Re-Educating The Reflective Practitioner: A Critique of Donald Schön's Reflective Practice and Design Education For Engineering

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> *The primary mission of constructivists, therefore, is to help students "find their inner voices" (in a quasi-religious deification of "the real self"), rather than help students share in the bodies of knowledge (math, science, literature) that constitute our species's effort to understand itself and the world.*
>
> Martin Kozloff, 1998, Constructivism in Education: Sophistry for a New Age

Abstract: The factual, epistemological and pedagogic bases of Donald Schön's Design Education and its underpinning scheme, Reflection-in-Action, are examined from an objectivist point of view. Past and recent successes that question the existence of crippling dichotomies between technical knowledge and practice, and which Schön alleges prevent innovation and creativity in current Engineering, are pointed out. The scheme's supporting examples are shown to be either factually false or incorrect, disproving its main hypotheses. The inadequacy of self-discovery, hands-on methods within the Reflective Practicum for the learning of counterintuitive physics or mathematics is highlighted trough specific examples. The impossibility of arriving to anything but arbitrary and subjective conclusions through self-observation and introspection is pointed out. Assuming that engineering design is a social construction and that creativity is a non-domain-specific skill the students need to develop through self-reflection prior to the technical formation are fundamental fallacies in Schön's Design Education. The lack of demonstrable achievements proves that the introspective, self-reflective learning method does not meet the expectations. Rather than the alternative and more creative form of rationality it claims to be, the inherent irrationality of the reflective scheme identifies it as a mystic by-product of the obsolete forms of Positivism Schön is meant to be critical of. Its implementation within Engineering should not be encouraged.

Keywords: Reflective Practice; Intuition; Design Education; Positivism; Constructivism.

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Introduction

The notions of *Reflective Practice* and *Design Education* put forward in the 1980's by the American thinker Donald Alan Schön (1987, 1983) acquired relevance amongst many Engineering educationalists in the past three decades in association with highly appealing but loosely defined concepts such as "*learning-by-doing, authentic experiential learning, authentic engineering design, bridging the theory-practice divide, real-world problems, flipping the classroom, industry-relevant teaching, teaching creativity, lifelong learning skills, threshold concept, transformative learning, embedded creativity, creative skill development, design based learning,"* etc. (Khisty and Khisty 1992; Valkenburg and Dorst 1998; McIsaac and Morey 1998; G. Green and Kennedy 2001; Waks 2001a; Adams et al. 2003; Hmelo-Silver 2004; Leonard 2004; Dym et al. 2005; Atman et al. 2008; Kavanagh and O'Moore 2008; Schwartzman 2009; Dall'Alba 2009; Russell 2010; Gainsburg et al. 2010; Lloyd 2012; Hargrove 2012; Hook et al. 2013; Ambrose 2013; Gómez Puente et al. 2013; Daly et al. 2014; Perdomo and Cavallin 2014; Haupt 2014; Kavanagh and Reidsema 2014)

Schön's *Reflective Practice,* while claiming to challenge the relationship between technical expertise and artistry, reduces the process of learning and, by extension, the subsequent professional praxis, to a subjective mechanism called *Reflection-in-action,* defined as thinking about the action, often while doing it. (Khisty and Khisty 1992) The reflective approach questions the usefulness of traditional approaches to knowledge-building for professionals since they seem to lead to a disjuncture between theory and practice. Practitioners are presumed to apply existing scientific theories in a deductive way to resolve specific situations. Alternatively, the reflective approach sees theory as implicit in actions, or "*knowing-in-action,*" therefore not necessarily consistent with the positivist theory the practitioner is assumed to act upon. The reflective approach emphasises intuition and artistry, and highlights the importance of context. (Fook 1999)

The driving hypothesis behind Schön's Design Education is that current professional practice is largely devoid of creativity. In his view, practitioners are subject to *"the straitjacket of technical rationality, where rules are blindly followed."* (Khisty and Khisty 1992) Professional practice implies using accepted aesthetic solutions, cost, performance time, etc., with little room for innovation, hence the idea that students should be introduced to authentic or creative design prior to the learning of the specific professional tools. (Ambrose 2013; Dym et al. 2005) In Schön's words: "*the student must begin to design before she knows what she is doing.*"(1987, p.99) The Reflective approach to learning relies on holistic and experiential methods (Waks 2001b), aimed at "*fostering self-directed, lifelong learning skills*" and in which 'learning how' takes precedence over the mere 'learning about facts.' (Ambrose 2013; Hmelo-Silver 2004) Schön's Design Education anticipated in many regards the current STEM *vs*. STEAM controversy (see, e.g., Havyatt (2015)), where the acronyms stand for Science, Technology, Engineering, Art, Mathematics.

Reflective Practice and Design Education

Schön's ideas, as described in his best known books: *The Reflective Practitioner: How Professionals Think in Action*, and *Educating the Reflective Practitioner* (Schön 1983, 1987) are summarised below.

In Schön's view, most business are conducted through professionals especially trained to carry those functions, whether it be "*making war, educating our children, diagnosing and curing disease…designing and constructing buildings…*" (1983, pp.3-4,12-8) By ascribing most of what appeared questionable in the US society of the time, (and by extension, in all others developed societies) to inadequate professional performance, he concluded: "*although we are wholly dependent on them, there are increasing signs of a crisis of confidence in the professions.*" The continued developments in new technology, regulations and information management impose unprecedented requirements for adaptability in such a way that, he argues, for Physicians, Architects or Engineers the patterns of task and knowledge are inherently unstable: "*The situations of practice are not problems to be solved, but problematic situations characterised by uncertainty, disorder and indeterminacy*." The current professional practice then has as much to do with finding, or "*setting*" the problem, as with solving it, and he points out that "*professionals can be counted on to do their job but not necessarily to define their job*."

Crippling Dichotomies: Schön's critique centres on what he calls Technical Rationality (hereafter referred to as TR), described as the "*heritage of Positivism*," which he claims is at the core of the Learned Professions such as Medicine and Engineering. (Schön 1983, p.31)(1987, pp.78, 320) He asserts that during the past 300 years TR became a pillar of conventional wisdom despite being increasingly characterised by deep dichotomies separating "*means from ends,*" and *"knowing from doing*." A prevalent TR authoritarianism in current universities subordinate professional practice to fundamental science, neglecting empirically acquired skills, introducing a further dichotomy between "*research and practice."* These dichotomies, he argues, curtail professional creativity to the point of preventing most Engineers (and other science-based practitioners) from solving any issues except for the simplest and most straightforward ones in which a prior "*agreement about ends"* can be found. Professional activity based on TR education is thus reduced to "*instrumental problem-solving"* based on "*the use of crucial experiments to choose among competing theories of explanation." "When ends are fixed and clear, the decision to act ...is just an instrumental problem"* whereas, "*when the ends are confused and conflicting, the problem cannot be solved by the techniques derived from applied research.*" *"Within this framework, there is little room for professional artistry, except as a matter of style grafted onto technical expertise."* (Schön 1983, pp.21,31,41,68-69); (1987, p.34)

Reflection-in-Action: Schön points out that despite the limitations that TR imposes upon them, many practitioners are still able to deal with indeterminacies and value-conflicts, but do so through artful ways that follow "*deviant traditions that stand…outside the normative curricula of the schools.*" (1987, pp.15-6) He claims that these performances create a new type of conflict amongst practitioners: "*they find it unsettling* to *be unable to make sense of these processes in terms of the model of professional knowledge which they have largely taken for granted.*" The positivist epistemology of practice to which they are bound "*leaves them at a loss to explain, or even to describe, the competences to which (*they*) now give overriding importance."* (1983, pp.19-20)

Schön explains these artful, outstanding performances through the "*reflection-in-action"* mechanism which, being only partly conscious, "*follows rules that have not yet been made explicit."* (1987, pp.30-1,35) Using the concept of *Tacit Knowledge,* borrowed from the existential philosopher Michael Polanyi, he argues that the reflective mechanism is a process humans "*can deliver without being able to say what* (they) *are doing.*" (1987, pp.23,52-4)

The Reflective mechanism enables a distinctive means of communication between practitioners: when the reflection-in-action becomes reciprocal, they have reached a "*convergence of meaning."* (1987, p.101) As a pivotal example, Schön states: *"when good jazz musicians improvise together, they...display reflection-in-action smoothly integrated into ongoing* *performance*." "*They reflect-in-action on the music they are collectively making, though not, of course, in the medium of words.*" (1987, p.30)

He argues that "*many practitioners (*are*) locked into a view of themselves as technical experts*." "*For them uncertainty is a threat; its admission is a sign of weakness*." "*Others, …more adept to reflection-in-action* can proceed, even *in situations of uncertainty or uniqueness, because* (for them) *the process is not bound by the dichotomies of TR.*" (1983, p.68) The intuitive basis of the reflective mechanism, in this view, enables creativity beyond the rule-governed inquiry which, in line with the formality of TR education, is at the core of "*thinking like"* an Engineer or a Physician. (Schön 1987, p.34).

Factual Base: Schön offers in support of his scheme the following 4 examples.

