Developing Engineering Education Using a Community of Practice Model

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Abstract: To meet the challenges of providing engineering education in and for the knowledge era, a model of engineering education, drawing on the concept of community of practice, is discussed. The term communities of practice originated in the idea that professional community acts as a 'living' curriculum for novices to that community. Professional cultures and communities tend to be stable and resist 'deep redefinition', but they also change over time. Understanding the mechanisms of stability/continuity and change in community can inform our pedagogy as we endeavour to define 'good' educational practice capable of providing the community with novices able to fully participate in all the aspects of the professional community. The proposed model acknowledges the continual tension in engineering education between maintaining existing/current [reproduction] and developing new, innovative [transformation] knowledge and practice of both engineering and pedagogy. This is a feature often missing from other analyses of engineering education. Examples of different frameworks of learning within the engineering community of practice and how they have been mapped into the development of 'academic' learning tools for engineering education are explored. The emergence of revised work-based learning models of engineering education and their synergy with the community of practice model are discussed.

Keywords: community of practice, curricula, transformation

Introduction

The term "communities of practice" originated in the idea that professional (or trade-based) community acts as a 'living' curriculum for apprentices to that community (Lave & Wenger, 1991; Mavor and Traynor, 2001). A community of practice (CoP) is a system in which participants share understandings that give meaning to: what they are doing; who they are (ie their identity); the knowledge, tools, artefacts and structures of the community. Meaning (and hence practice), however, is not fixed but negotiated within the community recognising that it is embedded in a historical and social context including both the explicit and tacit (Wenger, 1998) knowledge(s). Later work by Johns (1997) links CoP to those of discourse communities who share practices and values that hold communities together (ie the 'culture' of a community'). Communication links these ideas of community and culture together because 'it is not simply a matter of knowing the semantic meanings of the words. For the words are schematically connected to form conceptualisations of reality which define the culture [the ways we do things around here] of a particular discourse community (Widdowson, 1998).

The ‘engineering culture’ (Schein, 1996), whose reference group is outside and across specific ‘engineering’ organisations, is compatible with the understanding and application of the concept of CoP outlined above. CoP also provides a way of interpreting how engineering education contributes to the maintenance of continuity, and yet can and does effect change in the CoP.

Learning in a Community of Practice

Learning in a CoP is considered, on one hand, to have elements of an ‘apprenticeship’ (Lave, 1991) whereby as novices participate within a CoP, learning occurs through working alongside ‘experts’. For the novice, participation in the community is from the margins of the community – not as an outsider, but as a legitimate member of the community, albeit ‘the apprentice; the *boy*’. Learning in an apprenticeship mode is *reproductive* of the community’s practices.

The second aspect of learning is the ‘enculturation’ into the CoP. This occurs as new and experienced members of the community interact, negotiating meaning. In CoPs where novices learn to become a member of a profession (Tonso, 1996), there is not a single, uncontested ‘expert’ practitioner identity (Nespor, 1990). Novices forge (or develop) identities congruent (albeit not identical) to the range of practitioner identities available in the community. Studies (eg Crofton & Mitchell, 2000) indicate these identities are associated with ‘discipline appropriate ways of belonging’ that give them access to the requisite (ie visible and tacit) knowledge and skills for being a part of this [engineering] community, hence establishing continuity of the community. This interaction also provides opportunities to negotiate ‘other’ meanings, enabling change and *transformation* across and within the community.

At one level, the ideas around CoP are not unfamiliar to engineering. Learning communities are a feature of the contemporary university and many academics will have resonance of this framework in their own teaching and learning practices, particularly with group work (Rover, 2003). In this paper, CoP is extended beyond the local experience, in that, engineering education as a whole is viewed from the perspective of community of practice providing a flexible model capable of meeting the challenges of engineering education in a knowledge era.

