Theory, practice and interiority: an extended epistemology for engineering education

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Abstract

Engineering education is appropriately concerned with technical problem solving. However the philosophical tradition has periodically asserted that technical rationality is but one mode of rationality. Informed by experience in both design practice and engineering education the authors agree with Donald Schön that professional artistry is an essential dimension of both engineering practice and teaching. Advertence to this artistry elucidates the scope and limitations of technical rationality. An extended epistemology for grounding professional practices such as engineering and teaching is offered as a valuable resource for the CDIO community. It is argued that this epistemology implies firstly that engineering education must address design artistry, secondly that a reflective element is needed and thirdly that for creative professionals, learning outcomes defined without due consideration of process are educationally misconstrued. Two curriculum examples from the University of Limerick problem and project based civil engineering programme that address these concerns are offered for consideration.

Keywords: engineering education, epistemology, CDIO, PBL, reflection,

Introduction: CDIO Challenges Hidden Assumptions

Educational structures, policies and practices result from a complex interplay of many influences both past and present. Among other influences, as Hederman says 'Educational theory and practice are always inextricably linked to current trends of philosophical thought. Education is impossible without philosophy or a world view' (Hederman 1976, p.2). Pring agrees, noting in regard to the implicit beliefs and understandings that guide practice that 'no practice stands outside of a theoretical framework…To examine practice requires articulating those beliefs and understandings and exposing them to criticism' (Pring 2015, pp.150-151).

Theories of knowledge (epistemologies) and related value systems, whether tacit or explicit, are always at work, influencing educational discourse and practice. Personal experience and cultural context combine to influence individual educational practice (Brookfield 2017, pp.2-3). Such practice may contradict explicitly espoused values and aims: as Brookfield notes concerning teachers '…the sincerity of their intentions does not guarantee the purity of their practice' (Brookfield 1995, p.1). Alongside explicitly espoused aims and outcomes, there is a hidden curriculum at work in education or, as Schön argues, an institutional epistemology which is evidenced in the concrete procedures and institutional arrangements which are implemented (Schön 1995, pp.27-28, Eikeland 2001, p.145) and its power is all the greater for being hidden.

The 'Conceive-Design-Implement-Operate' (CDIO) movement of engineering education reform emphasises project-based, experiential learning and the development of professional skills such as teamwork , collaboration and design (Crawley *et al.* 2007). CDIO addresses the gap between, on the one hand, the content and practice of many university engineering education programs and, on the other, the needs of industry (Edström and Kolmos 2014 p.541). In academia students often solve carefully crafted problems configured to exercise the procedural analytical competence proper to each engineering science sub-discipline (e.g. mechanics, thermodynamics etc.). However the sub-disciplinary theoretical knowledge may not be cognitively integrated in a problem solving context and the 'problems' may be more like puzzles that have one pre-determined correct answer requiring analytical skill but no integrative or creative capability (Bucciarelli 1994 p.98 et seq, Edström 2018) . Some graduates, confronted with a real world problem, may demonstrate procedural competence with little understanding of how the concepts and principles at play in these procedures relate to each other or to actual system behaviour (Brohn and Cowan 1977, Brohn 2004). Their education may have lacked a meaningful problem context to integrate disciplinary knowledge within a professional collaborative problem solving process. CDIO seeks to align the teaching of disciplinary knowledge, curriculum implementation and assessment practices to provide such an integrating and creative context. It is worth noting that in setting the scene Crawley and his co-authors instance an appeal by an authoritative commentator for skills 'that can be acquired only by doing' (Crawley *et al.* 2007, p.11). This observation is one manifestation of an epistemological debate concerning theory, practice and education that has surfaced periodically in various forms for over two millennia. The CDIO reform agenda implicitly challenges university values, curricula and educational practices in various ways (Edström and Kolmos 2014 p.549). It is suggested here that the CDIO movement is, in effect, challenging fundamental epistemological assumptions about two practices, those of teaching and of engineering that underpin much of the resistance to reform. Therefore an examination of epistemological positions bearing on those practices is likely to be both informative and useful. Hederman's observation alerts engineering educators and, *a fortiori*, educational reformers to the necessity for uncovering the philosophical tensions and tacit assumptions that operate beneath the surface of educational practice. Elucidating such tensions and assumptions can aid constructive critique and clarify sources of resistance to reform but it can also aid initiatives such as CDIO to access rich philosophical resources when plotting its future course.

This position paper argues for an extended epistemology for engineering education integrating theory, practice and reflexivity. To begin with, the theory-practice epistemological dichotomy which is relevant to the practice of both engineering and teaching is outlined. The eclipse of practical understandings of knowing and the rise of technical-rational ways of thinking about teaching is then described. The violation of the integrity of education as an ethical practice implied by technical rational approaches is elucidated. The work of Donald Schön, who advocated the need for an epistemology of design artistry that he called reflective practice, is discussed. The character of education and engineering design as social and ethical practices embodying professional artistry is explored and then linked to Aristotelian epistemology and its ideas of *praxis* and *phronesis*. The associated need for an integrated consideration of process and outcomes is argued for. The thought of Bernard Lonergan is then proposed as offering a unifying epistemological perspective. Some current educational responses to the reflective dimension of Schön's work are then outlined. Finally, having established the philosophical principles of an extended epistemology, two curriculum examples from Civil Engineering at the University of Limerick (CIVIL @ UL) which originally adopted the Problem Based Learning (PBL) approach are offered as an indication only of possible responses to the agenda of an extended epistemology. Edström and Kolmos note that, while CDIO reform proceeds from outcomes (ends) and PBL reform proceeds from process (means) they are nevertheless complementary approaches that overlap in many areas (Edström and Kolmos 2014). Therefore the examples cited here are as relevant for CDIO practice as they are for PBL.