(i) The glass panes falling off the John Hancock Tower in the city of Boston during 1972/3 are used to highlight the extent to which TR prevents Engineers from properly dealing with the complexity of current real-life situations. In Schön's words: "*it was impossible for skilled engineers to arrive at a confident analysis of the problem,…the phenomena were too complex to analyse… Every once in a while, one still shatters.*" (1983, p.16 and endnote #45 to Chapter 1)

(ii) A thought-case of engineers building a road through a densely inhabited part of a city illustrates the "*swampy lowland*" situations. Schön asserts that TR education prevents them to properly deal with the dilemmas of "*rigour or relevance"* stemming from the social, i.e., non-technical, issues involved in this sort of situations. (1983, pp.40-3)

(iii) Wilbert Moore's assertion: "*… professionals apply very general principles, standardised knowledge, to concrete problems."* (1983, pp.22-4) In Schön's interpretation, since general principles are seen to occupy the highest level of professional knowledge, empirically-developed *"technical skills of day-to-day practice"* are relegated to the lowest intellectual level. (1987, p.9) Empirically obtained knowledge and skills are therefore seen as an ambiguous, secondary kind of knowledge that "*does not fit neatly into Positivist categories,"* and the alleged dichotomy separating knowledge from practice follows. (1983, p.33)

(iv) Schön argues that 85% of the cases faced by physicians "*are not in the book,"* forcing them to invent and test new diagnoses, thus making evident that TR education is both unrealistic and unnecessarily formal. (1987; p.35) Intuitive guessing is presented as evidence of the *reflection-in-action* mechanism: "*Stimulated by surprise, (*practitioners*) turn thought back on action and on*

the knowing which is implicit in action." (1983, p.50) "*Surprise… leads her to rethink her knowing-in-action in ways that go beyond available rules, facts, theories and operations*" (1987; p.35). The mechanism keeps no relation with existing knowledge or prior experience: using face recognition as an example: he claims, with Polanyi, that the process "*involves no comparison…with images of other faces held in memory.*"(1987, p.23) Reflection-in-action is thus described as central to the art by which practitioners "*deal well with uncertainty, instability, uniqueness and value conflict.*" (1983, p.50)

Philosophical Fundamentals: Drawing from Karl Mannheim's *Sociology of Knowledge*, Schön argues that self-reflection, i.e., self-observation and assessment of the person own actions, allows the practitioners and their clients to be aware of the "*multiple approaches to reality,"* or "*Frames,*" involved in their practice. (1983, pp.309-15) This explicitly locates his scheme within Postmodern Relativism, as do his many references to (Schön 1983, p.139,182,312) Thomas Khun's works. (Kuhn 1962, 1977) The postmodernist character of the scheme has been stressed by many of Schön's followers. (B. Green and Bigum 1993; Parker 1997; Fook 1999; Pease and Fook 1999; Pryce 2002) Consistently, Schön made explicit that the Reflective Practitioner keeps a Constructivist view: "*our perceptions, appreciations and beliefs are rooted in worlds of our own making that we come to accept as reality,*" as opposed to the TR Practitioner's Objectivist view by which "*facts are what they are, and the truth of beliefs is strictly testable by reference to them."* (Schön 1987, p.36) The references to John Dewey, Polanyi, Donald Spence, Carl Rogers and Sören Kierkegaard locate his experiential, self-reflective pedagogy within Pragmatism and Existentialism. (Schön 1987, pp.16-7;22-3;89-92;222-3) The consistencies with Martin Heidegger's views have also often been pointed out by his followers. (Bronfman 2005; Yanow and Tsoukas 2009; Dall'Alba 2009; Erdman 2014)

Design Education and the Reflective Practicum: Schön claims that the inability of positivist science to deal with the indeterminacies of real-life creates a dilemma of "*rigour or relevance.*" (1983, p.49) This dilemma can be dissolved through the epistemology of practice implicit in "*the artistic, intuitive process that some practitioners do bring to situations of uncertainty, instability, uniqueness and value conflict*." Within this epistemology *"applied science and research-based technique occupy a critically important though limited territory.*" At its core is "*artistry,"* described by Schön as *"an exercise of intelligence, a kind of knowing, though different in crucial respects from our standard model of professional knowledge. It is rigorous in its own terms; and we can learn a great deal about it by carefully studying the performance of unusually competent performers.*" (1987, p.13)

Schön uses the concept of "*on-the-spot experiment*" to illustrate how the artistry of design, through self-reflection, meets internal rules of rigour and consistency: in situations when it is not possible to keep all contextual variables under control, the practitioner resorts to (on-the-spot) experimentation, in which, e.g., a building, is progressively shaped until he is satisfied or likes what he gets. As long as "*he strives to make the situation conform to his view of it while* (remaining) *open to evidence of his failure to do so*," the on-the spot-experiment is characterised by its own "*distinctive norms for rigour*." (Schön 1987, pp.68-79); (1983, pp.141-62)

Drawing from Dewey and Rogers, he argues that formal teaching is a futile exercise. He proposes, instead, education in a Reflective Practicum, modelled on the Architectural studio and coordinated by Reflective Coaches. Learning within the Practicum would happen through experiential "*learning-by-doing.*" (1987, pp.16-7;89-95) The Practicum's disposition to "*educate the students for artistry in practice*" would counter the current Schools' tendency "*to train them as technicians.*"(Schön 1987, p.315)

Schön calls for Universities to incorporate reflective thinking as the core of an all-encompassing Design Education (1987, pp.80-99), aimed at producing practitioners able to deal with the process of Design, defined as "*converting existing situations into preferred ones*."(1983, pp.46,77) If adopted, Design Education would take explicit advantage of the extensive creative commonality between the arts and the hard sciences, currently subdued because of the authoritarianism of TR which "*squeezes artistry out"* of the current educational system, in what he calls the "*squeeze play*." (1987, pp.314,5)

Implementing Design Education would require that Universities introduced a layer of Reflective Coaches whose status should be assured through salary, tenure and promotions, and whose legitimacy should be based solely "*on the artistry of his coaching practice*," rather than "*on his scholarly attainments or proficiency as a lecturer*." (1987, p.311)

Despite its popularity, the fundamentals of Schön's Reflective scheme are not without critics, often amongst its supporters: the works by Grimmett (1989), Munby and Russell (1989), Gilroy (1993), Eraut (1995), Newman (1999) and Friedman (2002) are notable efforts aimed at either putting order on their wide variety of interpretations or at solving some of the scheme's inherent contradictions. These criticisms are considered in the Discussion.

In what follows the fundamentals of the Reflective scheme and its ensuing Design Education, as applied to Engineering, are discussed adopting an objectivist, science-realist point of view.[1] To maintain consistency, two works by the British physicist John Desmond Bernal (1967, 1971), "*The Social Function of Science*" and "*Science in History,*" arguably amongst the most comprehensive and influential studies available on the relationship between science and civilisation, were adopted for the task as main references, complemented by two similarly oriented and equally comprehensive works by the British historian Eric Hobsbawm (1995a, 1995b), *"The age of capital"* and *"The age of extremes."* Further references, consistent with the above point of view, are cited as needed.

Discussion

The issues to consider are broadly sorted out as:

- *Dichotomies in Current Engineering*
- *Dealing with Uncertainty*
- *Factual Base*
- *Design Education and the Reflective Practicum*
- *Documented Achievements*
- *Reflection-in-Action as a Rigorous Means of Communication*
- *Radical-but-Soft Duality*
- *Philosophical Fundamentals*
- *Hard Science and Literary Culture*

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1 Drawing from Nola (1998), this point of view implies, that "*science makes discoveries about a human independent world."*

- *Dichotomies in Current Engineering*

Not all of Schön's followers agree with him: Grimmett (1989) characterised the claim of sharp dichotomies as "*sometimes unrealistic*," and reduced the assertion to a distractive "*rhetorical device*." Eraut (1995) expressed very similar concerns.

Against Schön's claim, Bernal's historical account shows that never in the history of humanity have scientific knowledge and practical applications have been so closely interrelated, challenging each other with questions and providing each other with solutions, than since the start of the Industrial Revolution in the late 1700's. (Bernal 1967, pp.17-32) As a symbolic example of this fruitful interaction, Bernal mentions the introduction of automatic textile machinery, on itself the product of uneducated craftsman, powered by the steam-engine, which to a large extent was the product of science. Once the Industrial Revolution was underway, science became an indispensable necessity, both "*in measuring and standardising industry"* as much as in making the industrial processes increasingly efficient, hence economically more feasible. In Bernal's words: "*the professions of the modern engineer are very largely directly due to scientific progress*. *The very names of the different kinds of engineers there are today, electrical engineers, chemical engineers… indicate they were all originally branches of science that have now become branches of practice.*" (Bernal 1971, pp.41,2) Hobsbawm makes a similar point when he remarks that the overwhelming development of technology by the mid 1800's led to the establishment of many new branches of industry that relied on the latest advances in scientific knowledge, in particular those related to chemistry and electricity. (Hobsbawm 1995a, p.42)

These historical conclusions are naturally extended to current times: new branches of Engineering keep stemming out as practical applications of new science on a large scale, driven by social or economic needs, hence the strong demand for graduates. As obvious examples, Quantum Mechanics led to solid-state electronics and computers, and Electronic and Software Engineering followed, Nuclear Science led to Nuclear Power and Nuclear Engineering, Artificial Intelligence led to industrial automation and Mechatronics and Robotics Engineering, and the same can be said about Aerospace, Materials, Environmental Engineering, etc. For a detailed discussion of the close interrelation between science and engineering see Bernal (1971, pp.590-8,804-23).

Bernal also provides a most illustrative example of praxis and knowledge being effectively divorced: "*Science under the Greek philosophers was characterised by a fatal division between* *the man of theory and the man of action."* (1967, p.17)[2] At the time Hellenistic knowledge and attainments in fields like pneumatics were in themselves quite sufficient to have produced the major mechanisms that gave rise to the Industrial Revolution (Bernal (1971, p.218-22); Gordon (1991, p.203)). The reason why this did not happen, attesting to a real dichotomy between knowledge and practice, was the lack of a social motive: the market for large–scale manufactured goods did not exist at the time.

Schön also blames TR for an authoritarian culture in current universities, which, he alleges, creates a research-practice dichotomy subordinating professional daily practice to fundamental science and research. (Schön 1983, p.24-30);(1987, p.314-20). Once again reality is at odds with Schön's claims: Bernal's analysis shows in detail the extent to which in several branches, Engineers, such as Mechanical, Electrical or Chemical, are indeed part-scientists, which seems to support Schön's argument, but he also states "*their work cannot be classified as scientific research as it mostly consists in translating into practical and economic terms already established scientific results."*(Bernal 1967, p.55) Hobsbawm makes a similar point concerning the mid 1800's: "*The research laboratory now became an integral part of industrial development."*(Hobsbawm 1995a, p.42)

In short, both history and current reality deny the existence of dichotomies between knowledge and practice: like Medicine, Engineering can claim a line of successes that deeply transformed the economy and the cultural and social life over the past two centuries, and continue to do so by closely linking objective knowledge with practice.

