

THEORY, PRACTICE AND REFLEXIVITY: THE NEXT CHALLENGE FOR CDIO?

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ABSTRACT

The 'Conceive-Design-Implement-Operate' (CDIO) movement of engineering education reform emphasises project-based, experiential learning and the development of professional skills such as teamwork, collaboration and design. As well as disciplinary theoretical knowledge, implementation of the CDIO educational agenda calls for expertise in both engineering design practice and teaching practice. This agenda, it is argued, involves fundamental epistemological and normative shifts and involves engineering educators, like it or not, in what Donald Schon called "the battle of the epistemologies". This paper situates the CDIO agenda within the wider context of current professional educational thinking. In doing so it argues for the need for engineering education to advert to a third epistemological dimension of reflexivity, beyond theory and practice, now long since embedded in health care, managerial and teacher education. The authors then outline how the reflective dimension has been embedded in the Civil Engineering undergraduate program at the University of Limerick. Examples of both teacher's and students' reflections are offered for consideration. Pedagogical practice, approaches to assessment and some challenges encountered in implementing the reflective dimension in an engineering curriculum are outlined.

KEYWORDS

Epistemology, CDIO, PBL, Reflective Practice, Standards 2, 3, 5, 10, 11, 2.

INTRODUCTION

The CDIO approach to curriculum design involves students engaging in the kinds of activities that characterise the industrial practice of engineering: designing, collaborating, presenting, leading and so on (CDIO refers to 'professional skills'). In so doing, CDIO addresses the problematic theory-practice tension that is a feature of engineering curriculum reform. It has been argued elsewhere that the source of this tension is at root epistemological (Cosgrove & O'Reilly, 2018) and some argue that history suggests that the tension is both persistent and ineliminable (Edström, 2018). Epistemology is the philosophy of knowledge, its possibility, nature, scope and validity. Educational reform raises fundamental questions: What kind of knowledge is valid and valuable? What competencies are and pedagogical practices are required to inculcate such knowledge? Such questions challenge existing practices and power

structures. In fact, philosopher and educator Donald Schön has called this theory-practice tension 'a battle of the epistemologies' (Schön, 1995).

Schön characterised practitioner knowledge as 'professional artistry', a kind of 'knowing in action' which may be made apparent in what Schön called 'reflection in action' (Schön, 1983, 1987). As he says:

there is a great deal of critically important knowing-in-action that is not captured in research results as they are usually formulated in textbooks or published papers (Schön, 1995, p. 30).

This knowing includes what CDIO calls professional skills. Schön goes on to say that we can all reflect on our action, objectify it and consider how we might modify our approach. That is the fundamental argument for what Schön calls Reflective Practice [RP]: to learn from our lived experience as practitioners or budding practitioners (Walker, Keogh, & Boud, 1985). Therefore Schön suggests that all students of practice disciplines stand to gain from reflecting on action or engaging in RP. According to Schön, both the practice of and the teaching of practitioner skills involve a reflexive move. Schön's work has spawned a movement of reflective practice in professional education, especially in the health and caring professions and in teacher education where RP is now deeply embedded in curricula. Curricula that adopt RP typically require students to engage in reflective writing usually about practice placements. Educators who embrace RP now consider that truly professional practice is constituted as truly professional by its lifelong critically reflexive stance. RP then becomes a way of professional life often taking the form of Action Research [AR]. In fact, AR may be considered a form of RP. The RP movement now draws on many other thinkers in addition to Schön including Dewey, Freire and Brookfield (Brookfield, 2017; Lyons, 2006, 2010; Moon, 2004).

REFLECTIVE PRACTICE and CDIO

Engineering educators who adopt the CDIO approach sit astride the theory-practice divide in two respects since both engineering and teaching are practices in Schön's sense (Cosgrove & O'Reilly, 2018). If such educators research their own educational practice, it is argued that this also involves a reflective dimension. Both Dewey and Freire emphasise that educational enquiry requires a critical stance since neither institutional assumptions nor power interests are transparently apparent. Carr and Kemmis agree and they elucidate the epistemological and methodological shifts required to move beyond assumptions derived from the natural sciences and embrace a critically reflective stance in research that is educationally authentic (Carr & Kemmis, 1986). Furthermore, they insist that for research to be truly educational, it must be in the service of improved practices, and therefore it must involve as participants teachers and, as far as possible, their students.