Theory, Practice and CDIO

There is a long, rich and still-active scholarly tradition that addresses questions about knowledge (epistemology) and its relation to experience and action. This tradition addresses, *inter alia*, the relation of theory to practice (Dewey 1926, Dewey 1960, Schön 1983, Dunne 1993), of 'knowing that' to 'knowing how' (Ryle 1949) , of knowing to doing. The theory-practice dichotomy bears on professional education generally but it raises issues that, it is suggested, may be particularly problematic for engineering educators whose work, it is argued, is situated astride two potentially conflicting epistemological territories. On the one hand they teach technical *content* based largely on empirical science, but on the other are involved in two *practices* : teaching that, from an epistemological point of view, belongs with the humanities and engineering design practice which, as will be argued, while informed by science is not a science. A certain epistemological sensitivity and agility is therefore called for to negotiate the potentially confusing and uncomfortable situation of engineering educators if the categories and procedures of technical rationality (discussed below) are not to be imported uncritically into engineering teaching practice.

An epistemological account is offered that has the potential to elucidate and resolve potential epistemological tensions in engineering education. Specifically it is suggested that the notion of an extended epistemology spanning theory, practice and reflexivity (Coghlan 2016) can vindicate and ground the CDIO community's concern for wholeness in engineering education, strengthen its argument for an integrated educational approach and suggest directions for its future development. Reflexivity herein is the turning back of attention and thought towards the experience, thought and actions of the self. This extended epistemology retrieves and later elaborates on Aristotle's three categories of theoretical (episteme), productive(techne) and practical (phronesis) knowledge (Dunne 1993), links them to Donald Schön's ideas of 'professional artistry' and 'reflective practice'(Schön 1983) and, following Coghlan's work (Coghlan 2010, Coghlan 2016), integrates them using Bernard Lonergan's reflexive category of interiority (Lonergan 1972). Lonergan characterises interiority as a shifting of attention from mental contents to mental operations, from *what* we know to *how* we know. A case is then made for the integration of reflective practice into engineering education. Two curriculum examples of active learning from CIVIL @ UL, one with embedded reflection, are briefly described. (A more extensive treatment of the practice of reflection in CIVIL @ UL is the subject of a further paper, in preparation). The tradition clearly articulates the loss of educational integrity entailed by a separation of educational means and ends that may be implied by an uncritical adoption of an outcomes-based framework. Such a separation is inappropriate in general and, it is argued, *a fortiori* inappropriate for the education of creative professionals.

Technical Rationality in Education and Design Practice

The teaching of scientifically based laws and analytical procedures, to predict and control the behaviour of various physical systems dominates much of engineering education. If the ends are known (some system configuration or process to meet specified needs), what is required is the most efficient configuration or process to achieve those ends (Skolimowski 1966). Engineering design on this account is conceived as the identification of the most efficient means to achieve a pre-defined end by a controlled manipulation of materials and processes. The rationality characteristic of this approach to design may be called ‘technical’ or ‘means-ends rationality’ so called because the means are, in principle, a matter for separate consideration from the ends (Dunne 1993, Schön 1995, Dunne 2005).

Technical rationality on the one hand co-opts science (theory) and on the other may itself stimulate fundamental scientific enquiry in its pursuit of ‘effectiveness’ and ‘efficiency’ in solving problems (Skolimowski 1966). Its power is plain to see in the uncountable profusion of useful technical products that characterise and even dominate human life on planet earth today. Yet imagining and designing these products involves something more. As Biesta notes, Dewey is of the opinion that advances in engineering are fundamentally *practical* in that they result from *doing* things differently. Having scientific knowledge is never a *sufficient* condition for practical change, and Dewey even suggests that such knowledge may not even be a *necessary* condition (Biesta 2009, p.14). What is required for change and improvement is a ‘creative leap’, that is, ‘the inventiveness in using existing scientific material in a new way, for new consequences' and also 'the courage to think out of line with convention and custom' (Dewey quoted in Biesta 2009, p.14). Considering CDIO as a movement of educational reform, it is worth noting that Dewey's point was made while arguing that Engineering practice could be used as an instructive *analogy* for how improvements in educational practice might best be pursued. In doing so he drew attention to the limitations of technical rationality in *both* contexts and to certain similarities between teaching and engineering as social practices (Dewey 2009). However, as noted by Tomlinson, notwithstanding Dewey's efforts, technical rational thinking underpinned by a pervasive scientism, came to dominate educational thought and policy in 20th century America (Tomlinson 1997).

From the 19th century onwards empirical natural scientific method extended its hegemony to encompass the human sciences of psychology and social science. As Carr and Kemmis note: 'Rationality was now exhaustively defined in terms of conformity to the rules of scientific thinking, and, as such, deprived of all creative, critical and evaluative powers' (Carr and Kemmis 1986 p.133). In education, this movement bore fruit in the form of behaviourist (stimulus-response) theories of prediction and control, theories which, in an educational context, Tomlinson characterises as mechanistic and dehumanising (Tomlinson 1997). The application of technical rationality to teaching was to find clear expression in the work of Tyler (Tyler 1971 pp.98,99). He advocated selecting appropriate educational outcomes (or behavioural objectives). The most effective and efficient approaches would then be identified experimentally. Teaching would then consist of implementing the most efficient techniques to produce those outcomes. Teachers could thus be made accountable for their practices based on their students' achievement of the stipulated outcomes. It is worth noting how the technical-rational approach, when transposed to human practices, tends towards a system of surveillance, control and de-professionalization. It has political implications. Indeed Dewey contended that this technical-rational division of knowing and doing, the separation of ends from means (Tomlinson 1997 p.366) expressed in hierarchical social structures was anti-democratic and must be resisted for that reason. Schön details a case from MIT where the educational development work of Bob Shaler (a pseudonym) in Civil Engineering was rejected as a basis for securing tenure: 'members of the committee judged Shaler's research to be of poor quality--or even more damaging, unable to be evaluated' using technical-rational assumptions (Schön 1995). It is noteworthy that Shaler's work addressed precisely the same gaps in understanding as those identified by Brohn and Cowan noted above. Schön notes that the profoundly reductive epistemology of technical rationality that informed the rejection of Shaler's work argues in regard to knowledge generation (research) in general:

> that if you can't name the variables and measure their values, and if you can't create control groups or manage random assignment of subjects to treatment and control groups, then you can't possibly generate valid knowledge. In the absence of these conditions… you're not doing rigorous research- (Schön 1995).