Schön describes professional "*artistry*" as an aesthetic feature that locates creativity and innovation outside the realm of technical knowledge: "*In professional practice, applied science and research-based technique* (are) *bounded on several sides by artistry*" (1987, p.13). Although he accepts that "*an art* (is) *necessary to mediate the use in practice of applied science and technique,"* he claims that the "*artistry of extraordinary practitioners"* demands them to follow "*deviant traditions"* in order break free of the constraints imposed upon them by their TR education and be able to deal with challenging situations. Schön expects these assertions to be

[2] Bernal (1967, p.17) stressed the point even further quoting Plato's words: "*Science is pursued for the sake of knowledge of what eternally exists and not what comes for a moment into existence and then perishes.*"

taken at face value: save for one personal relationship whose practice produced "*ambiguous results*" (1983, p.202), no names of, nor concrete examples of the extent to which, creative practitioners deviate from the normative curricula of their schools are given. Some of his followers also question the fact that his critique is largely based on "*aesthetic exemplars*," ignoring other professional practices and circumstances (e.g., the teaching environment) that also involve reflection and innovation. (Grimmett 1989; Eraut 1995)

The actual, intimate relationship between technical expertise and creativity is better understood through Bernal's description of modes of social behaviour. (Bernal 1971, pp.40-3) He distinguishes between the Scientific mode, which being indicative, only tells humans how to act, and the Artistic mode, of which the tasks are, first, creating *the wish* and then *the will* for specific actions. The Artistic mode, being imperative, tells humans what to do. Neither in science nor in art is one mode to be found without the other.[3] Against such utterly sensible description, claiming, with Schön, that the formality their technical education forces practitioners to follow *deviant paths* in order to be creative or innovative is equivalent to stating that the carpenter's tools, i.e., a set of passive elements at her disposal, prevents her from satisfying her urges of technical innovation or artistic creation. Considering how powerful those tools are, namely, Quantum Mechanics, Relativity, Computer Science, Mathematics, Thermodynamics, Organic Chemistry, Structural Analysis, Materials Science…, Schön's claim appears arbitrary to say the least.[4] It is not hard to guess why Schön garbles the practitioner's creation with her tools: under the pretences of boosting freedom and creativity, he aims at rejecting objective rationality, something explicitly acknowledged by many of his supporters. (Grimmett 1989; Gilroy 1993; Eraut 1995; Waks 2001a; Adams et al. 2003)

Schön's arbitrary insistence in the need for artistry to be explicitly added to the technical education to counter the schools' disposition "*to train them as technicians"* (Schön 1987, p.315), rather than addressing a dichotomy, would introduce an artificial one.

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[3] The closely related issue of the role of personal genius in science's discoveries, and its dependence on the historical circumstances, is discussed at length by Bernal (1967), and, in contrasting philosophical and political terms, by Kuhn (1962).

[4] See also the discussion of Wilbert Moore's words concerning the bounds imposed by physical laws upon intuition in the section *Factual Base*.

- *Dealing with Uncertainty*

In Schön's view, real-life, or "*wicked*" problems involving uncertainty, being a manifestation of late 20th century complexities, are largely unsolvable within the realm of TR, hence requiring deviant (i.e., non-technical) approaches or solutions instead. (Schön 1983, pp.39-49);(1987, pp.15-20) In some of his followers' words: "*rationality does not help much when solving wicked problems"* (Perdomo and Cavallin 2014)*;* "*In times of change and uncertainty,…there are no rules or formulae which can be followed"* (Broekmann and Cornish 2000); "*Design involves ambiguity and… lack of procedural and declarative rules*" (Atman et al. 2008); "*Attempts to apply a theory of rationality to engineering are likely misguided,*" since "*the higher levels are characterized by less rational deliberation and greater emotional involvement"* (Bulleit et al. 2013). None of these wide assertions includes examples to turn them credible. Not surprisingly, reality again denies such claims, as argued below.

In engineering parlance, uncertainty takes the forms of overlapping constraints and conflicting objectives when optimising a particular design. Drawing from a foremost Engineering educator: "*The problems of relative weight are old: engineers have sought methods to overcome them for at least a century*. *The traditional approach is that of assigning weight factors to each constraint and objective and using them to guide choice*." The process can be made more sophisticated through Fuzzy Logic, which involves adding ranges to the weight factors, but the process still relies heavily on personal judgment and experience. Subjectivity, however, can be eliminated by a systematic approach to identify the active (i.e., the most restrictive) constraint/s and by combining the conflicting objectives into a single Penalty Function containing one or more exchange constants, and use it to determine a Pareto optimal. These standard tools of multicriteria optimisation produce mathematical solutions which are transparent, hence defendable, and this is what makes them valuable. (Ashby 2011, p.213)[5, 6]

[5] A related, albeit more restricted example, is the production of composites using natural fibres. This sort of fibres is characterised by a high degree of variability in their properties. However, the final properties can be predicted through simple mathematical methods involving upper and lower bounds, see, e.g., Ashby (2011, Ch. 11).

[6] For an example of Penalty Functions applied to environmental issues, see Cáceres (2007). For a political analysis of Urban Decay involving Pareto's optimal and Kuhn's and Bernal's points of view see Harvey (1972). An illustrative example by a Schön's supporter showing that when faced with conflicting regulations, engineers regularly carry out trade-offs involving standard TR methods is in Solli (2013).

Against the claim that only intuition, through *deviant paths*, can lead engineers out of *wicked*, or *swampy lowland* situations, science indicates, and engineering practice proves, time and again, that rationality is what opens trustworthy paths across uncertainty. Dealing with non-technical issues as part of complex designs is considered in the section *Introspection and self-directed learning*.

- *Factual Base*

Schön provides very few supporting examples, a point often made by his supporters. (Grimmett 1989; Eraut 1995; Adams et al. 2003; Fischler 2012; Ambrose 2013) The four examples mentioned in the Introduction are considered below in detail. See footnote #20 for a further example.

(i) *The falling of glass panes off the Hancock tower:* In Schön's account, "*…the phenomena were too complex to analyse… every once in a while, one still shatters*."[7]

Schön's version of events is negated by the relevant historical records: "*wind tunnel experiments proved that the deformations imposed by the wind could not account for the loss of the glass panels. The failure of the glass was due to cyclic thermal stresses caused by the expansion and contraction of the air between the inner and outer glass panels which formed each window, thus causing the glass to fail.*" (Schwartz 2001; Wikipedia 2015d)

Moreover, the wind tunnel revealed two further issues, largely stemming from the tower's minimalistic profile: under certain wind actions the whole structure twisted, causing motion sickness to the occupants, and it even risked collapse. They were solved by adding a sophisticated dynamic damping system and supplementary structural reinforcement. That is, against Schön's claims, the Hancock tower posed no issues engineers could not successfully deal with through standard TR methods.

(ii) *Swampy lowland situations*: Schön uses the case of civil engineers building a road through a densely inhabited part of a city to argue that the formality of TR education prevents them from dealing with the dilemmas of *rigour or relevance* stemming from social, i.e., non-

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[7] The assertion "*every once in a while one still shatters*" made by Schön 10 years after the events is hard to accept considering the US's highly regulated environment, and more so in relation to the city of Boston. It suggests that, rather than on facts, the whole claim is based on an urban myth.

technical issues, hence his references to "*messes incapable of technical solutions" or* "*swampy lowland"* situations.

Again, reality denies Schön's claim: e.g., in the past 30 years countless cities all over the world successfully either expanded their Metro systems or built new ones. The size and variety of the cities involved (Wikipedia 2015e): Buenos Aires, Mexico City, Chicago, Montreal, the London "Tube," Paris, Prague, Hong-Kong, Beijing, Bangalore, Osaka… more than attest to the ability of engineers to successfully cope with Schön's dreaded *swampy lowlands* of urban planning. Underground trains are not just a technically sensible solution to public transport, they are also a proper alternative to the highway madness that helped depopulate so many large cities in the 1970/80's (Wikipedia 2015f; Glasser 2000), proving beyond doubt that TR-trained engineers can successfully tackle deeply involved social projects.

Schön's followers would probably try and credit the success of the Metro systems (or of any similarly socially involved projects) to the Engineers' personal artistry while negating any credits to the TR methods used. However, it is most unlikely that any of the practitioners involved will declare that dealing with such challenging projects[8] required from them to follow "*deviant traditions that stand outside… the normative curricula of the schools*." (Schön 1987, pp.15-16) This is not to deny that some practitioners are more gifted than others, a personal feature made evident by their innovative approaches and solutions to practical challenges, and which ultimately add to the long tradition of engineering creativity. But, as explained in the next subsection, rather than step outside as Schön pretends, creativity and innovation must remain within TR's strict bounds to be feasible, efficient and safe. Incidentally, Schön's supporters provide an example of implicit recognition of the strictness of TR's bounds: Bronfman (2005) used a standard structural design software to modify civil engineering structures in order to create "*surprise"* and induce "*reflection*," i.e., no "*deviant paths"* are involved in the process.

(iii) *Wilbert Moore's assertion*: in Schön's interpretation, Moore's words imply that empirically acquired, practical skills are an ambiguous, secondary kind of knowledge in relation to the fundamentals of science, creating a dichotomy that subordinates practice to fundamental knowledge. This line of thinking is followed, e.g., by Waks (2001b) and Gainsburg et al. (2010).

[8] The complexity of projects involving Metro systems can be appreciated, e.g., in K.-H. Chang (2015).