This article considers engineering education and the CDIO movement in particular in the light of these ideas and suggests the need for a reflexive element in engineering education. The work reported here adopted the AR approach which is consistent with RP. While the research reported here relates to curriculum development, the epistemological shifts noted by Carr and Kemmis that distinguish theory, practice and critically reflective practice are outlined. Curriculum exemplars are described, including tutor and student reflections from the

University of Limerick undergraduate program in Civil Engineering. A number of educational benefits are argued for and some problematic issues are noted.

NATURAL SCIENCE AND POSITIVISM

Science searches for law-like regularities (correlations and causal relationships) among variables in systems with a view to explaining and predicting behaviour and in the case of man-made technological systems, facilitating control of system behaviour. Its theories are constructed incrementally and inductively and it proceeds by controlled experiment to test hypotheses. Epistemologists have characterised natural scientific knowledge as positivist (Giddens, 1978). Within academia the discipline of engineering is closely allied to the empirical natural sciences and engineers' assumptions about knowledge, their implicit epistemology and research methodology tend to mirror those of their natural scientist colleagues.

FROM POSITIVISM TO INTERPRETIVISM

In the 19th century, Auguste Comte proposed that the Social Sciences should adopt the methods of the natural sciences which he called 'positive science', hence the title 'positivism' (Cohen, Morrison, & Manion, 2007; Giddens, 1978). The perceived, dehumanising effects of adopting positivist assumptions and methodology (Outhwaite, 1987, p. 6) in social science resulted in a reaction. The pioneering sociologist Max Weber declared: "the course of human action and human expressions of every sort are open to an interpretation in terms of meaning..." (quoted in Outhwaite, 1987). Thus, for example, no scientific experiment or analysis performed on coins can reveal the nature of or value of money. That can only be revealed by reference to complex social understandings, practices, rules and contextual conditions. Interpretivism, therefore, seeks an understanding of the subjectively held meanings in play in a social context. This, in turn, leads to the positivist charge that interpretive approaches are not objective (in positivist terms) and are therefore unreliable and invalid. Notwithstanding the early emergence of interpretive approaches, the tendency to import inappropriate positivist assumptions and methodology into the social sciences is still pervasive (Artigas & McCone, 2006; Bennett & Hacker, 2003; Hyslop-Margison & Naseem, 2007; Smit & Hacker, 2014; Tallis, 2004, 2014). Therefore engineers should pay particular heed to Borrego's warning about the tendency of engineering educators to transfer in an inappropriate way positivist assumptions into their educational research (Borrego, 2007). Contrary to systems examined by the natural sciences, social systems can often only be understood 'from the inside' by reference to the commonly held meanings of the participants.

TECHNICAL RATIONALITY AND EDUCATION

Engineers, informed by empirical science, often design systems by identifying the most efficient means to achieve a pre-defined end by a controlled manipulation of materials and processes (although engineering design artistry certainly involves much else besides (Cosgrove & O'Reilly, 2018)). This approach separates the means from the ends and is called technical rationality (Dunne, 1993, 2005; Schön, 1995). Schön notes that this profoundly

reductive epistemology of technical rationality argues in regard to knowledge generation (research) in general:

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

Borrego's observation that engineers tend to transfer this kind of rationality (assumed as normative) into their educational research has been noted above. It is this hegemonic claim of technical rationality rooted in the causal categories of empirical scientific explanation that Schön contests and that is challenged here. Peters explains the conceptual error involved in such attempts to separate educational means from educational ends.

Talk about 'the aims of education' depends to a large extent on a misunderstanding about the sort of concept that 'education' is....Education is not a concept that marks out any particular process...rather it suggests criteria to which processes...must conform. One of these is that something of value should be passed on... People think that education must be for the sake of something extrinsic that is worthwhile, whereas being worthwhile is part of what is meant by calling it 'education'. The instrumental model of education provides a caricature of this necessary feature of desirability by conceiving of what is worthwhile as an end brought about by the process.... (Peters, 1956) quoted in (Carr & Kemmis, 1986 p.77).