Reproducing Engineering Community

Critical for a community to ‘remake’ itself is the *reproduction* of members who are capable and competent learners of all the forms of knowledge, ways of thinking and ways of practising the learning modes residing within the community. Research suggests that in science and engineering based disciplines, students engage in a long apprenticeship – the learning of ‘an atomistic, sequential, hierarchical knowledge framework’ (Robertson, 2003). Robertson suggests that this ‘long’ apprenticeship does not enable the learner to participate in any meaningful way in the community, until the ‘time’ has been served. This is a limited way of understanding the nature of this apprenticeship. Johnston (1998) argues, an isolated (atomistic) piece of technological knowledge is useless (has no meaning or value) unless it is understood relative to the theoretical, evidential, *application* context in which it has emerged. To achieve this form of learning ‘requires a considerable investment in establishing the necessary interpretive context of theory, concepts, data and tacit experience’ from which the meaning has originated. Hence, the high costs associated with engineering education as we try to mimic application contexts, but also the deficiencies where students can graduate but be unable to convert their knowledge into profitable use (Johnston, 1998).

Learning Engineering: Learning the language

For the 'novice', coming to 'know' through the interpretive support systems (Lave & Wenger, 1991) of the community enables the novice not to talk *about* the knowledge of the community, but to *talk from within* the community as an increasingly proficient practitioner of this knowledge. *Talking from within* implies that the part of this 'long' apprenticeship is about learning the language(s) of the engineering community (Stonyer & Dodd, 2002). These languages are variously defined as mathematical, visual, conceptual, symbolic, abstract, metaphorical and technological (eg, Vincenti, 1992; Dasgputa, 1996). 'Engineers use these languages to create 'representations' of real objects in which the representations and objects are inextricably interconnected, but the engineer who participates in the process of creating a concrete [real] object, may only 'know' the object through its representation in writing, drawing, graphics and mathematics' (McGregor & Saunders, 2001). This notion of apprenticeship detailed above is captured in the shifts over the last decade in undergraduate curriculum focusing on 'design'. Design has become the locus of the 'social process' of engineering education in which 'participants negotiate their differences and construct meaning through direct, preferably face-to-face, exchange'(Bucciarelli, 1994). Further, since apprenticeship is a language learning experience, this suggests implications for the ways engineering education can engage in the current 'academic learning and literacy' focus of tertiary education to ensure that the mathematical and graphical languages of professional engineering are supported in this work.

Therefore, in engineering this 'long' apprenticeship is more than just about the formal bodies of knowledge in the discipline. Emerging from the sociology of scientific knowledge are ways of categorising knowledge such as Fleck (1997) (see table 1 following).

Knowledge classification	**Examples**	**Acquired through**
Formal knowledge	Embodied in codified theories, formulae, Encoded in textual or diagrammatic form	Formal learning
Instrumentalities	Embodied in tool and instrument use	Demonstration and practice Requires other components (informal, tacit, and contingent) for effective use
Informal knowledge	Embodied in verbal interaction (rules of thumb, 'tricks of trade') Held in verbal and sometimes written form (manuals, guidebooks)	Interaction with a specific context/milieu
Contingent knowledge	Embodied in specific context, Distributed knowledge Can appear trivial Sometimes can be looked up	Acquired by on-the-spot learning
Tacit knowledge	Embodied in people, Rooted in practice and experience	Transmitted by apprenticeship/mentorship
Meta knowledge	Embodied in the organisation General value cultural and philosophical assumptions Can be local or cosmopolitan	Acquired through socialisation

Table 1 Classification of types of knowledge according to Fleck (1997) (cited in Johnson (1998))

Applying Fleck's proposed categories of knowledge to the engineering context suggest that, apart from formal knowledge, knowledge appears to be mainly 'learned' in 'experiential yet social' contexts of the engineering 'learning' community. Research (eg Crofton & Mitchell,

2000) support how various learning contexts contribute to reproduction (both the good and the bad) of the engineering CoP.

Case Study: Capability Journal

Understanding this concept of learning through participation in the cultural practices of the community can guide the development of engineering pedagogy, for instance, pedagogy relating to occupational capability. In general, graduate capabilities (eg teamwork, critical thinking, creative thinking, communication etc) have been defined externally to the engineering profession as context free, hence, completely transferable across different communities of practice. This approach affords a certain 'status of reality' (Milton, 1999) to capabilities, assuming they are knowable, 'out there' ways of being a professional around which pedagogic practices can be designed to 'learn' these attributes. This is, nevertheless, problematic. Locating capabilities outside the meaning systems (ie CoP) where they are learned and comprehended effectively reduces effective student learning and consequently, their full participation (using these capabilities) in the CoP (Stonyer & Dodd, 2002). It is critical to redefine how these capabilities are constructed in and through 'practice' and to reproduce 'practice' in the curriculum. Further, this reproduction of 'practice' must take account of the notion of 'apprenticeship'. To illustrate - when learning to work in a team, students generally need to be coached/mentored through the early years of their education/*apprenticeship* to develop the personal skills and attributes which enable them to work in teams (Stonyer, et al, 2001). Logically, this must happen before they meet their final year engineering design project team!