A practicing engineer would understand Moore's words in a more realistic way, making evident a bias in Schön's view: framing into general principles, rather than dismissing familiarity with practical skills and experience, is meant to make sure from the outset that no physical laws are violated during the development of the project. For example, should a designer consider having a single lift all the way to the top of a high-rise building, there are physical laws that place a bound on that option: the use of cables for tethering is limited by the strength/density relationship of existing materials. In short, great ideas may find themselves bound by the cold reality of physical laws. Ignoring them is not only potentially unsafe, it can make the whole design exercise time-inefficient, frustrating and wasteful. Instead, facing any physical limitations upfront will make evident the need for innovation wherever it is needed, opening the door to smart and creative solutions. Science, and even more so engineering, prove, time and again, that need is the mother of invention, but for this to occur efficiently, or rather, intelligently, the boundaries to intuition/artistry/creativity must be carefully identified first. That is a far more sensible understanding of Moore's words.[9]

Examples of intuitions proved wrong are plentiful, even within pure positivist science: a classical example is the British physicist Rumford dressing in white during winter to reflect the frigorific radiation. (H. Chang 2004)[10] Successful intuitions are not scarce either: Mendeleev's Periodic Table comes to mind. But, closer to the point, in fields that rely heavily on empirical knowledge and tradition, such as ship building, examples of myths, superstitions and physical misconceptions leading to faulty practices that dragged on for centuries not just abound, they often defined the craft to the point that the introduction of physical principles changed the practice dramatically. (Bernal 1971, p.42) E.g., Gordon points out that diagonal iron bracing, explicitly meant to prevent the sliding of planks under the effect of waves, was first introduced into wooden

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[9] For illustrative examples of engineers dealing with regulations, design from first principles and innovation, see, e.g., Müller (2015).

[10] The structural problems of the John Hancock Tower can also be considered as examples of unchecked intuitions gone wrong: the building was too thin for its width and height. A cynical observer would probably point out that the Tower is yet another example of TR engineers' ingenuity rescuing an overly artistic project gone overboard.

hulls *ca*.1830, putting a stop to the continuous water leakage, hence to the continuous need to use hand-pumps that so dreadfully defined the sailors' lives over the ages. (Gordon 1991, pp.149-50)[11]

At the end of the day TR is what proves intuitions and empirical knowledge right or otherwise by quantifying their effects on the material world, i.e., where Constructivism is not necessarily valid, and where there is little room for *deviant paths*. In down-to-earth words: should the tunnel of an underground train collapse, a bridge break or an aeroplane fail in mid-air due to an identifiable engineering oversight/miscalculation/misconception, no claims of artistry, creativity or relevance over rigour will save the Engineer's neck, and rightly so.[12] For an example where, following Schön, empirical knowledge is blindly put ahead of fundamental laws without any qualifications, i.e., without mentioning potential risks, see Gainsburg et al. (2010).

Even more to the point, and concerning current engineering, Bernal states: "*the strength of technical tradition is that it can never go far wrong-if it worked before, it is likely to work again; its weakness is that it cannot…get off its own tracks. Steady and cumulative improvement of technique can be expected from engineering, but notable transformation, only when science takes a hand.*" (Bernal 1971, p.42)

(iv) *85% of the cases faced by physicians are not in the book*, continuously forcing them to inventing and testing new diagnoses. [13'14]

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11 Gordon also provides a most illustrative account of superstitions within craftsmanship in the fabrication of materials. (Gordon 1991, pp.20-2)

12 The closing scene in Antonioni (1996) classic movie "Blow up" in which two mimes simulate a game of tennis comes to mind. In a Constructivist's view, the mimes' game is as real as it can get. The movie's argument, which spins around whether spots in a photographic film represent reality, provides also an alternative clue: paraphrasing Kozloff (1998), should those spots be on an x-ray film identifying cancer in the Constructivist's lungs, faced with the cold material certainty of illness or death, i.e., faced with unavoidable facts, the game's construed image would quickly collapse.

13 The 85% assertion is hard to take at face value: on the one hand, claiming that Medicine's lecturers are oblivious to the daily reality of un-descripted symptoms and illnesses affecting the vast majority of common patients makes little sense; on the other, hospitals and universities are indeed one outstanding example of research, teaching and daily practice closely knitted together. Schön (1987, pp.15-6) acknowledges this carefully crafted integration of science and practice but, with no elaboration, labels it a "*deviant tradition.*"

14 Schön (1983, p.64) even extends the claim onto ophthalmology. By his own example: out of every 100 people seen by any ophthalmologist, only 15 mean to get new glasses; the other 85 require an out of the

The main tenet of this example is that physicians guess at first sight rather than look at problems in the formal, systematic way TR demands, something that is certainly common in engineering practice as well. In Schön's words, when faced with a new problem, "*surprise leads her to rethink her knowing-in action in ways that go beyond available rules, facts, theories and operations*." The reflection-in-action mechanism allows her to respond *"to the unexpected ... by restructuring some of her strategies of action…., and she invents on the spot experiments to put her new understanding to the test*" (1987, pp.23-35). Schön explicitly denies any role of memory or prior experience, describing the reflective mechanism as a non-domain specific skill, a claim explicitly questioned by many of his followers. Grimmett (1989) pointed out that the diagnosis expertise in Schön's example was indeed case- or domain-specific: expertise in one field did not turn the doctors into experts in other fields. Likewise, Gainsburg et al. (2010) and Bulleit et al. (2013) explicitly point out that Engineering skills are domain-specific. In simpler terms: when faced with a new problem, skilful practitioners guess only because they have seen it before. [15]

That experience shapes intuitions is firmly established in the literature. E.g., regarding mathematics (Fischbein 1987, p.85): "*The basic source of intuitive cognitions is the experience accumulated by a person in relatively constant conditions"* or, more generally, (Kirschner et al. 2006): "*Expert problem solvers derive their skills by drawing on the extensive experience stored in their long-term memory.*" With reference to Medicine amongst other professions, Kahneman and Klein (2009) concluded: "*No magic is involved. A crucial conclusion emerges: Skilled intuitions will only develop in an environment of sufficient regularity, which provides valid cues to the situation*." None of the above involves mental processes that "*go beyond available rules, facts, theories and operations"* or "*follow rules that have not yet been made explicit and cannot be put in the medium of words"* as Schön pretends (1987, pp.30-1,35). (See also the section *Introspection and Self-directed Learning.*)

book approach to save them from undefined diseases, unbearable suffering and eventual blindness. Anyone wearing glasses will smile at such a claim.

[15] For the sake of completeness, it should be mentioned that a systematic, from-square-one approach is used by practitioners of all persuasions in problems for which the first guessing fails, or, more likely, to double-check. The flawed mirror of the Hubble space telescope (Wikipedia 2015c) is a good example of how risky it is to omit double-checking.

Schön’s reflection-in-action can thus be identified as a standard mechanism within the human cognitive architecture based on the long-term memory by which past-experiences and accumulated knowledge are taken advantage of. [16,17] It is not only a hardly original idea, it appears self-contradictory because of his denial of the involvement of long-term memory. It begs mentioning here that later on Schön accepts that the practitioner’s memory is explicitly involved: “*she builds up a repertoire of examples, images, understandings and actions*” in order to *“bear on a unique situation.”* (1987, p.66) Likewise, he accepts that “*exemplars…useful to reflection-in-action* (vary) *from profession to profession.*” (1983, p.315)

All four of Schön’s examples appear built upon either misrepresentations of facts or far-fetched assumptions, and do not support his assertions, leaving the scheme, as described in his books, largely baseless. Not surprisingly, his followers not only question the reality of the alleged dichotomies in professional practice, as already mentioned; they still cannot agree on the meaning of reflection-in-action (Grimmett 1989; Gilroy 1993; Eraut 1995; Newman 1999; Yanow and Tsoukas 2009), nor on how to solve a fundamental contradiction identified by Schön himself, [18] that of when to stop the loops of reflection. (Gilroy 1993; Newman 1999)[19] More significantly, Schön’s Design Education can hardly claim any educational success, as shown in the section *Documented Achievements*.

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[16] Karl Popper (1990, pp.31-3) discussed at length the case of surprises triggered by mismatches between unconscious expectations, or hypothetical or conjectural knowledge, and practical experiences, and pointed out that making a conclusion out of a mismatch (or in Schön’s terms, reflection-in-action following a surprise) is just a standard human way of adding certainty to conjectural knowledge, where certainty, or truth, “*means correspondence with the facts.”*

[17] For a fuller discussion of the role of short- and long-term memory in the learning process at both, the novice and expert learner student levels, see Kalyuga et al. (2003), Kirschner et al. (2006), Clark et al. (2012).

[18] Schön (1983, p.277-8) points out that practitioners often think about what they are doing while doing it, i.e., they perform a “*reflection-on-action.*” “*If we begin to reflect-in-action, we may trigger an infinite regress of reflection-on-action,”* with a paralysing effect, concluding: “*so understood, reflection-in-action is a contradiction in terms.”*

[19] Paralysing self-reflective loops are inherent to Mannheim’s *Sociology of Knowledge* (from which Schön developed his reflective scheme), see, e.g., Hartung (1970) and Romero Reche (2009). Likewise, they characterise Constructivism (Suchting 1998) and Postmodern Relativism (Gellner 1992, p. 41) at large.

- *Design Education. The Reflective Practicum*

Five issues will be examined: (*i*) Experiential learning and counterintuitive knowledge; (*ii*) Introspection and self-directed learning; (*iii*) Intellectual freedom and creativity; (*iv*) Time-efficiency; (*v*) The accountability of the reflective coaches.

(*i*) *Experiential learning and counterintuitive knowledge:* With references to Dewey's pragmatism and Rogers' existentialism, Schön asserts that proper learning can only occur through self-discovery and personal experience, or *learning by doing.* (Schön 1987, pp.16-7;89-92) The extent to which learning through self-discovery is feasible within the Physical Sciences must therefore be considered.