Or as Carr and Kemmis express it compactly 'educational "ends" are constitutive of educational "means" as educational' (Carr & Kemmis, 1986). If the means employed are not congruent with the avowed educational ends, then questions about instrumental efficiency do not even arise (Cosgrove & O'Reilly, 2018).

For those seeking to conduct research on their CDIO practice, the technical-rational prejudice must be challenged by acknowledging the valid knowledge category of practical-professional knowledge or artistry and asserting the ethical basis of education as a practice. Reflective Practice is one avenue to elucidating the nature of and nurturing the development of such professional artistry.

CRITICAL REFLEXIVITY IN EDUCATIONAL RESEARCH

Many educational researchers do apply interpretive methodologies in their research. However, education is a human social practice (Dunne, 2005) with its own ends and values. As noted above, practices (including engineering and teaching) involve aspects of what Donald Schön named 'professional artistry' (Schön, 1983, 1995). If research is to be characterised as educational, then its aims and values must be congruent with those of educators. A research approach, even an interpretive approach, drawn from the social sciences that seek to develop theoretical understandings and leave practice untouched cannot properly be called educational (Carr & Kemmis, 1986, Chap. 4). Furthermore, Carr and Kemmis point out that it is not sufficient simply to elucidate all the meanings at play in an educational situation, in an interpretivist mode:

'The subjective meanings that characterise social life are themselves conditioned by an objective context that limits both the scope of individuals' intentions and the possibility of their realisation. By adopting an epistemology for the process of self-understanding that excludes critically questioning the content of such understandings, the interpretive approach cannot assess the extent to which any existing forms of communication may be systematically distorted by prevailing social, cultural or political conditions (Carr & Kemmis, 1986, p. 135).'

We need a critical point of view. The critical theorist Jurgen Habermas proposes that knowledge is constituted by three kinds of interests: the technical, the practical and the emancipatory. The technical interest is closely aligned with the natural sciences. The practical interest generates knowledge as interpretive understanding (Weber's '*Verstehen*') which can inform practical judgements about action. Because it informs action it has a necessarily ethical character. However, in addition to interpretive understanding we need to identify the forces that distort and render inauthentic educational practices. For example, whose interests are served by the 'hidden curriculum' of lectures divided into subjects, conducted in 50 minute time slices and assessed predominantly by end-of-semester written exams (Eikeland, 2001, p. 145; Schön, 1995)? A critical social science seeks to identify and provoke action to eliminate distortions in the interest of rational autonomy and freedom. This interest Habermas calls an emancipatory interest. The role of critical theory in social relations is analogous to the role of psychotherapy in individual living: to identify, articulate and reconfigure mistaken, oppressive or dysfunctional understandings, structures and relations that frustrate the flourishing of human life in all its potentialities. To this end, a critical social science asserts the need for a self-reflective understanding because we unknowingly reproduce in our practices the inauthentic patterns of our own experience.

So we see that teaching and learning practical or professional skills involves a reflexive move and researching our teaching practice also involves a reflexive turn. It is argued therefore that an epistemology adequate to these tasks must be further extended beyond theory (natural and social) and practice to include a critically reflexive category of meaning which we may refer to as '*interiority*' (Coghlan, 2010, 2016). For a more complete argument and account that expands on and situates such an extended epistemology in a wider philosophical and historical context see (Cosgrove & O'Reilly, 2018).

Participatory research to promote beneficial change is called Action Research (AR) (Carr & Kemmis, 1986 Chap.7). The essence of the process is ongoing cycles of planning, acting and reflecting conducted collaboratively in particular contexts with the practical end of improving current practice and this is the approach was used for the development work reported here.

