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Understanding Best Practice in Engineering Education Using the Concept of Pedagogical Content Knowledge

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BACKGROUND
The concept of Pedagogical Content Knowledge (PCK) is used in educational research to explore the complexities of effective teaching practice. PCK is the 'knowledge-in-action' and 'knowledge-of-action' (Park & Oliver, 2008) which allows teachers to make decisions about what to do in order to teach well. It is a type of expertise that is specific to the discipline in which it is applied, but is distinct from either disciplinary content knowledge, or general knowledge of pedagogy. The nature of PCK is yet to be researched specifically for the engineering discipline. To date, in the disciplines for which PCK constructs have been defined (for example, in History, Science or Literature), there is a close similarity between how the discipline is studied and how it is practiced. In engineering, the study of the discipline and the practice of it are very different, raising questions about how the make-up of engineering PCK accounts for the nature of the discipline, and how it reflects the nature of best practice in engineering teaching.

PURPOSE
This paper asks how PCK may be defined for engineering education research purposes, and what the implications of this are for existing work in the discipline. This involves elucidating the interrelated variables which determine how teachers undertake engineering teaching. It suggests that some modification to accepted PCK constructs is necessary in order for PCK to capture the practice-based orientation of the engineering discipline.

DESIGN/METHOD
The paper draws on research findings from the higher education research field generally, and engineering education research specifically, to illustrate how the PCK construct can be applied to the engineering discipline. It uses the PCK model of Park and Oliver (2008), itself a synthesis of PCK research, to explore the complexities of teaching practice in engineering education. Data from an ALTC project ("Curriculum Renewal in Engineering Through Theory Driven Evaluation" PP10-1647) are used to further illustrate the argument, and Pierre Bourdieu's "Field and Habitus" (1990) is proposed as an appropriate theoretical framework for undertaking further exploratory research.

RESULTS
An appropriately modified PCK construct promises to be a useful means for understanding the variables affecting teaching practice in engineering. Its particular strength lies in the fact that, when studied with an appropriate methodology, it has the capacity to capture the culturally and contextually contingent nature of teaching practice, as well as the many other interrelated factors which determine *how* engineering teachers undertake practice. For example, although all of the courses examined in the ALTC study were first year project-based courses with similar objectives, different teachers had different conceptions of the knowledge, skills and ways of working required of students, and therefore undertook their teaching in different ways. This difference can be understood in terms of the variation in how each teacher's PCK is formulated, including their prior experience and beliefs, and the institutional context in which they were operating.

CONCLUSIONS
By looking at how PCK can explain teaching practices in engineering education, and by examining how the many variables comprising PCK interact for teaching engineering, we can begin to develop a clearer picture of how best-practice (as informed by the plethora of wider research in engineering education) may be achieved, and the realistic pathways towards this ultimate goal.

KEYWORDS
Pedagogical Content Knowledge (PCK), Bourdieu, Field and Habitus, Engineering knowledge

Introduction

A large proportion of work in the engineering education research field is geared towards understanding how to best prepare students for engineering practice (Heywood, 2005). It is known that engineering practice in industrial settings is rapidly evolving (Cameron et al, 2011). However, in engineering education there are significant structural and institutional barriers which work against enduring innovation (Graham, 2012). Whilst research is often preoccupied with the redesign of engineering curricula in order to address this (Heywood, 2005), an increased focus on the role and practices of the teacher is also necessary. Ultimately, it is through teaching that curriculum is *enacted* for students.

This paper argues for the importance of understanding the ‘cognitive roadmaps’ that guide engineering teachers, the context-dependent and contingent nature of their decisions and actions, and the opportunities and impossibilities that exist in their teaching practice. What is the “knowledge-in-action” and “knowledge-of-action” (Park & Oliver, 2008) of engineering teachers, and how does this determine actual teaching practice? How does this derive from teachers’ beliefs and conceptions about their discipline and how the discipline should be taught? How do relevant variables such as the specific learning context and institutional culture interact to affect practice? How do engineering teachers manage to teach *for* practice? Whilst answers to these questions are some way off, this paper concentrates on the question of which research agenda and methodology which have the capacity to answer them.

