-setting, for example, Krajcik et al. (2008), problem based learning (Albanese and Mitchell (1993), Hsieh and Knight (2008), Yadav et al. (2011)), reflective practice Kolb (1984) and active learning with expert feedback Wieman and Gilbert (2015a, b).

Evidence of the merits of the practice of expert thinking and associated expert feedback has been widely acknowledged (e.g. see Wieman and Gilbert (2015a, b)). Such practices are common in design schools where operation within studios has been adopted with associated critique from subject experts. Problem based learning has been widely adopted in engineering with some studies reporting significant advantages over traditional passive approaches (Yadav et al. (2011)).

Modern engineering degrees tend to involve both technical and transferable skills. As noted previously, regulatory factors have a significant influence in defining curriculums
such as UK SPEC, in the UK, and ABET, in the US. The National Academy of Engineering (2004) has defined attributes for the engineer of 2020 to include strengths in science and mathematics, practical ingenuity, creativity, good communication and mastery of the principles of business and management. Childs et al. (2010) suggest that the modern engineer needs to have diverse skills including: re-design, co-design, customisation, management of resources, intellectual property and technical expertise. Effective practice and implementation of these represents an advanced skill-set enabling the engineer to operate in changing circumstances. While regularity bodies, globalisation and market factors, have had some harmonising effects on educational offerings there are some national and regional distinctive offerings. Chinese design and engineering can be characterised by a convergence between science and the rich cultural heritage (Brezing et al. (2010)), while in South Korea there is an emphasis on creating industrial and economic value by merging the humanities, sciences and the arts.

Design can be viewed as a core or integrating factor in engineering pulling together skills in engineering science, manufacture, management and commerce. As noted in the definitions given for design and engineering there is significant overlap. Nevertheless the domains have established distinctive traditions and cultures. As an example, compliant materials tend to be considered very differently in engineering in comparison to design. Various hybrid educational pathways have emerged exploring the boundaries between design and engineering. A pioneering programme in this area has been the IDE masters run jointly by Royal College of Art and Imperial College London. This was founded in 1980 under its original moniker of Industrial Design Engineering and was renamed in 2008 as Innovation Design Engineering, keeping the IDE acronym. IDE inhabits the tri-partite worlds of design, engineering and trans-disciplinary activity and also extends these by generating experimental and exploratory work (Childs and Pennington (2016)). A facet of the programme is the aspiration to generate people who are adaptable in their thinking, and able to explore both problems and opportunity and see design as an enabler. It was in the context of significant experience from the IDE programme and the rich heritage of engineering and design education and practice that a new undergraduate programme in design engineering was developed to meet both a sector need as well as to open up new opportunities as a result of such an offering.

Design modules at Imperial have tended to be popular. Examples include electives in subjects such as Design Art Creativity and Design Led Innovation and New Venture Creation (see Leon et al. (2012)), which have been consistently over-subscribed. A market review combined with knowledge of the domain indicated that several institutions were already offering degrees in related areas that were popular and fulfilling a useful purpose such as Product Design Engineering and Engineering Design. A survey of 100 schools resulted in a positive indication of interest in the potential for a design engineering MEng, and similarly a survey of 15 industries with connections to the university indicated a positive reaction to the proposal. These positive indications were taken as a mandate to proceed with more detailed development of curriculum and assembly of the resources that would be required.

Alternative options were considered for the degree including:
- Fat and studio based (fat in this context being students taking a module intensively without parallel activity)
• Thin and studio based (thin in this context typically associated with students undertaking a few to several modules simultaneously)
• Thin and project intensive
• Portfolio based
• Thin and partial studio and project intensive hybrid.

A fat structure as used on IDE was considered as it is associated with high levels of deep learning, enhances motivation, avoids distraction and provides opportunity for reflection on a significant outcome. However, despite the many attributes associated with a fat structure this was ultimately not selected, with consideration being given to the nature of the majority of students in their early years in higher education, where learning styles are still maturing combined with the unforgiving nature of fat modules. If a student misses a part of an intense module, for example due to illness, then they are likely to drop behind very quickly and if they fail to fulfil a learning outcome then, unless there are opportunities to recover the learning, a student may not be able to progress, at least until the module repeats in a subsequent year. Another major stumbling block to the adoption of a fat structure was integration with other existing degrees. There was a desire to make some of the modules from the new MEng available to other programmes in the faculty, and such aspirations became a significant factor in decision making, particularly around some of the proposals to run multidisciplinary group projects.

While each of the schemes considered had merits, the option ultimately selected was a thin structure with typically three or four modules being undertaken simultaneously for the first 2.5 years, followed by a six month industrial placement, prior to the students returning for a final year. The programme can be considered to comprise a series of broad themes:
• Design
• Engineering
• Professional Practice and Enterprise
• Cyber Physical
• Mathematics

The programme commences with development of skills in communication addressing development of sketching, presentation and CAD abilities, alongside mathematics and engineering science. A key aspect of the degree is major design and design engineering projects. These commence in term 1 and increase in scale and levels of integration term by term. As the skills base in engineering science, analysis, mathematics and professional practice builds the projects become increasingly design engineering in focus requiring integration of skills and consideration of more ambitious project scope. While considerable freedom in project scope is offered to the students with the majority of project ideas being student generated, training in a series of key skills is provided in order to assist students to have confidence in taking forward their project ambitions.

A major feature of the degree is project work providing opportunities for students to undertake substantial items of work within a studio environment where there are opportunities for peer to peer and expert panel reviews, critique and self-reflection. This focus is extended to many of the engineering science modules where much of the learning is achieved through project work. An example of a strand featuring
significant levels of project work include computing 1 and 2, electronics 1 and 2, gizmo, robotics 1 and 2. The programme includes a significant proportion of attention to commercially orientated activities in the major design and design engineering projects, design 1 & 2, engineering design project, the group and solo projects and enterprise roll-out. Enterprise roll-out provides an opportunity for students to select one of their projects and further develop this to test the market reaction.

Having launched the degree in 2015, Students are now in their fourth year of the programme. As such, it is not possible to determine any sensible measure of success or otherwise, however demand has been high with a ratio of about 7:1 of eligible applicants versus places.

In conclusion, we have had the opportunity to develop a new curriculum with the benefit of prior knowledge and experience from the design and engineering domains. In the process we have leveraged best practice across domains and learning theories, with implementation of an interplay between cognitivism, constructivism, humanism and behaviourism to deliver a curriculum in design thinking, engineering thinking and practice within a culture of innovation and enterprise.

References