It is this hegemonic claim of technical rationality that Schön contests. For those seeking to conduct research on their CDIO practice, this technical-rational prejudice is worth keeping in mind. Indeed Borrego has documented the tendency of Engineering educators to transfer in an inappropriate way the technical-rational machinery of academic engineering research into their education research (Borrego 2007).

Technical Rationality and Educational Values

Tyler claims his technical rationality is a 'values free' methodology, asserting that it can be evenly applied in all educational contexts. However Tyler cannot identify which of the multifarious factors operative within an educational context might influence outcomes. As

Dunne has pointed out, such judgements are massively underdetermined by Tyler's rationale (Dunne 1993 p.4) . Tyler's rationale neglects the consideration of teaching as an interpersonal process and cannot allow for the complexity and uniqueness of each educational context where the teacher must address in real time diverse student needs while negotiating multiple institutional and curriculum constraints. Furthermore educational objectives must typically be chosen by reference to some values of a broad nature, qualities of mind and character (Dunne 1993 p.6) which Tyler's rationale does not address at all. If objectives have no bearing on the development of habits of mind and character then how can they be educationally worthwhile? One cannot reasonably hold that educational means are value neutral with respect to ends. For example could one suggest that in a classroom where there was no opportunity for student discussion that ability for independent critical thought was being developed (Dunne 1993 p.7) ? We cannot lecture students about the need to be pro-active or creative and provide no meaningful opportunity for them to *practice* being so. Dunne asserts that objectives based education is not in fact, value neutral since it embodies the hegemony of technical rationality as the one authoritative conception of rational action (Dunne 1993 p.7). Peters explains the conceptual error involved in attempting to separate educational means from educational ends.

> Talk about 'the aims of education' depends to a large extent on a misunderstanding about the sort of concept that 'education' is….Education is not a concept that marks out any particular process…rather it suggests criteria to which processes...must conform. One of these is that something of value should be passed on… People think that education must be for the sake of something extrinsic that is worthwhile, whereas being worthwhile is part of what is meant by calling it 'education'. The instrumental model of education provides a caricature of this necessary feature of desirability by conceiving of what is worthwhile as an end brought about by the process…. (Peters 1965) quoted in (Carr and Kemmis 1986 p.77).

Or as Carr and Kemmis express it compactly 'educational "ends" are constitutive of educational "means" as educational' (Carr and Kemmis 1986). If the means employed are not congruent with the avowed educational ends, then questions about instrumental efficiency do not even arise.

Professional Artistry in Engineering Design Practice

Schön's (and Dunne's) counter argument to technical rationality is that a wide range of professional practices are characterised by forms of rationality that are not exhausted by technical considerations. Schön notes Boyer's proposal for extending the notion of research to include a scholarship of integration , of application and of teaching (Boyer 1990, Schön 1995). Teaching is a practice characterised more by practical artistry than by technical rationality (Dunne 1993, Dunne 2005) **.** Engineering practice also involves aspects of what Donald Schön named 'professional artistry' (Schön 1983, Schön 1995). It is a creative but indeterminate artistry, tacit and difficult to articulate but emergent in the moment-to-moment living of the practice. It is a kind of knowledge that is inseparable from actual practice and which does not consist simply in the application of technical rationality to the instrumental problems of practice (Schön 1995). Bucciarelli's fascinating ethnographic study of engineering practice in a variety of industrial contexts elucidates the impact of individual perspectives and the tension between various individual and institutional human interests operating within and on the design process to determine criteria and outcomes. If a design is 'good' for whom is it good? Bucciarelli concludes (and Bernhard agrees) that Engineering is a social process whose outcomes are determined as much by social and cultural context as anything else (Bucciarelli 1994, Bernhard 2015). Artistry may emerge in collaborative design where engineering is brought into dialogue with design disciplines such as architecture. Engineering artistry is plainly visible in the creative work of such outstanding engineers as

Candela, Isler and Nervi (Chilton 2000, Addis 2007, Garlock and Billington 2008) where an architectural value system is plainly at work variously facilitated or constrained by the designers' very diverse national contexts. Frei Otto, working in post-war Germany was explicit about his political motivations for pursuing lightness in structure as a core value (Schanz 1995, Nerdinger 2005). The signature product range of the Apple Corporation is another salient outcome of collaborative design artistry. Indeed the CDIO movement has noted that from its earliest days professional engineering has defined itself as an art rather than a science (Crawley *et al.* 2007)

It is suggested here that Aristotle's work cannot be overlooked in any discussion about practical artistry. Two of Aristotle's contemporary interpreters, Dunne and Eikeland (Dunne 1993, Eikeland 2001) allow us to place his work in dialogue with Schön's.

Professional Artistry as a retrieval of Aristotle's Phroneisis

The classical Greek ideal of knowledge was certain knowledge of necessary and unchanging eternal (one could say heavenly) truths, the contemplation of which (*theorein*) conferred philosophical (divine) wisdom, or *sophia* on the soul (Eikeland 2008). A slightly broader category of theory was *episteme*, justified systematic knowledge traced back by logic to self-evident principles Unlike Plato however, Aristotle, came down to earth, as it were, and also accounted for two kinds of practical or experiential knowing. Technical or productive knowing, *techne*, manipulates materials to produce artefacts while *phroneisis,* in contrast, is demonstrated not in products but in prudent social action. It is knowledge of when and how best to act in a particular situation. For Aristotle an ethical or intellectual virtue 'is an acquired ability, skill, habit, or incorporated disposition and proclivity for acting and feeling in certain ways, resulting from practice, exercise or habituation' (Eikeland 2008 p.53) The exercise of *phroneisis* (which Aristotle called *praxis*) forms and expresses the identity of the wise actor who reveals her character (*ethos*) through action, (Dunne 1993, Eikeland 2008), much as an engineer's character is expressed in her designs, whether timid and conservative or bold and innovative.