Hobsbawm points out that the physics and mathematics of the 1800's dominated architecture, farming and medicine well into the 20th Century, i.e., they depended on knowledge that could be largely acquired by daily experience. (Hobsbawm 1995b, pp.525-9) That is, to a large extent, knowledge based on Newton's Mechanics can be applied, in Hobsbawm's words, through "*experience, experiment, skill and trained common sense*." In the second half of the 20th Century applications of the most esoteric forms of high science, namely Quantum Mechanics and Relativity, found their way into everyone's daily life (the former through solid-state electronics, the latter through satellite communications) hence the need for engineers specialising in the new technologies. Hobsbawm stresses that both require a conscious attempt on the side of the scientists to explain them to the uninitiated, however technically educated. It could not be in any other way considering that a conversation on many of the relevant topics involved often requires education at the Ph.D. level to begin with. As examples of inaccessible science, Hobsbawm cites Otto Hahn's discovery of nuclear fission and Alan Turing's celebrated paper on logical mathematics that opened the door to computer science.

What makes this situation different from the first half of the 20th Century is the counterintuitive and obscure nature of the physics and mathematics involved, which precludes upfront any form of learning through self-discovery. E.g., the differences in elastic moduli stemming from weak and strong atomic bonds can be experienced through manually flexing thin bars of plastic, metal or glass. A physical experience involving, say, tunnel diodes, short of the observers turning themselves into particles in a box, is just not feasible. At best the phenomenon can be observed mediated by instruments based on the same principles the experiment purports to get a feeling for, i.e., with hardly any room for the observer to develop a "*merely personal nature of his view.*" (Schön 1987, p.92) This fundamental contradiction of Constructivism in Education has been often pointed out, see, e.g. Matthews (1998).[20]

Thus, assuming that Quantum Mechanics or Boolean algebra, which hardly relate to (Schön 1987, p.17, 94): "*an understanding of poetry,"* can be learnt "*by a kind of contagion*" or transmitted through "*mystery and magic in the atmosphere - the magic of great performers, the mystery of talent that falls capriciously, like divine grace, now on an individual, now on another,"* appears as plain delusional. Motivated and intelligent students must be carefully trained in mathematics and physics if they are to reach a sufficient level of understanding, hence of proficiency. These skills, necessary for innovation and creative applications in professional practice, which, incidentally, go well beyond Schön's narrow aesthetic conception of creativity already discussed, rather than developed through self-reflection or sense experience, depend on objective knowledge necessarily transmitted through progressive, instructional teaching methods.

(*ii*) *Introspection and self-directed learning*: Self-observation and reciprocal reflection-in-action constitute the core of Schön's Design Education. (Schön 1987, pp.44-99)

The emphasis on metacognitive aspects of learning, as opposed to the learning of, and from, the facts, implies, again, that professional creativity, rather than a domain-specific skill is an ability to be developed through self-reflection, independently and in advance (see, e.g., Ryan (2005) or Atman et al. (2008)). Experiential learning and self-observation are assumed to "*connect thinking and doing,"* helping students to "*develop self-directed, lifelong learning skills"* (Hmelo-Silver 2004; Ambrose 2013), while "*reflection … encourage(s) students to learn how to learn.*" (Khisty and Khisty 1992) Consistently, first year Design courses are expected to "*focus more heavily on conceptual design and less on discipline specific artifacts*." (Dym et al. 2005)

Schön's self-reflective pedagogy attracted early criticism: Munby and Russell (1989) advised against its implementation after concluding that "*Schön's work needs considerable empirical investigation before the promise (*of understanding how knowledge is acquired through

[20] The case study on the blue patina in steels provides a glaring example of how unlikely to lead to a useful conclusion Schön's experiential method is: after two semesters of trying, the students "*were not more able to explain the new process than they had been to explain the old.*" (Schön 1983, p.175)

self-reflection) *can be fulfilled."* Closer to the point, Popper (1970), in his critique of Mannheim's *Sociology of Knowledge* (which underpins Schön's self-reflective Frame analysis (Schön 1983, p.312)), points out to the impossibility of arriving to anything but arbitrary and subjective conclusions through self-observation due to the exclusion of the verifiability of results and the falsifiability of hypotheses and theories by others, as scientists systematically do. The extent to which self-reflection as a "*lifelong learning (metacognitive) skill*" purportedly avoids all explicit connections with objective knowledge and/or epistemology, thus stripping the alleged skill of all practical value while ensuring its immeasurability, can be appreciated, e.g., in Kavanagh and O'Moore (2008) and Figueroa et al. (2014). Not surprisingly, Schön's Design Education can hardly claim any success, see the section *Documented Achievements*.[21]

It begs questioning here the extent to which hands-on-learning in first year can involve "*authentic practice*" or "*real-world problems*," as often claimed by Schön's followers. (Khisty and Khisty 1992; Dym et al. 2005; Hmelo-Silver 2004; Atman et al. 2008; Gainsburg et al. 2010; Ambrose 2013; Reidsema et al. 2014)[22] Introducing major simplifications into a real-world problem to make it suitable for an introductory course is an obviously self-defeating aim sometimes thinly-recognised (Gainsburg et al. 2010; Ambrose 2013), although not to the point of realising that the logic behind the whole idea is faulty, logically as much as epistemologically. This assertion is explained through Bernal's critique of Aristotle's celebrated syllogism: "*All men*

[21] The emphasis on introspection has two convenient consequences for the constructivist teacher. Firstly, it turns essay marking into an arbitrary, quick mind-reading exercise disconnected from objective knowledge (c.f. footnotes #28 and #35 re. the *organization of consensus*). In the words of a leading educationalist supportive of self-reflection: "*It takes far less time to assess a batch of 158 one-page reflections than 158 3,000-words essays, and the reliability and the manageability of the assessment have increased very significantly*." (Race 2010, p.226) Secondly, it removes the need for technical expertise: *"the teacher/facilitator is an expert learner, able to model good strategies for learning and thinking, rather than an expert in the content itself."* (Hmelo-Silver 2004) That teachers need no expertise on their subject/s generally characterises Constructivism in education and is consistent with the idea that knowledge cannot be imparted. (Kragh 1998; Matthews 1998)

[22] Schön's and followers' frequent references to "*authentic*" or "*real-world"* examples as opposed to physical or mathematical models imply that the latter depart from reality. In Schön's words: *"scale models, wind tunnels and computer simulations"* are *"virtual worlds"* to which *"Engineers become adept at the uses of"* (1987, p.77); or "*they may try and force the situation into a mold which lends itself to the use of available techniques*." (1983, pp.44-5) See also, e.g., Gainsburg et al. (2010). Such a biased vision purportedly ignores that physical models are meant to isolate the dominant variables, turning the problem tractable, hence verifiable in practice, and are indispensable for trustworthy design.

are mortal. Socrates is a man, therefore Socrates is mortal." Bernal states: "*as if we could ever know the general before knowing the particular*." (Bernal 1971, p.199) This trivial-logic turns faulty when assuming that (Waks 2001a; Perdomo and Cavallin 2014) Design, i.e., 'the general,' is a metacognitive holistic skill to be acquired prior to understanding 'the particular,' i.e., prior to learning how to design what is dismissively called "*discipline-specific artifacts.*" (Dym et al. 2005; Ambrose 2013)

Concrete examples put the above arguments into perspective. In Schön's followers' view, an aircraft is a just a set of "*discipline-specific artifacts,*" i.e., a set of beams and panels, on wings, created following pre-established recipes. Such a simplistic view ignores that successful engineering design requires setting the overall goal/s (the general) using physical principles during the earliest stages. (Cross and Cross 1998; French 1998; Ashby 2011, 2015; Dieter and Schmidt 2012; Steele 2015) Only then the individual components, (the particulars) can be re-designed/optimised to meet the set goals.[23] Outstanding examples of this type of first-principles, integrated design are the (Wikipedia 2015a) Airbus A380 and the (Wikipedia 2015b) Boeing 787 Dreamliner. Both aircrafts were designed to maximise the fuel efficiency through lightweighting via intensive use of fibre composites and hybrid panels in their respective structural components. That is, for proper (i.e., safe and efficient) Engineering design, and against Schön's (1987, p.99) and supporters' assertions (Khisty and Khisty 1992; Waks 2001a), the student must know what she is doing before she begins to design. Or, as Bernal stated 50 years ago: "*We are beginning to understand that it is impossible to have good engineers that are not also scientific, …capable of using the techniques of science to … find out what they are doing and should be doing, rather than applying sound experience, common sense and formulae taken from textbooks.*" (Bernal 1971, p.820)[24]

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[23] At the student's level the process is necessarily reversed, making evident the epistemological shortcoming of the holistic approach: against Schön's supporters claims, the basics of designing 'particular' components (e.g., structural beams and panels) must be learnt first; the optimisation of the same components in order to meet a 'general' physical design principle (i.e., lightweighting through an optimal combination of cross sectional shape and material) can only follow (Ashby 2011; Cáceres 2007). See also (Kozloff 2002, Inventory point #6) or Precision Teaching in (Kozloff et al. 1999).

[24] The above conclusions concerning first principles in engineering design should be hardly surprising to anyone (whether technically qualified or not) familiar with the history of science, and not just through Bernal's or Hobsbawm's work. E.g.: Neffe (2007, p.56), with reference to Galileo's anticipation of

The above conclusions justify adopting an objectivist position for the present analysis. Further, they show the extent to which current engineering is indeed applied science, and highlight its dependency on science for innovation, e.g., through new materials and techniques, regardless of how much in some fields it uses traditional knowledge to advantage, as already stated. This does not deny that engineering design often involves non-technical aspects on top of the purely technical ones. Design, as Dieter and Schmidt describe it, involves creativity as much as the ability to deal with complexity, making choices and eventually reaching a compromise. (Dieter and Schmidt 2012, p.3) The point to stress, drawing from Ashby (2015, Ch.3), is that the objective layers of the solution, that is, those involving technical, economical and legal issues, need to be settled first in order to provide a safe ground from where to deal with the incommensurable variables, e.g., cultural or personal value-dependent issues, that may require a compromise. Engineering Design, however challenging, is a rational, systematic process that hardly requires following deviant paths and group or social thinking, let alone metacognitive skills developed through self-reflection and sense experience prior to the technical formation, as Schön and followers pretend.