In an attempt to define these capabilities and their development within the CoP engineering, a project focussing on the development of the capability journal for Master of Engineering has been undertaken. The journal is based on a model of professional practice (which also informs the IPENZ graduate competency programme) in which competence is seen in performance as a whole, not in fragmented series of unrelated knowledge or skill components (Bowen-Clewley, 2001) as often happens in a reductionist approaches adopted by engineering curricula. This model of the non-formal learning/workplace learning encompasses reflective practice where the consequences of actions are used to adapt actions and behaviours, and to explore, and potentially refine thoughts, feelings and beliefs. The latter being 'double loop learning' (Schon, 1983) or 'deliberative learning' (Eraut, 2000).

The ME is a graduate programme and many students undertake projects in association with industry sponsors. IPENZ agreed for the use of their definitions of professional practice (relating to a graduate) in the ME Capability Journal. These understandings have been adopted and integrated in a way that reflects both the expected workplace practice learning (while recognising the limitations of the associated academic environment in which the thesis is conducted) and the associated professional formation. The pilot of the journal was conducted in 2003, with initial feedback supporting the journal as a tool to enhance and give meaning to all aspects of learning in a workplace research project. What has been intriguing is the ongoing difficulty of getting students to shift to the 'double loop learning' or 'deliberative' learning – for instance, one student responded to one section of the journal in the following manner:

Element	Student Response
5.2 Follow an accepted code of ethics (including: demonstrating honesty (eg no plagiarism in thesis or research data), fairness, integrity and a proper concern for people (requirements including any ethical consent required for project), the environment, cultural, social and moral consequences of actions)	Demonstrate Honesty – HOW? Demonstrate Fairness - HOW? Demonstrate Integrity - HOW? Demonstrate Proper concern for people, the environment, cultural social and moral consequences of actions: (answered in a full and comprehensive manner because of risk arising from solvent in use)

Table 2 Sample response in capability journal pilot project

As we try to make sense of this feedback from students recent research (Riemer,2001; Scott & Yates 2000, Chisholm, 2003) suggest we may not fully understand the nature of knowledge within these professional competencies. Our focus on 'knowledge-based' and or 'behavioural' skills and attributes in workplace environments may limit the identification and development of emotional intelligence (EQ-i) attributes and a related range of capabilities. The notion of the engineer as a 'reflective practitioner', supported in the model driving in the capability journal development, corresponds with core aspects associated with EQ-i development. However, little work appears to have been done to correlate the understanding and development of EQ and related attributes in the workplace. In this way our efforts to engage our students in identifying and becoming novices in the learning 'modes' within the engineering community are far from complete.

Transforming Community

One of the real challenges ahead for engineering education is to respond to the various calls 'not to train in the ways of the past, but those of the future'(eg Godin, 1999; Broberg, 2001) – to produce not the 'same' engineers as today, but engineers who can 'lead their teams, their companies, their research into new territory' (Jackson, 2003). These calls do not diminish the success of contemporary curriculum, but point to a bigger task for engineering education – to begin to educate in such a way that engineering communities can transform or change themselves. Professional cultures and communities tend to be stable and resist 'deep redefinition' (Barke, 1999), but they also change over time – change often being catalysed in three ways. The first, as experts engage with novel problems, secondly through the introduction of 'new knowledge' to the community and thirdly through the interaction of sub(versive)-CoP which exist at the periphery of the CoP (Lave & Wenger, 1991). Understanding change occurs in these ways raises questions relating to pedagogy: how can we prepare learners for the unknown by means of the known (Marton & Trigwell, 2000, Donald, 2003); what do we need to emphasise and redefine in our current pedagogy and practices (Fromm,2003).