The exalted Greek other-worldly ideal of theoretical knowledge stands in sharp contrast to the lack of esteem in which practical or productive, transient knowledge was held. Dewey suggests the long-established 'deprecation of action, of doing and making' arose, prior even to the early philosophers, from the relative uncertain and risky nature of action (Dewey 1960). Dewey drew attention to the prejudice against knowledge attained through action, and sought to undercut it (Tomlinson 1997) . As Dewey says 'The whole classic tradition down to our day has continued to hold a slighting view of experience as such…' (Dewey 1960 p.27) and is the source of the theory/practice divide that is still with us today. It reappears in our day in Donald Schön's famous metaphor:

> In the varied topography of professional practice, there is a high, hard ground overlooking a swamp. On the high ground, manageable problems lend themselves to solutions through the use of research based theory and technique. In the swampy lowlands, problems are messy and confusing and incapable of technical solution. The irony of this situation is that the problems of the high ground tend to be relatively unimportant to individuals or society at large, however great their technical interest may be, while in the swamp lie the problems of greatest human concern. The practitioner is confronted with a choice. Shall he remain on the high ground where he can solve relatively unimportant problems according to his standards of rigor, or shall he descend to the swamp of important problems where he cannot be rigorous in any way he knows how to describe. (Schön 1995, p.28)

After Galileo, the scientific *ideal* was universal (theoretical) laws usually expressed in mathematical form arrived at by controlled experimentation and exploited in man-made technologies for practical ends. This ideal therefore undercut the Greek division of *theoria* and *techne* (Tomlinson 1997). However, notions of practical knowing (*praxis*) became neglected in the Anglo-American philosophical tradition (Coghlan 2016) only to re-emerge in our time in the work of Dewey , Schön and others (Dewey 1926, Schön 1983, Eikeland 2008, Kinsella and Pitman 2012). Schön described how professional schools, seeking respectability and prestige had become absorbed into the university system that was increasingly modelling itself on the German research university (Schön 1987, Schön 1995, Edström 2018) which saw its mission as 'true scholarship that contributes to fundamental science' (Schön 1995) . In this context 'fundamental science' may be read as 'theory'.Schön described the 'tug-of-war' going on in the 20th century academy between theory and practice as a 'battle of the epistemologies' (Schön 1995) . Edström considers that this tension is both perennial and ineliminable (Edström 2018). It is striking how Schön's characterisation so closely reflects the diagnosis of the former Dean of Engineering at MIT Karl Söderberg writing 16 years before Schön: 'many of our teachers live out their lives in an uncluttered world of deceptive simplicity, isolated from the general messiness of real life' (quoted in Edström 2018). Unlike the problems of empirical science, the 'messy' problems practitioners address cannot, by and large, be abstracted from their context for laboratory study nor can mathematical analysis generate solutions. As Bernhard notes, the civil engineer's problem is largely *constituted* by its context of which the site with its ground conditions is just one element (Bernhard 2015) .

Schön's case is that the expertise demonstrated by practitioners is neither purely, or even essentially, propositional nor technical-scientific in nature. In fact this artistry cannot be conceived correctly or demonstrated and transmitted except in a practical context. Schön considered that he was reinterpreting Dewey's theory of reflective thinking (Dewey 1926). Dewey had written about the reflective thinking of practitioners as being in a conversation with the situation. Practice does not consist 'of the application of science or systematic knowledge to the instrumental problems of practice' (Schön 1995): practice is *constitutive* of practical knowledge. It follows therefore that learning outcomes chosen without due consideration of process are fundamentally misconstrued because based on a truncated epistemology.

Phroneisis or 'practical reasoning' is a habit of reasoning towards social action (*praxis*) (such as teaching or collaborative design). *Phroneisis* involves questions of value: is the possible course of action worthwhile? Could it be harmful? Unlike commonsense judgements of fact, common sense judgements of value become *phroneisis* when we ask: 'what kind of person will I become if I take such an action?' This speaks to the embodied nature of *phroneisis* (practical wisdom) also noted by Dunne above in his examination of *phroneisis* (Dunne 1993). As teachers and practitioners we reveal who we are and what we really value in our educational and design practices.

In summary then engineering practice coopts technical-rationality when solving contextually embedded problems. It brings together theoretical knowledge with knowledge of contingent particulars. Its exercise involves an ineliminable element of creative artistry, often collaborative, that is constituted by its practice and that can only be learnt by actual practice modelled by experienced mentors. The practitioner through her practice gradually comes to embody the virtues of that practice which are directed towards the social good. So theory is integrated into and serves practice and practice forms character.

Lonergan: An Explanatory perspective on Schön's account.

While Schön provided a richly detailed *description* of professional artistry in action across the domains of Architecture, Music Performance, Psychotherapy and Town Planning, Bernard Lonergan provides an *explanatory* account of knowing, working from the experience of the knower (Lonergan 1983). His cognitional theory defines knowing as a tri-partite activity of experiencing, enquiring and judging, the authentic exercise of which becomes a self-correcting cycle (though we are subject to psychic, personal, group and general bias). Human intelligence spontaneously asks of experience 'what is it?' It searches for a plausible explanation to order the data in some explanatory perspective. An insight or bright idea may occur. Lonergan defines this pivotal cognitional operation of insight as 'grasping the intelligible in the sensible' (Lonergan 1993 p.114). Insights transform our apprehension of the world. We move beyond the infant's world of the nursery mediated by sense to the vastly more complex and rich world that is mediated by meaning. The insight, if theoretical, may be formulated creatively as concepts in words or in mathematical or chemical symbols. An artistic insight may be expressed in a work of art or a design. Then the critical question arises spontaneously: 'Is my idea correct?' or in design terms: 'Does this design solve the problem? Can it be made or made to work?' Underpinning this dynamic structure are two desires, desires that can be distorted by ignorance and bias and that lie at the root of all human questioning and acting: the desire for the true and the desire for the good (Morelli 2015). To be authentic learners and doers, Lonergan commends to us four 'transcendental precepts', three epistemological and one ethical: be attentive (don't ignore any relevant data), be intelligent (don't overlook relevant explanations in forming insights), be reasonable (consider carefully the coherence of insight with data) and be responsible (act consistently in accordance with your judgements) (Lonergan 1972, Coghlan 2008). The person thereby attains epistemic and moral objectivity through the exercise of authentic subjectivity, the unrestricted unfolding of the desire for the true and the good (Naickamparambil 1997, McCarthy 2015).