(*iii*) *Intellectual freedom and creativity:* Schön's describes the Reflective Architectural Practicum as an ideal learning environment in which "d*esigning* takes *a form of artistry…essential to competence in the undetermined zones of practice."* (Schön 1987, pp.17-8) Against this claim, two of Schön own examples show the extent to which the Practicum can naturally turn into an arbitrary and submissive environment, in line with its Constructivist nature.

The first example refers to when to finish an on-the-spot experiment, something that occurs once the Practitioner either is "*satisfied*" or "*likes"* the outcome. (Schön 1983, p.151) It may be rightly argued that the term *satisfied* implies artistic freedom. Still, Hobsbawm's account of the late 1800's architecture comes to mind: he refers to the "*orgy of building into which a prosperous bourgeois society threw itself"* and which, in terms of artistic achievement, is more likely to "*stimulate apology rather than universal admiration.*" (Hobsbawm 1995a, pp.279,288-90)[25] In

Newton's mechanics, states: "*He thus became one of the founders of the art of engineering based on scientific principles*." Similar conclusions abound in Gordon's book (1991).

[25] Hobsbawm (1995a, pp.279, 288-90) also makes a point that further questions Schön's claims of lack of creativity within TR when he remarks that this pretentious End-of-Century architecture took good care of hiding behind their "*fine art facades*" the "*work of the brilliant and imaginative engineers.*"

other words, the act of stopping when he is *satisfied* can be strongly conditioned by the practitioner's (or, more likely, his client's) class attitudes, taste and interests, turning the entire 'experiment' into an arbitrary decision.[26]

The second example involves a student's project that, although functional, in the eyes of the coach, "*architecturally it's horrible*." (Schön 1987, p.81) Schön does not explain what 'architecturally horrible' means, although, considering again Hobsbawm's arguments, it seems likely that the student's project is only too far removed from the coach's and/or the client's class/taste/interests. If so, the student seems to have only two options left: either toe the prevalent line defining beauty, or find another practicum. The American architect David Glasser (2000) made similar points regarding the dominant cultures within major architectural studios.

The above conclusions are in close alignment with Kozloff's (1998) analysis of the relations of power in the Constructivist classroom, in which some voices shape the interpretation, or voices, of other members, pointing out the conforming reality intrinsic to unstructured learning: amongst novice students, consensus, by necessity, reflects the culture, sex and class interests of the more powerful voices of the learning team. The constructivist environment of the reflective practicum, while claiming to liberate the individual from the repressive forces of traditional bodies of knowledge and methods of reasoning,[27] in actual reality moulds the individuals' minds and morality within and by the constructivist led community, in which insight means agreement and truth means conformity.[28] The above constitute further evidence of intrinsic dichotomies in

[26] Social class issues, occasionally mentioned by his followers (Grimmett 1989; Fischler 2012; Eraut 1995), are considered by Schön as alternative views within the practitioner's *"multiples approaches to reality*" or "*Frames*" (Schön 1983, p.312), a conception borrowed from Mannheim's *Sociology of Knowledge*, cf. the section *Philosophical Fundamentals*.

[27] The idea that TR (Schön 1987, p.314,5) exerts an intellectual authoritarianism that curtails creativity is central to all constructivist/postmodernist views, see e.g., Lyotard (1984, Ch. 5, first published 1979). Within these views, scientific knowledge is just one "*discourse*" or "*narrative*" amongst many, and deserves no especial status beyond, e.g.: "*Helping students make sense of what they're learning*." (Kavanagh and Reidsema 2014) See Nola and Irzik (2003) for a critical discussion.

[28] Kragh (1998), in his critic of physics education within social constructivism, points out that in the constructivist's view experiments are used in the classroom only as long as it is the *organization of consensus* that is the focus of attention rather than an abstract idea or the proper outcome of experiments. In other words, neither the notion of error in an objective sense, nor intellectual elaboration upon the obtained results are parts of the constructivist teaching and learning process.

Schön's scheme, in this case between the claim of creative freedom and the reality of conformity imposed by its constructivist environment.

(*iv*) *Time-efficiency:* Schön himself both poses and answers this question: "*Not surprisingly, confusion and mystery reign in the early stages of …any reflective practicum. Yet, often, in a matter of a few years, or even months, some students (-those who do so-) begin to produce in some significant measure what they and their coaches regard as competent designing." "A reflective practicum demands…duration far beyond the normal requirements of a course." "…it takes a long time."* (Schön 1987, pp.163,311)

The Practicum's unstructured ways of learning are obviously to blame for its low time-efficiency. An unstructured environment is in contradiction with solid evidence that indicates that learning environments for novices require detailed guidance: holistic or experiential approaches that expect novices to discover essential contents or develop skills on their own wishfully ignore that learning to practice a profession is not the same as practicing the profession. (Kirschner et al. 2006; Clark et al. 2012) Further, Kalyuga et al. (2003) showed that only novice students need to develop sufficient expertise through carefully guided study in order to deal with open-ended problems (over time the student becomes an "expert learner"). The well-established, and successful practice of using "capstone" projects to complete B.E. degrees (not to mention postgraduate degrees), is solid empirical evidence supporting this conclusion. Schön's supporters sometimes recognise the latter. E.g.: Ambrose (2013) states: "*integration across contexts …and to synthetise and transfer what students have learned to new and complex situations…is what senior capstone courses are lauded for,"* although without realising that such success proves that creativity is inherent to TR, and evolves under the current objectivist/instructivist teaching methods in the early stages of the students' formation.

(v) *The Accountability of the Reflective Coaches*: As part of Schön's master plan for the implementation of his Design Education, Universities are expected to introduce a layer of Reflective Coaches whose status must be assured through salary, tenure and promotions, and whose legitimacy should be based solely "*on the artistry of their coaching practice*," rather than "*on his scholarly attainments or proficiency as lecturers.*" (Schön 1987, p.311) Such a loose

accountability is consistent with the social managerialism underpinning Schön's scheme, briefly described below.

When considering the role of the professions at large, Schön postulates that Reflective Practitioners, armed with a suitable ethics to carry on "*cooperative inquiry within an adversarial context,"* should be able to solve all sorts of social, labour or economic conflicts. Inherent to this managerial aspect of his scheme are a nascent "*Social Contract"* and a still underdeveloped "*Action Science*." (Schön 1983, pp.287-354) Shielding the Coaches from the demands of scholarly performance is only consistent with Schön's idea of a socially privileged class of self-anointed Reflective Managers.

The existence of a layer of socially detached, self-reflective intellectuals whose special task is to provide an interpretation of the world for the society at large is central to Mannheim's *Sociology of Knowledge.* (Hartung 1970; Popper 1970; Romero Reche 2009) Schön derived his frame analysis from Mannheim's *Sociology,* but in order to extend it "*beyond mere relativism"* and into current professional practice, he substituted Mannheim's free floating intelligentsia by his layer of reflective managers. (Schön 1983, pp.309-15)[29] Schön's managerial proposal, (in his words, "*however…utopian, in the pejorative sense*" it might be (Schön 1983, p.353)), is hardly new: it is at best a revamped version of the classical (Bernal 1971, p.1137) anti-Enlightenment work by James Burnham (1941), **"***The Managerial Revolution,*" and as such meant to fit within the 20th Century's corporative society and, of late, into the corporative university. (Meyers 2012) A managerial application of Schön's ideas is in McIsaac and Morey (1998), and, in conjunction with Heidegger's philosophy, in Yanow and Tsoukas (2009). Given the unaccountability of the Reflective Managers/Coaches, it seems hard to differentiate a Reflective Practice University from the current ones that, according to Schön, are under an authoritarian TR regime that "*squeezes artistry out*." (1987, p.314-20)

[29] Romero Reche's assertion (2009) concerning Mannheim's' *Sociology: "Postmodern theory seems to be the ideology for an intellectual class engaged in self-observation. Hence its solipsism,"* Gellner's description (1992, p.79) of Postmodernism "*as practiced by at most some academics living a sheltered life,"* and Kozloff's. (1998*)* description of Constructivism as the "*anarchical utopianism of a socially privileged class,"* come necessarily to mind.

- *Documented Achievements*

Considering the 30+ years passed since Schön first published his books and the scheme's popularity within engineering educationalist circles, a sizable amount of empirical evidence regarding both, teaching and professional practices, could be expected. The relevant literature, however, makes ostensible that the reflective scheme generally lacks educational verification, even at the introductory level, largely because when tried it did not meet the expectations. E.g: (*i*) it was still (Perdomo and Cavallin 2014) being planned; (*ii*) was only (G. Green and Kennedy 2001) at the pilot project scale, based on a few, hand-picked students; (*iii*) was an (Hook et al. 2013) initial exploratory study*;* (*iv*) was just (Valkenburg and Dorst 1998) a 2-day long exploration aimed "*to develop tools and guidelines for team design"* that require "*future experiments;"* (*v*) (Dym et al. 2005) *"in terms of… potential benefits of first year design courses, little data are available;*" (*vi*) (Adams et al. 2003) only "*gave us a new way to analyse our empirical data;"* (*vii*) (Broekmann and Cornish 2000) over a period of 6 years showed that "*the grade point average steadily decreased,"* whereas "*the more able students are not performing as well as they could. It is possible that they…are becoming bored;"* (*viii)* (Hmelo-Silver 2004) produced, at best, uncertain results: "*still, careful research is needed to understand if and how these potentials might be realized."*

A recent study across US universities concluded that although some undergraduate programs do incorporate Design Education, "*holistic," "hands-on design courses"* integrated along entire programs are "*the exception and not the rule."* (Ambrose 2013) Likewise, Dym et al. (2005) stated that whereas in some cases some positive effects like an increased retention rates of minorities were noted, overall "*there is no definitive data specific to design courses.*" Adams et al. (2003) concluded as well: "*the reflective practitioner model has not had a significant or broad influence on engineering design or engineering design education*."[30] Even in the field of Urban Planning, one of Schön's favourites, Fischler (2012) pointed out that out of over 250 works that quote Schön, very few engaged the scheme in a direct manner, attempted to apply it in novel ways, or tested or expanded his ideas.