The 'Conceive-Design-Implement-Operate' (CDIO) movement of engineering education reform emphasises project-based, experiential learning and the development of professional skills such as teamwork, collaboration and design (Crawley, Malmqvist, Östlund, & Brodeur, 2007). Problem Based Learning (PBL) shares many of the concerns of CDIO practitioners. Edström and Kolmos note that, while CDIO reform proceeds from outcomes (ends) and PBL reform proceeds from process (means) they are nevertheless complementary approaches that overlap in many areas (Edström & Kolmos, 2014). Therefore the examples cited here from Civil Engineering at the University of Limerick (CIVIL @ UL) which were originally informed by the PBL approach are as relevant for CDIO practice as they are for PBL. Both CDIO and PBL

are intended to provide many of the experiences of practice placements and as such can offer similarly rich potential for reflection.

REFLECTIVE PRACTICE IN EDUCATION

Given the character of both CDIO and PBL it will now be clear how such approaches include both theory and practice. The first author encountered the educational work of John Cowan (Cowan, 1998) in 2009. Cowan, a Civil Engineer, advocates the need for reflection for (prior to) as well as on (after) action (Cowan, 1998). For Cowan, reflection is concerned with any experience bearing on learning with a view to further development:

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

He proposes a protocol for reflective writing that moves from a selective description of experience through the critical interpretation, evaluation and self-challenging to forward planning and metacognitive self-review (Cowan, 2013, 2014). It is distinct in emphasising anticipation (reflection for action) and in pivoting to the future after reflection-on-action. Because of its practical, developmental and ethical thrust and its expression in accessible language likely to be congenial to engineers, Cowan's model has been adopted and embedded in the problem-based program in Civil Engineering at the University of Limerick since 2009 (Cosgrove, Ryan, & Slattery, 2014), and with the support of John Cowan is currently undergoing development through Action Research. The preparatory research phase, to align practice with Cowan's model of reflection, lasted 3 semesters. The formal action research phase after receipt of ethical approval has involved 3 cohorts over 5 semesters and finished in the summer of 2018. Cowan summarises his key conclusion about reflective practice thus:

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

Self-assessment is simply another name for the core of reflective practice.

IMPLEMENTATION IN THE UNIVERSITY OF LIMERICK

Reflection is required at a number of points throughout the UL program but just two are noted here: The first is a second year module, Design Studio (DS) where students are individually tasked to choose a problem (e.g. a design or organisational problem) or problematic situation of personal interest and examine possible measures to ameliorate the problem or improve the situation (Quilligan, Phillips, & Cosgrove, 2017). Problems proposed by students range from a design for real-time coach-player communication systems in non-helmeted sports to durable silage pit covers to the amelioration of binge drinking. The module is lecture-free and moderated by two tutors. Students typically spend some days off campus to help stimulate creative thought and they present periodically on their developing ideas. The second example

is a third-year group based Integrated Design Project (IDP) spanning 4 modules including Soil Mechanics, Structural Analysis, Reinforced Concrete Design and Professional Skills which requires groups to survey a site and design and present a whole-frame structural solution including foundations. Third-year cohorts (typically 30 to 40 students) include between 4 and 9 Chinese students newly arrived in UL and a small number (between 1 and 6) of American or European international students. Students carry out their own site survey and are supplied with a geotechnical investigation report including soil samples and Architectural planning drawings for a real project with planning permission on the surveyed site. Most subject lectures happen during the morning and moderated and unmoderated group meetings and workshops happen about twice each week over the 12 week semester.

ASSIGNMENT STRUCTURE AND WORKSHOPS

The reflective writing assignment used in CIVIL @ UL was developed in collaboration with John Cowan and is drafted so as to be generally applicable to many contexts. The reflective task is structured in 3 stages (see table 1) in order to motivate early engagement and 'get the ball rolling' with an unfamiliar mode of thought. Online feedback is provided by the tutor at stage 1, independently and confidentially by John Cowan at stage 2 and by a peer at stage 3.

Week no.	Stage	Content	Notes
3	1	Review experience to date; Anticipate 3 likely Demands/Abilities/Dispositions	Description of each chosen ability as performed in practice Personal plan to develop ability Kind of Data to be collected to demonstrate development in each ability to a prospective employer for work placement
6-7	2	Interim Reflection on Action :	Review progress and feedback to date. Make interim learning claim with supporting data
11-12	3	Final Reflection and Look Ahead	Final learning Claim with further data and implications for future development

Table -1 Reflection Stages

Submissions and feedback are administered through the UL online learning management system, SULIS apart from John Cowan's feedback which is emailed confidentially. Apart from noting that those that engage early and respond to formative feedback do better, it is not felt that a detailed analysis of development over the stages would yield important insights.