Lonergan celebrates everyday practical knowledge as well as theoretical knowledge and cognitional process is essentially the same for both. His account of knowledge of the particular, contingent situation, which he calls 'common sense', (Lonergan 1972, Lonergan

1983), is proposed by Byrne as providing an explanatory account of Aristotle's *phroneisis* (Byrne 1997). The spontaneous, personal descriptions of commonsense contrast with the rigorous, systematic explanations of science but commonsense insights are no less real. Social insights must grasp realities that are partly constituted by the beliefs of the social actors (Lonergan 1967 pp.240-251). All reality is mediated by meaning but social reality is also constituted by meaning. A network or background of insights built up through experience in related contexts over time characterises common sense living (and also professional practice), yet in each particular circumstance a kind of wisdom (*phroneisis*) is required that supplies at least one contextual insight to be added to the background to meet each situation. Common sense or concern with practical problems is the pattern of experience in which most of us dwell most of the time and indeed most engineers are practical in their outlook. As such it is the default pattern into which we fall most easily. Lonergan and his commentators note that people of common sense may harbour a bias against theory, so reflexive awareness is needed to prevent the practical frame of mind interfering with disinterested intelligent enquiry when the occasion demands (Lonergan 1983).

Lonergan's thought echoes Dewey's concern with experience, with the practical and pragmatic as constituents of knowledge (Dewey 1926, Dewey 1963, Shea 1991). The ontological implications of Lonergan's work are encapsulated by Meynell in a pithy formula perhaps congenial to engineers (and to Dewey's pragmatism) when he says:

> The world or reality is nothing more than what conscious subjects or persons tend to come to know by asking and answering questions about their experience (Meynell 1998, Preface)

Lonergan calls the unbiased unfolding of cognitional process General Empirical Method, general because he includes not only the data of sense as empirical but also the reflexive data of our intentional conscious operations of experiencing, understanding and judging (and cognate operations). The unfolding of scientific knowing is one instance of General Empirical Method in operation. Modern empirical science no longer pursues Aristotle's epistemic ideals of necessity and certainty. As McCarthy notes:

> Empirical science, in fact, is a fallible self-correcting collaborative enterprise that depends on the critical control of socially transmitted belief… [It is] a distinct but limited realm of cognitive meaning…Truth is what practising scientists are commonly seeking, not what they finally possess. Objective knowledge is the common epistemic goal that they strive for through collaborative enquiry and critical methods of verification. For the global scientific community, epistemic objectivity is the fruit of authentic intersubjectivity, of their mutual fidelity to the specialised methods and norms of scientific research…The practice of modern science is now understood as a fallible, dynamic, self-correcting process of systemic communal enquiry (McCarthy 2015 Chap. 2).

Lonergan begins with actual cognitional performance as experienced. His entire project is therefore founded on a reflexive move. Lonergan argues for a shifting of attention from the contents of our cognitional operations to the operations themselves, from what we know to how we know. This reflexive move reduplicates cognitional structure, bringing it to bear on its own operations, attending to them, grasping them in their relations and affirming them as so. This process he terms self-appropriation (Naickamparambil 1997). We move into the realm of interiority. Coghlan shows how this first person move allows us to integrate our first person knowing (of personal experience and cognitional operations) with our interpersonal and third person knowing and navigate without confusion the shifts in cognitional mode between practical or common sense and theoretical patterns that characterise teaching and engineering practice (Coghlan 2010, Coghlan 2013, Coghlan 2016). Lonergan's central idea of self-appropriation, a reflexive insight-into-insight, resonates powerfully with Schön's notion of reflexive practice and, although predating Schön's work by three decades, is consistent with his reflexive turn. Interiority '…calls for a self-knowledge not just of our feelings and dreams, our motivations and character, but of the very processes by which we see, hear, think, imagine, remember, criticize, evaluate, conclude, and judge. Grasping the activity of human understanding is the main characteristic of interiority; not as it happens in others but as it happens in oneself' (Cronin 2001, p.30). Interiority shifts attention from the contents of consciousness to the operations of consciousness. It is a process of intellectual self-awareness, a first person activity and it can critically ground both common sense and theory. Another Lonergan commentator concurs, noting that 'the opposition between the intelligible and sensible worlds…between the abstract and the concrete …can be resolved through understanding your own activity of understanding which mediates…these opposite but related realms (Flanagan 1997 p.29).' Interiority allows us to grasp the dual validity of, on the one hand describing the commonsensical phenomenon of sunset and then on the other explaining the same phenomenon in terms of a heliocentric solar system. The former (practical commonsense insight) grasps phenomena as related to us; the latter (theoretical insight) grasps phenomena in their relations to each other. Lonergan himself noted that since our shared humanity is not pure intelligence, intellectual self-appropriation is a beginning. It is a springboard, a 'framework for creativity' (Naickamparambil 1997, Carley 2005) for self-appropriating the whole person.