Reasons for the failure of Schön's scheme to gain widespread acceptance amongst Engineering academics and practitioners must be partly sought in the shortcomings of the self-

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[30] These authors identified a single reference to Schön's work on a major Engineering database.

learning method discussed above. Further reasons are put forward in the section *Hard Science and Literary Culture.*

- *Reflection-in-Action as a Rigorous Means of Communication*

Using as example jazz players improvising together, Schön argues that when reflection-in-action becomes reciprocal, the musicians share a "*convergence of meaning.*" "*They reflect-in-action on the music they are collectively making, though not, of course, in the medium of words*." (Schön 1987, p.101) [31]

References to these coordinated forms of action are not new. Animals exhibit them as much as humans, and a classic example is Frederik Engels' description of the fox outsmarting dogs and hunters at the game of chasing by taking advantage of its knowledge of the locality and especially of those features of the ground that cause its scent to be lost. (Engels 1987b, p.460)

The more developed the nervous system, the higher the degree of awareness and the subtler the approach to life challenges. In humans, however, the cooperation of several individuals in the pursuit of game with their bare hands or unshaped sticks became possible only by the use of gestures or words. Language, as the natural consequence of social interaction, or coordination, through labour, over time became humans' most powerful means of cohesion and development. (Engels (1987b); Bernal (1971 p.72)) Along the same lines, when discussing intuitions in science and the use of language, Fischbein (1987, p.7) stated: "*By way of reasoning, we know infinitely more than we know through direct perceptual representations.*" It is thus hard to agree with Schön that intuitive knowing shared through a coordinated reflection-in-action overtakes language as a communication means, or that, *"when a practitioner displays artistry, his intuitive knowing is always richer in information than any description of it*." (Schön 1983, p.276)

A textbook example of Schön's idea was penned already back in 1865 by the German philosopher Eugen Dühring: "*He who can think only by means of language has never yet learnt what is meant by* abstract *and* pure *thought.*" (Engels 1987a, p.78) In his renowned 1877 "*Anti-Dühring*" rebuttal, Engels reduced this idealistic misconception to its bare bones: **"***On this basis animals are the most abstract and purest thinkers, because their thought is never obscured by the*

[31] Schon's supporters have made extensive use of the Jazz Band as an exemplar of a socially creative environment that "*promotes well-coordinated improvisation*" or as "*a form of social organization that produces order with little or no blueprint.*" (Itabashi-Campbell and Gluesing 2013; Bernstein and Barret 2011)

officious intrusion of language."[32] Schön's supporters also disagree with him concerning the value of language: "*reflective practice… requires explicit knowledge, rendered articulate for shared communication and reflection.*" (Friedman 2002) Or, drawing from a leading constructivist: "*Except for animal psychologists, social interaction refers to what is going on among humans, and involves language.*" (Von Glasersfeld 1998)

Returning to the jazz players, it is well established that communication through music between musicians and with their listeners is a manifestation of a common musical taste predetermined by their shared social and cultural backgrounds. To use John Davies' (1991) memorable statement: "*The greatness of Mahler generally fails to survive a trip to Brixton, and the greatness of Jimmy Hendrix fails to survive a trip in the opposite direction*."

In sum, Schön's "*convergence of meaning*" is at best evidence of common experiences stored in the participants' long-term memories, i.e., of something that facilitates mutual understanding in specific contexts, but hardly a superior form of communication by itself, let alone internally rigorous, as discussed next.

The claim of internal rules of consistency that Schön ascribes to the reflective mechanism (Schön (1987,pp.68-79);(1983, pp.150-6)) locates his scheme under Wittgenstein's game metaphors, or Fideism, something explicitly acknowledged by his followers (Gilroy 1993; Newman 1999; Waks 2001a). A game metaphor implies that on its restricted environment any particular discourse, in Michael Martin's words, "*can be seen as embedded in a particular form of life and has its own rules and logic.*"(Martin 1990, pp.256-61) Or, in Schön's own words: "*its validity is relative to his commitments to a particular appreciative system and overarching theory. His results will be compelling only for those who share his commitments.*" (Schön 1987, p.79)

Fideism suffers from the unrealistic assumption that social practices, or games, are so clearly demarcated as per the beliefs of their practitioners that they have no consequences for other games. (Martin (1990, pp.256-61); Fuller (2000, p.335)) Demarcation means that there could be

[32] Hobsbawm (1995b, p.290), in his account of Realism in the Arts during the 1800's, points out that amongst all arts Architecture was the one that "*lacked a truth of its own*," i.e., its meaning could "*not be expressed in words*." It is then perhaps not surprising that Schön (1983, p.76) selected Architecture as a model for Design Education. It follows that within his scheme the arts with an explicit meaning, e.g., Painting, Sculpture, Music and above all Literature, are all necessarily subordinate to Architecture.

no external standards that could be used in criticizing them. Communication, and especially disagreements between practices would not be possible, or would make no sense, turning all particular discourses equally logical, be that religion, astrology, fortune telling, or, more sinisterly, Nazi practices. In actual reality, cross-communication and disagreements are possible, and do occur, proving that, as Martin asserts quoting from Kai Nielsen, "*there is not 'religious language' and 'scientific language.' There is instead the international notation of mathematics and logic; and English, French, Spanish, and the like."* They all *"are part of the same conceptual structure, which is neither religious, nor scientific."* (Martin 1990, pp.256-61) Likewise, the anthropologist Ernest Geller (1992), in his critic of postmodernism, states that although "*all knowledge must be articulated in some idiom*"… "*there are idioms capable of formulating questions in such a way that answers are no longer dictated by the internal characteristics of the idiom…but, on the contrary, by an independent reality*."[33]

Schön's claim of distinctive norms for rigour for the reflective mechanism fails Logic's rigour test, once again highlighting the arbitrary nature of his scheme. Some of his followers are equally sceptical: Gilroy (1993) accepts the scheme's Wittgensteinian character, but questions whether that is enough to warrant knowing-in-action as a new kind of knowing which is revealed in practice, turning reflective practice into a new epistemology. Eraut (1995) expressed similar reservations.

The logical inconsistencies pointed out above are not privy to Schön's scheme: they characterise all forms of Constructivism (cf. footnote #19 re. self-reflective loops), and, again, stem from the reluctance to accept objective reality as the deciding factor in the acquisition or application of knowledge.

- *Radical-but-soft duality*

D. C. Phillips (1998), drawing from the British philosopher W.H. Newton-Smith's book, *The rationality of Science*, points out that Kuhn first described his renowned scientific revolutions (cf. footnote #35 re. paradigms) by making claims which were strong and exciting, but false. However, when under pressure, Kuhn softened them so they became more credible, the claims became "*weak*

[33] Cioffi (1990) characterised Wittgenstein's Fideism as a form of obscurantism that "*allots reflection explanatory powers it does not have*."

and boring." Phillips remarks that the same radical-but-soft duality is observed at crucial places in many social constructivists' theories, meant only to avoid serious criticism.

Schön consistently adheres to this double-sided strategy. E.g., after claiming that "*applied science and research-based technique…are bounded on several sides by artistry*," he accepts that "*an art is necessary to mediate the use in practice of applied science and technique.*" (Schön 1987, p.13) Likewise, after introducing his alternative "*epistemology of practice implicit in the artistic, intuitive process*," he immediately accepts that "*applied science and research-based technique occupy a critically important though limited territory*;"[34] or, when using face recognition as an example, after denying any involvement of long term memory in the reflection-in-action mechanism ("*no comparison…with images of other faces held in memory*"), he accepts that long term memory is indeed necessary: "*she builds up a repertoire of examples…"* in order to *"bear on a unique situation,*" or for "*repertoire-building research.*" (Schön (1987, pp.23,52,66);(1983, p.315))

The double-sided strategy is also apparent in Schön advice to the reflective practitioner: "*…although normal science research cannot be conducted in practice,… experience in the methods of normal science can be a superb preparation for reflection-in-action."* (Schön 1987, p.322) Thus*, "a* r*eflective practitioner must be attentive to patterns of phenomena, skilled at what he observes, inclined to put forward bold and sometimes radically simplified models of experience..*.to *acquaint individuals with forms of inquiry not literally applicable in practice, from which to improvise the kind of inquiry that can work in practice."* Schön's warnings about the reflective practicum operation: "*If it is to avoid becoming a precious island,…it must cultivate activities that connect…to the theories and techniques ..taught in academic courses*" can be seen in the same light. (Schön 1987, pp.311-2)

A closely related point is that Schön often takes the high moral ground, e.g., when he asserts that for TR practitioners "*uncertainty is a threat; its admission is a sign of weakness,*" as opposed to others "*more adept at reflection-in-action* (that)… *choose the swampy lowlands* (using their)

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[34] Schön's apologetic use of scientific language is not far from what modernist religions, such as Intelligent Design, do to hold their own in cultured circles (Bernal 1967, p.5). His contradictory assertions are reflected by his supporters' diverging interpretations: while some stress that Schön ***"****rejects science as the method of reflection for practice, and so rejects the spirit of science as the soul of the research university,"* calling ***"****for an epistemological battle against technical rationality, not a peace settlement with it"* (Waks 2001a), others read him in a far more conciliatory mode (Grimmett 1989; Eraut 1995; Friedman 2002).

experience…and intuition." (Schön 1983, pp.43,69) The same moralistic attitude characterises his description of the *Squeeze play* (1987, pp.314-20), and is even more evident in his social managerialism (1983, pp.336-8), see the section *Accountability of the Reflective Coaches*. Such a moral arrogance characterises Constructivism at large, see Matthews (1998) for examples.