A variety of instructional documents have been developed for each stage of the process, emphasising a) keeping a journal or log of learning experiences, b) personal choice in the ability, skill or disposition chosen for reflection, c) a clear account of the skill or ability in performance, avoiding bland generalities, d) the specific kinds of data that would tend to support a credible claim of development in the chosen skill or disposition, e) an account of salient events or learning experiences (including learning from failure) with data relevant to the specific claim, f) a before-and-after comparison of capability g) a look forward to future implications for professional development. Workshops are held in advance of each submission stage to encourage i) identification of possible skills for reflection, ii) assessment of exemplar

texts and iii) self- and peer-assessment of draft submissions and iv) raising awareness of the relevance of self-assessment of professional skills for employment.

As each action research cycle of development has progressed, in the spirit of collaboration that animates AR, 3 prompts are tabled to students at the conclusion of each workshop as follows:

1. The most important thing you do when facilitating our workshops is to.....
2. You could help us more effectively if you would.....
3. It's not really helpful when you.....

Responses are written on anonymous post-it notes. These responses allow modification in practice where that seems warranted by the comments. Similarly, anonymous post-it notes are used to gather responses to a wide variety of questions that arise during workshop discussions, for example, 'how many hours of study and meetings per week would be required to succeed on this project' or 'what is the most frustrating behaviour among teammates?' These answers can then be posted as feedback so students can gauge their own opinions and expectations against those of their peers.

WHAT THE STUDENTS WRITE ABOUT

Some 300 odd submissions have been stored in a database (NVIVO) that facilitates a comprehensive analysis of data in multiple formats. A first cycle of coding has been completed. This identifies the wide variety of themes apparent in the text by name e.g. presenting, time management, group work, feelings, learning by doing, confidence, motivation, creativity and so on. Further cycles of coding will allow consolidation of themes into related clusters of themes. Examining only final submissions (170), the most commonly presenting single word is 'time' (970 times). Abilities (or skills or dispositions) have been filtered from the themes identified in the first pass of coding and the most frequent 7 are shown in Table 1 together with the number of submissions in which they occur.

Theme	Occurrence
Teamwork	109
Communicating (not presenting)	96
Time Management	95
Presenting	92
Planning	73
Research	49
Interpersonal Skills	43

Table -2 Reflection Themes

It is apparent that some themes such as 'Time Management' and 'Planning' may overlap and further analysis is required in this regard. One theme, 'challenge of freedom' occurs predominantly in the Design Studio (DS) example (17 times) and only twice in the IDP where the required outputs are specified quite tightly. One DS student comments:

'Although I was allowed to choose any topic which suited my fancy, I was confounded by the choice, as I had not been given such freedom ever before in my academic life'.

Similarly, 'creativity' occurs 25 times in Design Studio reflections but only 4 times in the IDP. The link between freedom of choice and creativity is apparent in the following:

'to be handed a blank page and told to come up with your own idea/concept was very different. This process required creative thinking.'

One requirement of the Design Studio module is to consult end users or stakeholders related to the student's choice of topic. This develops further skills:

'Then once I had a possible solution I had to see if there was actually a demand for such a product (football vending machine) this led to multiple conversations with basically every football player in the course, the manager of my own local team, players from my local team and players from all other teams also. This was a major factor in my ability to develop my communications skills.'