Engineering expertise

Transformation of the practice, direction and development of the community occurs as experts of a community respond to novel problems (Billett, 2001). Engineers when trying to handle a novel or new situation, attempt to make use of what has been learned earlier in other similar situations. It is precisely this cross-over effect of 'existing' knowledge, experience, intuition and ways of thinking being 'reutilised' in the exploration of new solutions which generates 'new' knowledge and ways of 'doing' the practice(s) in the community. In general, solutions to engineering problems are not 'discovered', but:

> selectively constructed as impinging factors which shape a situation are weighed against each other. The iterative … movement between possible paths and constraints

> … leads eventually to the mapping of a provisional path … where movement continues until the final stages of production of the artefact. The activities leading to the making of choices are definitely not linear in their progression, nor do they follow a fixed cyclical pattern (Rowell et al, 1996).

'Expert' engineers 'read' a situation, establish the causal factors contributing to the problem, and 'match' a range of problem solving and thinking processes according to the complexity of a particular problem and the resources – knowledge, experience, project constraints - at hand (Donald, 2003).

Understanding the development of engineering expertise and its associated schema (ways of thinking, doing, 'sense' of a problem etc) is important to the engineering community because it can lead to ways of teaching and learning 'expert' thinking. Donald (2002) suggests this movement of novice to expert occurs as novices pass through an analytic stage where problem-solving time increases until they develop the representations [of knowledge, patterns] and thinking strategies or action schemas for applying these representations to problems, that are characteristic of the expert. In the context of the engineering community, evidence suggests most curricula reflect progress from novice to expert problem-solver (Fromm, 2003), correlating with the views of graduate engineers and their supervisors reported in recent Canadian and Australian studies (Rowell et al, 1999; Scott & Yates, 2002).

Problem based learning: a tool to develop 'expertise'

For pedagogy, this implies the teaching and learning approaches such as problem based learning (PBL) in design are appropriate for providing a context where 'expertise' can be developed. PBL for an 'unknown' future requires the introduction of a variety of different, 'novel', real world, contemporary problems (Marton & Trigwell, 2000) . A key criteria in establishing an appropriate set of case-based examples is the 'packaging' (Schon, 1987) around the problem scenario – rather than the focused technical 'piece' of the picture. 'Packaging' creates a space where the historical, social, economic contexts can exist, 'evidence' from prior experiences (eg technical drawings), together with 'learned experience' both formal and tacit from those persons with knowledge of the problem (eg oral reports, 'ways of doing') can be brought together to define the problem space. Without adequate 'packaging' students, confronted with a lack of knowledge about the problem space, may not see the multiplicity of pathways connecting the problem with the optimum solution. Further, the subsequent action of engineering 'intuition'/ 'judgement' in making decisions relating to one or more pathways may not be visible, and hence learning to 'negotiate the multiplicity of perspectives' in professional practice is likely to be compromised. However, incorporating 'experts' in the knowledge domain of the problem will only achieve success in a structured PBL situation when we more fully understand how the process of 'tacit knowledge transfer' occurs (Burns and Chisholm, 2003). This highlights further work to be done in understanding how 'tacit' becomes explicit knowledge within the engineering CoP.

New Knowledge

There is, however, no guarantee of existing technical expertise and/or resources held by an individual or group of engineers, being sufficient to realise effective solutions in each pathways. This introduces the second way communities change: through the introduction of new knowledge. In engineering, this occurs: from published research outputs which have some relevance to the problem at hand; through the interaction of research and project groups (eg brainstorming, visualisation and mapping activities); and by the use of reciprocal networks of colleagues . In the study conducted by Scott & Yates (2002), graduates indicated the 'half-life' of the specific skills and knowledge acquired during university was becoming shorter and success in employment was achieved by figuring out how to continuously update their technical expertise and using their ‘networks of colleagues to help solve ongoing problems’. Ultimately, this has implications for the community of engineering education as it is faced with an ongoing need to redefine what ‘knowledge’ will be the basis of community: what is learned; when and for what ultimate end? How will engineering education ensure students develop the skills (like those identified by these graduates) necessary for effective professional learning and practice during their career?