- *Philosophical Fundamentals*

The anti-intellectualism and experiential pedagogy of Schön's scheme closely fit within Bernal's description of Existentialism (Bernal (1971, p.1131);(1967, pp.2,3)), as part of the "*revolt from reason*" which developed in late 19th century and become more marked after WWII. These tendencies grew out of a historically pessimistic reaction against positivist science that despite its undeniable successes in conquering disease and avoiding famine, had also brought war, instability and inequality far beyond anything seen before. Instinct and intuition became in this view more important than reason, and often led to the abandonment of the intellectual advance since the Renaissance, and a return to medieval or oriental mysticism. Bernal qualifies these tendencies as "*obscurantists*," a label not hard to apply to Schön's scheme considering its Wittgensteinian base (cf. footnote #33). Schön acknowledges that irrational tendencies are implicit in the rejection of Positivism when he criticises the Vienna School: "*Amongst philosophers of science no one wants …to be called a Positivist, and there is a rebirth of interest in the ancient topics of craft, artistry and myth* (1983, p.48). Consistently, through a supporter's letter, he characterises his scheme as the "*Zen method of education*" (1987, p.93).

The scheme's postmodern relativism is illustrated by the following two examples. The first one relates to Schön's overly simplistic assertion (1983, p.33): "*scientific inquiry consists in the use of crucial experiments to choose among competing theories of explanation.*" Taken literally, this claim, consistently with Kuhn's *Scientific Revolutions*,[35] turns complementing physical theories such as Newton's Mechanics and Einstein's Relativity into competing ones, hardly a

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[35] Kuhn's Revolutions occur through "*paradigm shifts*" by which alternative theories replace each other over time. Being often incommensurable with each other, no objective comparison between paradigms is possible. Kuhn's critics point out that since meaning, truth and knowledge are specific to each paradigm, the act of choosing between them becomes an irrational action, locating his Revolutions at the core of postmodern relativism. (Harvey 1972; Fuller 2000; P. J. J. Phillips 2011, pp.19-22) Kuhn's view, as adopted by Social Constructivism, implies that science, rather than knowledge verified against facts, is mere "*negotiated consensus.*" (D. C. Phillips 1998)

defensible proposition considering, e.g., that aircraft are designed and flown following Newton's laws while their satellite navigation systems conform to relativity.[36] That is, against Schön's assertion, there are no conflicts nor competition: physical theories replace each other with more encompassing and powerful bodies of knowledge, a manifestation of the cumulative nature of science that sets it apart from other social activities such as religion, philosophy, law or the arts. (Bernal 1971, p.42) Schön's contemptuous assertion, aimed to discredit TR through a biased oversimplification of facts, is not only consistent with postmodern relativism: applied to the solid science behind current engineering or medicine[37] it is a gross overstatement, aimed to dismiss the whole of TR as a collection of arbitrary exercises within what he calls "*Positivist doctrines.*" (Schön 1983, p.33)

The second example concerns Schön's "*Frame Analysis*" (1987, pp.4-7), derived from Manheim's *Sociology of Knowledge*, and by which the understanding of reality by any social group necessarily bears "*the stamp of the perceived interest of those groups*." (Schön 1983, p.312) Within this view, Engineering Design is a social process, labelled (Waks 2001a; Gainsburg et al. 2010; Atman et al. 2008; Itabashi-Campbell and Gluesing 2013) "*Cognitive Framing*" or "*Frame-Experimentation*," involving the development of a common language or common practices that "*make the world meaningful"* to the designers and their clients.[38,39] So conceived, design is a form

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[36] A realistic, hence acceptable assertion would be: "*dedicated experiments to decide between possible micromechanisms or processes*." Cases in point would then be, e.g., the wind tunnel experiments that helped to elucidate the reasons for the falling of the glass panes in the Hancock tower, or the use of biochemical tests to choose a suitable antibiotic.

[37] While attempting to argue that Positivist science misrepresents reality, Schön goes as far as stating: "*Medicine, a learned profession with origins in the medieval universities, was refashioned in the new image of a science-based technique for the preservation of health.*" (Schön 1983, p.31)

[38] For Waks the "*language of design… is a Wittgensteinian form of life,*" whereas Gainsburg et al. (2010) refer to "*a behavioural perspective of knowledge as participation in practice amongst colleagues supported by tools, artifacts and social interaction,*" Atman et al. (2008) claim to demonstrate that "*a sociocultural theory of learning may be used in* (the*)…understanding of students' development as designers"* whereas for Itabashi-Campbell and Gluesing engineering problem solving is a form of "*collective wisdom*." For further examples see, e.g.: (Dym 1994; Adams et al. 2003; Dym et al. 2005; Trevelyan 2014).

[39] Mario Bunge's introduction to his book, *Finding Philosophy in Social Science*, comes to mind: "*...understanding a scientific text calls for substantive as well as linguistic knowledge. This platitude must be stated… to counter the fashionable claim that literary critics…are competent to understand the scientific literature*." ((Bunge 1996, p.47), mentioned by Romero Reche (2009).)

of social constructivism in which, drawing from Kozloff's critique of constructivism, "*group think"* replaces objective knowledge, or in this case objective design. (Kozloff 1998) Engineering Design as a social construction is at odds with the earlier conclusions showing that physical principles as driving forces from the outset are essential for successful design.[40]

In sum, considering its pragmatic anti-intellectualism, and its Wittgensteinian, postmodern relativistic and irrational, existential features, Schön's scheme appears as a mystic by-product of the crudest form of Positivism rather than the alternative form of rationality it claims to represent.

- *Hard Science and Literary Culture*

Bernal (1967, p.411) addressed already in 1939 an issue closely related to the main topic of this paper when asserted that the rejection of science by those of literary culture is partly a reaction to science dryness and austerity, whereas positivist scientists tend to reject any kind of irrational or mystic additions. Along the same lines, Kragh (1998) is critical of what he calls "*the positivistically coloured conception of physics*" in science education by which *"physics is just a collection of facts about nature… and that consensus about truth is the hallmark of scientific work."* The British crystallographer Alan Mackay (2007) expressed similar concerns, and added: "*the social and humane and literary faculties of our universities appear to be suffering from postmodernism and anti-rationalism.*"

For the two visions to merge, Bernal (1967, p.411) argued, science must change. He stated that while it is right for science to restrict itself to natural phenomena that follow a regular order, it is not right when it assumes that anything outside that regular order cannot be dealt with. This limitation of Positivism (Bernal 1971, pp.1160-1), together with Dewey's unprincipled pragmatism (Bernal 1971, pp.1091-3), leaves the door open to mystic and irrational tendencies as the one discussed herein.

Fuller (2000, Ch. V) points out that Kuhn's incommensurable paradigms became an instant success within social scientists and the humanities at large because they seemed to offer "*a*

[40] Collaborative design involving division of labour is common in current Engineering, but pretending, as Schön's supporters do, that cooperation turns Design into a Social Construction purposely ignores that internal consistency in all forms of engineering teamwork is ensured by the subjacent physical principles. For examples of this postmodern misconception, see Trevelyan (2014, pp.118-46).

blueprint for how a community of inquirers can constitute themselves as a science, regardless of their subject matter." Kragh (1998) and (Nola 1998) point out to the same situation regarding Science Education, and stress that the success within the soft sciences is counterbalanced by the physicists' overwhelming rejection of Kuhn's ideas because of their denial of objective knowledge. The parallel with Schön's Design Education is evidenced by the fact that despite its wide support within Educationalists, Engineering academics and practitioners simply ignore a scheme that lacking an objective base purports to solve non-existing issues, a reality acknowledged in practice by many of Schön's supporters, see, e.g.: Fischler (2012); Ambrose (2013); Borgford-Parnell et al. (2013).[41]

Concluding Remarks

Drawing again from Bernal (1971, p.1161), the advent in the early 1900's of atomic physics dismissed right away the Vienna School's positivists claim that only things that could be verified by sense impressions or mathematically proven could be trusted. In other words, for over a century both Physics and Engineering have been in practice far beyond the obsolete forms of Positivism Schön (1983, pp.30-7) claims are at the core of TR.

The present author shares, with Bernal (1967, pp.6-7) and many others, a rather more chastened view of the social effects of science and technology than the one held by the original positivist thinkers by which science is "a universal benefactor of humanity."

With Popper (1995, p.xxii) and Fischbein (1987, p.13) amongst others, the present author considers intuitions immensely important for the development of theories and models as well as for a successful professional praxis, but, at the same time, something that Scientists and Engineers alike must be severally critical of if they are to avoid being misled by them.

The author strongly favours innovation in teaching, and that includes, e.g., the learning of design through problem-based methods. However, as stressed all along this work, innovations must be carefully crafted to ensure close contact with objective reality at all times.

[41] Schön (1987, pp.314-20) anticipated this debate when he described the "*squeeze play*," regretting that "*technical rationality is by no means dead. On the contrary, it is on the rise*."

Neither Schön's Reflective scheme nor its ensuing Design Education offer to fulfil any existing needs in Engineering learning or practice, and that ultimately explains why both remain largely ignored by academics and practicing engineers alike.

As far as this author is concerned, current attempts to adopt the Reflective scheme or its Design Education within the Engineering curriculum are unjustified and should be actively discouraged, for the good of current undergraduate students as much as for the good of Engineering, Science and the society of the future. Mystic, irrational, obscurantists and historically regressive methods are hardly the right tools for educating the practitioners of one of the socially most significant and innovative intellectual and practical activities of humanity.

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