When we engage reflexively in Lonergan's sense, we are not being commonsensical, we are not engaging in theory: we are engaged in a third realm of meaning or field of development: interiority. Interiority is at the cutting edge of theory, practice and research (Coghlan 2010) and challenges us to attend to cognitional process in the present tense (like Schön's reflection in action) and in the past tense (like Schön's reflection-on-reflection-in-action) and to facilitate others in so doing. It is a theory of theories but it is a method rather than a series of arguments. Each must make the journey for herself. Furthermore, Lonergan’s subtle elucidation of the various patterns of experience (Walmsley 2008) heightens awareness of the rich diversity of our conscious modes but also of how one pattern can interfere with the proper operation of another. We develop self-awareness through interiority and strive to overcome our inauthenticity (Coghlan 2008). This is the work of reflexivity.

An Extended Epistemology of Theory Practice and Interiority

Expert practitioners access an established repertoire of practical approaches as the occasion demands. Schön called the educational approach of expert practitioners in dialogue with students grappling with real problems a ‘reflective practicum’. Practitioners demonstrate what Schön called ‘reflection in action’. ‘It is what a good teacher does as she tries to make sense of a pupil's puzzling question, seeking to discover, in the midst of a classroom discussion, just how that pupil understands the problem at hand’ (Schön 1995, p.30) and how to adjust her practice there and then to suit the demands of the moment. However, as Schön says: ‘if we want to teach about our ‘doing’, then we need to observe ourselves in the doing, reflect on what we observe, describe it, and reflect on our description’ (Schön 1995). We can, after the event, turn ‘thought back on the knowing-in-action implicit in action’. We can reflect on our ‘reflection-in-action’, making explicit the tacit assumptions and insights that have informed our decisions and actions. So, unlike technical rationality, the teaching or conscious development of professional artistry by its nature involves a reflexive move. Coghlan commends Lonergan to us as a guide in the difficult task of negotiating the diverse epistemological territories of theory, practice and reflexivity (Coghlan 2010, Coghlan 2016). Lonergan’s work has been accessed in particular by educators and transposed into accessible language and practice in ways that put both teachers and students in touch with their own intelligence in performance, drawing their attention to the progress of conscious performance from experience through insight to objective knowledge, both practical and theoretical. Coghlan instances his experience of interiority at work in himself in real time in his organisational consultancy work with adult professionals. He writes:

> My theory was that there was an emerging fundamental difference between those who understood the research as verification and those who understood it as discovery… What is relevant about this story is that I attended to the data of my consciousness and was aware that my understanding was an untested inference
> and that then shaped my concern for how I might respond … The theory of conflicting epistemologies, while relevant, might not have been helpful to share as it might not have engaged the practising managers in the room if a discussion on the philosophical nature of research had ensued (Coghlan 2010 p.302).

So, as well as discerning in the light of Lonergan's theory, the (probable) root of the difficulties he faced, Coghlan exercises phronesis in making a practical judgement. Lonergan's work does not have to be explicitly cited in order to inform practice and this is as true in the classroom or design studio as in Coghlan's context. Carley, in her work with both young children and undergraduate students used Lonergan's cognitional theory to frame, design and implement an educational strategy that 'encourages students to respond critically to data by using their own minds to follow through on questions' (Carley 2005 p.1). Her proximate concerns are neither philosophical not theological yet her book describes how Lonergan's cognitional theory was a powerful guide in her context also. Indeed one could read Carley's compact statement above as encapsulating an essential educational concern of both the PBL and CDIO movements and as a useful critical tool for evaluating curricula in general. Her statement is, in effect, an example of a criterion of value to which educational processes should conform, as noted in Peter's quotation above.

Lonergan's three 'realms of meaning', theory, practice and interiority have been proposed by Coghlan as grounding an extended epistemology (Coghlan 2009, Coghlan 2010) that integrates theory and practice. It is contended that this extended epistemology has the potential to ground professional education generally and engineering education in particular in an epistemological wholeness particularly appropriate to our age of life-long learning, wholeness that, it is suggested, is always under threat by the uncritical assumption of technical rational thought as definitive of rationality in general.

Implications for engineering education

How exactly should engineering educators respond in their curriculum designs to the three realms of cognitive meaning of theory, practice and interiority (and the realm of responsible action towards which authentic knowing points)? Given the contextual nature of educational practice no single answer may be possible or even desirable. The foregoing discussion notes the PBL and CDIO movements as two responses to the agenda of professional practice, each with its own emphasis. Outside of engineering education the movement of reflective practice that developed within healthcare and teacher education responds to the reflective dimension of Donald Schön's work. Following a brief review below of educational reflective practice, two curriculum exemplars from Civil Engineering at the University of Limerick are sketched briefly, the second of which incorporates explicit reflection on learning. These outlines are necessarily limited in scope. They are offered here as indicative illustrations of how the concern for the integrity of educational means and ends expressed in the foregoing argument has informed curriculum design and practice in one context.

Reflective Practice in Civil Engineering at the University of Limerick

When Schön challenged educators in professional programs to model ‘reflection in action’ themselves and embed ‘reflection in action’ in their programmes, this challenge was taken up enthusiastically in teacher education and nursing education as well as in business. The literature is now voluminous (Moon 2004, Lyons 2010). Various models of reflection were developed such as Brookfield’s (Brookfield 2017) who focused on teacher education. Cowan, a Civil Engineer, advocates the need for reflection for (prior to) as well as on (after) action (Cowan 1998). For Cowan, reflection is concerned with any experience bearing on learning with a view to further development:

> Learners are reflecting when they analyse or evaluate personal experiences that have a bearing on their learning and attempt to generalise from that thinking. They do this so that in the future they will be better informed or more skilful or more effective than they have been in the past (Cowan 1998).