The IDP spans 80% of all activity (4 out of 5 modules) in an entire semester. It is situated immediately before students go on their 8 month industrial placement and is designed with that in mind. Students must manage their time throughout the semester as 50% of the credits are for assignments completed during the semester. These assignments may be worked on in groups but each student submits individually. While there are a rich variety of experiences with a high potential for reflection, so far it has proved difficult to motivate students to keep a learning log or journal of salient experiences for later harvesting. Nevertheless, examples of competent and credible IDP learning claims occur with sufficient frequency to convince the authors that the effort is educationally worthwhile and two extracts follow:

'Communication (Verbal) - It has been over ten weeks since I started reading books to improve my vocabulary and so far, I have yet not seen any improvement. The feedback from my friends tells a different story. They tell me that I have no speech impediment ...In week 5 we had a mock presentation...The video provided at the end of this presentation with the constructive criticism by my classmates helped me to better myself for the real presentation. They told me to look forward and keep eye contact with the audience and look less at the notes or have sticky notes instead. For the final presentation, I followed the same steps as I did in week 6. ... There was a point when I went blank due to anxiety, but I was able to keep it together and finish my speech. This proved that the method that I chose was helpful and worked. Still, I had to practice more in order to completely overcome my anxiety.'

It is doubtful that the student would have engaged in such a focussed way and sought and received such effective peer support and feedback on an area that was problematic for him if the reflective assignment had not provided the motive and space to do so in such a conscious way.

'Working in Projects with Younger Members – Progression

'I offered an option to divide the work in the group and this has made a huge impact on my schedule as I didn't have to chase around for anyone and could manage my time and role in the project. One example was that we needed to get a group presentation done and they left everything to the last minute so I offered to work on other parts of the project and help them with that instead of getting involved in the last-minute pressure and it worked, ... They were happy for me to get other parts done for them and I was happy to have them done this presentation, so distributing the work has worked in this matter and I also indirectly was able to develop some leadership skills. ... I must respect whatever way a younger member of the team wants to do their work. This reflects their teenage moments in life and

I now understand because one day I was standing in their shoes.'

The above extract is from a stage 2 submission. A reading of all three stages shows a clear progression from frustration to action to resolution for this highly motivated mature student who learned how to work fruitfully with less well organised younger team members.

Since early on the first author has kept reflective notes and memos of salient events and has found Schon's conviction borne out: as teachers we need to reflect on practice in order to notice and understand what we do. We may be surprised at what insights can emerge that we may not have been aware of. One such example follows of a moment of classroom talk from my own workshop practice that would have been lost had it not been recorded shortly after the workshop:

“Paradox: You must look in the mirror to reflect.
[I modelled this physically with my hand as mirror]
If your attention is distracted from your reflection by looking at assessment i.e. thinking about what “they” are looking for, you will then no longer be reflecting.
So if you want to score high in reflection forget about the score!’

CREDITS AND ASSESSMENT

Assessment is by the first author using the assignment as a guide with an eye to the 7 points noted a) to g) above with particular emphasis placed on item d), persuasive data to support any learning claims of a kind likely to convince a prospective employer. Plagiarism checking software is used on submission. Grading is benchmarked each semester by sending a sample of graded assignments at C, B and A grades to John Cowan for cross-checking and sharing of judgements. In the DS module, the reflective work attracts 30% of the credits. In the IDP out of 400% across the 4 modules 35% is allocated to the reflective work, 10% from each of 3 modules and 5% from the fourth.

PRELIMINARY CONCLUSIONS

A significant number of students do learn how to reflect well and their efforts are both competent and credible, although many students find the task challenging and some submit narratives with unsupported claims of development.

Mature Students engage with reflective work willingly

Complex group based design projects makes many demands on students in the broad area of professional skills that are educationally valuable.

Reading students reflections opens up to the tutor a world of experience and learning, of educational life, that might otherwise go unnoticed and unrecorded. The teacher's own awareness, empathy and motivation can be significantly enhanced thereby. Furthermore, reflective writing allows tutors to access the student's experience in ways not allowed by other modes of educational engagement. This, in turn, provides an opportunity for educators to consider how the many kinds of valuable learning that are happening in CDIO type curricula, including the unforeseen yet valuable outcomes can become credit-bearing.

Each semester some students, without prompting, choose to write about the benefits they have derived from reflection in education and sometimes in their life generally.

Plans are being made to require students to update a learning log weekly on the learning

management system.

Consideration is being given to allocating a full 6 credit module to the reflective element in the IDP with the intention of requiring assembly of an employment-relevant e-portfolio to support learning claims.

Consideration is being given to including time-management as a mandatory element with explicit support as one of the three skills treated.

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