The emergence of a new models of work-based learning

The reducing half-life of knowledge suggests that pedagogy needs to move from a static system of knowledge and learning (both of which are principally hierarchical (Stonyer, 2002)) to a dynamic way of thinking about knowledge and learning. There are current initiatives in England, Scotland and New Zealand to realise an engineering curriculum based around the ideas proposed in work-based learning (WBL) models of engineering education. A WBL model provides an integrated approach between formal engineering curriculum and workplace learning which offer both both codifiable and tacit knowledge components (Chishom, 2003). The basis of a WBL model is the strategic objective of the host organisation to be achieved by the student and is found in many current ‘co-op’ scenarios. More recent WBL programmes carefully articulate specific (as opposed to general ‘industry project’ learning outcomes) for the student in achieving the project.

Peripherial sub-groups

The third way communities change occurs in the interaction with peripherial community dwellers. These peripheral sub-groups comprise two groups. Firstly, those with legitimate access to the community. Some groups of women, for example, have been identified on the ‘margins’ of professional communities of practice (Stonyer, 2002, Davis, 2001). Casey (1993) notes how peripheral participants in a community of practice brought dramatic change to their community:

> The communities continue to stand, but … they have been subjected to drastic renovations … These women are not content to live … in a structure that someone else built. Sometimes they portray themselves as builders …. Sometimes these women envision themselves as part of a demolition crew.

The influence of ‘margin’ groups can be targeted and specific. Advocacy for women in engineering was particularly dominant in the mid-late 90’s in Australasia where significant work relating to gender and engineering lead/contributed to changes in the culture and practice of engineering education (Mclean et al, 2000, Stonyer, 2001).

The second group of peripheral community dwellers are those characterised by trans-disciplinary interests. Individuals develop and change their identities as they appropriate ways of ‘talking’ (ie meanings, values etc) inherent in different communities (Stonyer, 2002) and it is precisely this change at the individual and process level which enables professional cultures to change. Jackson (2003) identifies this is occurring in contemporary engineering where:

> innovation and technological breakthroughs more likely are driven by convergence, where disciplines intersect. …. The technological and scientific complexity of today’s multidisciplinarity and interdisciplinarity necessarily entails increasing levels of collaboration and teamwork where the need to understand, explain, persuade and emphasize pertain … all of this makes a compelling case that engineers be educated more broadly and deeply to give them the requisite skills and experience for communication, collaboration and creativity, as they function in a wider arena than they have traditionally.

There are significant challenges arising from this: who is the engineer?; how do we continue to 'add' to an already filled nearly to capacity curriculum? Further, given the instrumentalist approaches of students (Orr, 1998) where engineering enables them to earn and have professional status, what is the likely impact of these shifting meanings of '*who* is the engineer?' ?

The engineering identity: Who is the engineer?

There is a need to continue to reframe 'new' successful identities for the engineer, especially 'identities' emerging from rapidly evolving trans/inter disciplinary connections. It is not simply a matter of more bridging programmes, or different degrees and majors – this is moving forward from the known. The WBL initiative addressed previously, has been driven by a working group comprising of industry, union, employees and education consultants in an attempt to meet the need for specific engineering skills within their industries. The WBL model represents a paradigm of education in which knowledge (both explicit and tacit) are recognised as the dominant transferable skill together with the needs of a community that industry maintains competitive advantage and contribution to national economic growth. This model is framing the identity of a 'new' engineer and a [re]new pedagogy for engineering education. It shows that by working within the community of practice, understanding the ongoing changing nature of engineering knowledge, practice and roles and then 'backward mappring' (Scott and Yates, 2002) from this knowledge it is possible to develop a vision of a practice-led curricula.

CONCLUSION

To meet the challenges of the knowledge era, a new model of engineering education, drawing on the concept of community of practice, has been proposed. Engineering plays a pivotal role in both the basis and future development of the knowledge era, hence the two aspects of reproduction and transformation are essential features of contemporary engineering practice. Both aspects need to be understood by educators. A CoP based model acknowledges the continual tension between reproduction and transformation aspects of engineering education – firstly, at the levelof maintaining graduates educated in existing/current practice and, secondly, developing graduates capable of articulating new, innovative knowledge and practice. From this emerging understanding of how learning occurs in the CoP of engineering it is possible to map these understandings back into a contemporary practice-led curricula. In this way, the model provides educators with greater flexibility to recognise and develop appropriate responses in curricula enabling graduates to emerge from engineering education as capable, confident, effective, transformative engineers of our future.

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