He proposes a protocol for reflective writing that moves from selective description of experience through critical interpretation, evaluation and self-challenging to forward planning and metacognitive self-review (Cowan 2013, Cowan 2014). Lonergan characterises his fourth precept, being responsible as, *inter alia*, involving the responsibility to lead our lives rather than to drift, to be makers of ourselves in some measure rather than to be the ‘sport of every wind’. In adulthood ‘the subject has more and more to do with his own becoming’ (Lonergan 1967 p.241). Cowan’s approach to reflection embraces this ethical responsibility for personal development as an aspect of reflective practice. Because of its practical, developmental and ethical thrust and its expression in accessible language likely to be congenial to engineers, Cowan’s model has been adopted and embedded in the problem-based program in Civil Engineering at the University of Limerick since 2009 (Cosgrove *et al.* 2014), and with the support of John Cowan is currently undergoing development through Action Research. Cowan summarises his key conclusion about reflective practice thus:

> I judge the introduction of self-assessment as the most powerful factor for change and development that I have yet encountered (Cowan 1998 Chap.7).

Lonergan like Cowan, in his fourth precept calls for responsible action based on verified insights and can therefore provide a unifying and critical framework for Cowan's reflective practice.

Programme Exemplars from Civil Engineering at the University of Limerick

Traditionally engineering education consists of disciplinary theoretical courses presented in predominantly lecture-based format. The need for curriculum change has been widely noted in the literature (e.g. in Edström and Kolmos 2014) and the CDIO and PBL movements address this need in complementary ways .Mindful of the need for change and of the rare opportunity for reform afforded when founding a new program, CIVIL @ UL was envisaged from its inception in 2008 as a problem-based programme. Collaborative design projects in all semesters would, as far as practicable, call for creativity and integrate learning across subjects (modules) (Cosgrove *et al.* 2010, Cosgrove 2011, Phillips 2011). Selected features of two of the many projects embedded in CIVIL @ UL are described here in order to exemplify the concrete realisation of the philosophical principles of the extended epistemology considered above.

The first week-long introductory project described is designed to challenge students' implicit notions of learning and to develop their self-efficacy by giving them creative freedom to work in a supported, collaborative, practical design process in PBL mode. The second project described, extending over 12 weeks, leans more towards the CDIO model and incorporates multiple technical learning outcomes. While the latter project has manifold educational implications, the outline given here emphasises how technical and practical learning is motivated, integrated and deepened by application in a design context. The reflective process explicitly required in this second project is outlined, noting the students' overwhelming choices of practical abilities (including reflection itself) as making demands (sometimes of an ethical nature) worthy of reflection.

Year 1: First Day, First Week, First Year Challenge

This project plunges the students into Schön's 'swamp' of real problem solving on their first day on UL campus, before the 'hidden curriculum' of lecture periods, classrooms and subjects imposes its constraints (Schön 1995, Eikeland 2001). Students embark immediately on an active and collaborative design process at what is perhaps their moment of greatest receptivity: their very first week on campus. A practical design challenge calls forth the problem solving *habitus* or disposition peculiar to the engineer. It stimulates creativity, promotes linking of existing common-sense and technical knowledge and encourages socialisation and collaboration. The students take a first step on the lifelong road of *praxis*. A typical project brief follows:

> *In one week, working as a group, design, construct, test and present your design for a working vehicle that travels at least 4 metres on a level floor under its own power without using electricity or gravity as an energy source* (Quilligan 2016).

The project engages the habitual everyday cognitive pattern of practical rationality (Lonergan's common sense), the most familiar pattern for most of us most of the time (Lonergan 1983, Cronin 2001, Fellows of the Woodstock Theological Center 2011). Dewey notes the futility and deadness of general rules, principles, classifications and the like (theory) 'when not properly motivated by familiarity with concrete experiences' (Dewey 1926 p.99). In a similar vein, he asserts the power of practical goals to stimulate thinking, noting: 'The need of thinking to accomplish something beyond thinking is more potent than thinking for its own sake' (Dewey 1926 p.41). Supported by mentors, students brainstorm, discuss and critique ideas in teams. They research new knowledge online, in books and by questioning mentors (perhaps the most common research mode for a young engineer in professional practice). They mobilise their existing practical and theoretical knowledge. They imagine, sketch, discuss, , design and apply elementary analysis. They procure materials, experiment and present as a team. The pervasive *active* character of the project reflects Peter's argument (quoted above by Kemmis) that the primary educational value of this project is *constituted* by the process. The process is not an arbitrary technique chosen to realise some other end. The active social process of practically motivated enquiry and design *is* what constitutes this project as educational because it demands that the students mobilise and integrate knowledge spanning the domains of theory and practice, including social practice. . In short, the students are initiated into the collaborative, creative and experimental practice (or *praxis*) of design where a disposition (*habitus*) of imaginative enquiry for problem solving is formed and outcomes are always uncertain. As Bucciarelli says 'If the process is sure from the start you can be sure it is not a design process' (Bucciarelli 1994 p.118). Subsequently, projects of gradually increasing complexity reinforce and extend the cognitive and social dispositions activated in this first week project.

Year 3: Integrated Design Project:

When they encounter this project in the autumn semester of their third year, students have already completed a number of semester-long design projects, some involving explicit reflection, The Integrated Design Project [IDP] combines four modules in the autumn semester of third year into a single design project. These modules are Geotechnical Design, Structural Analysis, Reinforced Concrete Design and Professional Skills. The project requiring a whole-building structural design solution as its main output spans the entire 12 week semester and culminates in team presentations to an invited audience of industry professionals, staff and students.

Each year, a live (as yet unbuilt) project in an Irish city is identified as the project context. In week 1 the students visit and study relevant built precedents. The project data comprises the actual site location, architectural planning drawings and a site investigation report. The project brief specifies outputs and key milestones. The practical problem motivates enquiry (as noted in the previous project) and is fully contextualised as any real engineering design problem must be (Bernhard 2015) . Therefore it calls for the additional contextual insights that characterise common sense or practical intelligence as well as theoretical knowledge (Lonergan 1983 Ch.6). Students are assigned to teams and develop a program to manage their progress. They survey the project site. After morning lectures, students meet in a moderated design studio environment twice weekly. They interrogate the precedents and debate the merits of alternative structural schemes. They identify and seek to ameliorate planning and safety risks particular to their site and design proposals. Often such risks are of a straightforward practical character requiring students to integrate their prior commonsense understandings with formal risk assessment procedures. Boyer's assertion of *integration* and *application* as valid knowledge categories are borne out. They select a scheme for qualitative (Brohn 2005) as well as quantitative analysis and design. They address whole-building lateral stability. Many students struggle with this shift from intuitively understood vertical gravity forces to horizontal destabilising forces and their associated load paths. So, in our experience Boyer is correct: the practical *application* of abstract concepts to specific contexts is not simply a matter of following procedure. It requires further insight to link a specific practical design context to theory and it marks an enriching growth in understanding of the related theory. Students consider foundation design criteria and identify the data required for foundation design. They arrange their own lab testing to generate that data (Ryan 2012). Thus, in contrast to many conventional curricula, the practical design context establishes the rationale for laboratory procedures. As Dewey says 'the activity is enriched by the sense that it leads somewhere, that it amounts to something' (Dewey 1926 p.164) . Technical presenting requires performative skill. It also requires, in Lonergan's terms, the formulation of insights as concepts expressed in word, gesture and image. The project climax is public team presentations (Higgins 2017) to a jury of industry practitioners followed by a celebration of achievement.

Explicit reflection on learning following Cowan's model is required in this project in recognition of the cognitive realm of interiority.

Reflection For, In and On action

Following Cowan's protocol outlined above, at stage 1 around week 2 of the IDP students anticipate and describe three abilities, skills or dispositions the project is likely to call for. They propose a learning plan with developmental goals including data collection to support a learning claim. At stage 2 (mid-semester) students submit an interim reflection on developments to date. The final reflection is submitted at semester end. A workshop is held just before each submission.

Formative feedback is provided by their tutor at stage 1 and by an independent 'critical friend' (John Cowan) at stage 2. Peer formative feedback is provided anonymously on line just before summative assessment at stage 3.

Students' choices of developmental theme vary but overwhelmingly feature practical skills. Time management arises frequently, often with honest consideration of how more responsible behaviour can be planned for and realised. Interpersonal aspects of team working, e.g. effective listening and sharing surface regularly. Students reflect critically on instances of bias in the design process:

> The enthusiasm of one or two in a team can push things on too fast before all the angles of the current issue are exhausted –Jack

Here Jack notes how the practical bias to get things done can lead to superficial thinking.

> The desire to avoid conflict in the group led to poor decision making. - John

John notes how the personal bias that favours social acceptance over sound decision making undermines professional ethical standards.

The actions and skills required for successful presentations appear frequently. Metacognitive themes, the precursors of interiority, (e.g. ‘how are we making decisions?’) also arise. Here David describes a personal thinking strategy for task management:

> I also noted that by developing a series of questions and answers to address the task, I created a structure for what I am trying to achieve, and during the task I can review these questions and answers to make sure I am going about the task correctly…
>
> My thinking behind these subsets was that in doing so I am creating a series of small structured steps which are much easier to understand as opposed to one large step which may not have any clearly defined beginning, middle or end. - David

Michael, a mature student, reflects on the challenge of leadership when working with teenagers.

> …they left everything to the last minute so I offered to work on other parts of the project and help them with that instead of getting involved in the last-minute pressure and it worked … Learning to be more flexible and patient has worked very well. I realized that the group is working hard and everyone has a different way to learn … This reflects their teenage moments in life and I now understand because one day I was standing in their shoes. - Michael

Michael makes decisions about responsibility and thereby grows in self-knowledge, empathy and effectiveness, surely an instance of *phroneisis* that has obvious relevance for his future career and life.

Tom indicates that reflection has itself become a useful ability.

> I also believe that this assignment has given me a great insight into paying more attention into [sic] other every day skills and developing them to make me a better person overall- Tom

Here Tom is becoming explicit about attending to and valuing the commonsense or practical realm of meaning. In so doing he demonstrates a move into interiority. His implicit epistemology is being extended by the process of refection and he has a potentially life-changing insight of personal responsibility for his own growth,

Concluding Argument

Engineering educators straddle two epistemological worlds or realms of meaning: the technical-rational and the human-practical. Advertence to the epistemological tensions implied by this situation is essential to avoid the inappropriate extension of technical rational thinking into teaching practice and to apprehend engineering practice as spanning both realms. In order to negotiate this complexity and vindicate the integrity of practice a reflexive turn is required, a turn to a third realm of meaning: interiority. Interiority can facilitate for both teacher and student a more conscious navigation of the distinct realms of theory and practice so as to improve practice.

Our students, if they are to be lifelong learners, to become their own teachers, must likewise be brought to engage in reflexive learning. CDIO practice addresses cognitive integration of third person theoretical knowledge and second person collaborative practical knowing in a problem solving context. Some CDIO programs may incorporate professional portfolios with a reflexive element. It may be time to consider how first person reflexive knowing can take its place more explicitly in engineering education as it has long since done in teacher education and in the health and social care professions.

Social practices are full of hazard and unanticipated potential. As Bucciarelli says 'The design process is about the new and the uncertain by its very nature' (Bucciarelli 1994). The joy of teaching is our students' potential coming to fruition in surprising ways. As teachers we pose considered questions to our students to channel their energies towards a worthwhile educational target, yet our best educational efforts must aspire to liberate the curious imagination, not confine it within pre-ordained outcomes. Creativity and innovation means bringing something new into being. Student reflections alert us to the unanticipated but rich learning that often characterises collaborative project work. Finding ways to keep the developing student at the centre of our endeavours in an age of managerialism and bureaucratic accountability involves some risk and much effort. With mutual support, we can embrace that risk, make that effort and adopt processes and practices that will honour and credit the surprises as well as the anticipated outcomes. To do less is to risk diminishing rather than enhancing the potential of our students.

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