The nature of the problem

A primary aim of engineering education is the preparation of students for work in industrial settings as professional engineers. Recent research suggests this may be an increasingly difficult undertaking:

> *Engineers are [now] called upon to develop innovative products and processes, exercise new and unfamiliar technical and professional skills, and function in an increasingly global environment. What it will mean to be an engineer in the twenty-first century and the incompatibility of current engineering curricula with that meaning have been the subject of many high-level studies. The debate so far has had little impact on engineering educators. (Adams & Felder, 2008, p. 239)*

Sheppard, Macatangay, Colby and Sullivan (2009) argue that the problem lies in the emphasis on the development of technical knowledge above professional skills. “Although engineering education is strong on imparting some kinds of knowledge, it is not very effective in preparing student to integrate their knowledge, skills and identity as developing professionals” (Sheppard et al, 2009, p. 6). Such arguments are not new in the engineering education research field. How to successfully achieve the necessary change has therefore occupied many other researchers. Sheppard et al (2009) argue that this is “in essence a [curriculum] design problem” which can be solved by the seemingly simple implementation of the following principles:

- “[Teaching] key concepts for use and connection
- [Integrating] identity, knowledge and skills through approximations to practice
- [Placing] engineering in the world: [encouraging] students to draw connections” (Sheppard et al, 2009, p. 9).

However, although such principles *can* serve as goals for curriculum design, they also require considerable skill on the part of teachers in order to be realised in the classroom. This is a complex undertaking which can only be achieved through skilful, intentional and reflexive teaching. Thus, the ‘problem’ goes beyond that of design, into the realm of the specific expertise required of engineering teachers; the know-how which would allow them to enact such curriculum principles in classroom practice. Insights about curricular change will not be made useful unless attention is also paid to how teachers in the classroom can change how they operate curricula.

Cameron, Reidsema and Hadgraft (2011) express significant concerns over the current capacity of engineering teaching staff to develop the necessary expertise:

> *[There is an issue with] the relative lack of engineering academics with professional experience beyond 4 years. The other issue is the currency of that professional experience, which in most cases was gained many years prior to entry into the HE sector. …This overall lack of experience in deep practice knowledge casts doubt on our ability to define and operate curricula more strongly in areas of authentic engineering problem solving, engineering application and practice, with themes of design, the engineering life-cycle, complex systems, and multi-disciplinarity. (Cameron et al, 2011, pp. 109-110)*

Thus, despite research offering clear findings about how to improve engineering education, solving the problem of 'teaching for practice' will involve acknowledging and overcoming the significant barriers that currently exist.

Developing understandings of the complexity of engineering teaching

To advance this work, it is useful to look further into how this research agenda could be pursued. There is a strong argument that developing a more complex understanding of the factors affecting teachers' thoughts and behaviours is required, because research into pedagogy does not on its own provide the vital link to improving actual teaching practice (Grenfell & James, 2004). Adams and Felder (2008) argue that fundamental questions need to be asked if we are to understand the role of engineering educators and develop them as teachers:

> *This is a substantial research agenda and requires creativity and serious scholarship. For example [this should include research into]:*
>
> - *Becoming an engineering education professional*
> - *Engineering education thinking*
> - *The engineering education culture*
> - *Theories to guide professional development of engineering educators*
> - *Assessing and evaluating professional development.*
>   *(Adams and Felder, 2008, p. 240)*

Not only do these issues require further exploration, but some understanding of how each of these aspects interact with each other also needs to be developed. The role of the engineering educator is particularly complex, partly because:

> *teaching is typically not the only responsibility of engineering educators who often have significant research and service responsibilities… engineering educators may not receive formal training for their role as educators, and engineering educators often have a great deal of autonomy in what and how they teach. (Turns et al, 2007, p. 297)*

Collectively, these arguments prompt us to progress beyond the idea that "*changing x to y*" in teaching practice is a sufficient approach for generating meaningful and lasting improvements. If research into improving teaching practice is to be comprehensively pursued, it needs to account for each of the following complex and interrelated issues:

- the effects of the epistemologies of engineering educators; their beliefs about and conceptions of teaching and learning for engineering;
- the effects of the institutional context in which engineering educators find themselves teaching, including how teaching is viewed, valued and rewarded; and,
- the degree of preparedness for teaching that engineering educators possess or are able to develop, both in terms of knowledge of how to teach effectively in a general way, and how to teaching effectively for engineering practice in industry.

Each of these issues is likely to relate closely to decisions about teaching and actual teaching practices in the classroom. Thus, the concept of pedagogical content knowledge may be brought to bear to better understand the complex picture of teaching practice in engineering education.

The Pedagogical Content Knowledge (PCK) construct

Most often, “pedagogical content knowledge (PCK) has been defined as a way of knowing that is unique to teachers, whereby they take an aspect of subject matter and “transform their understanding of it into instruction that their students can comprehend” (Shulman, 1986, p. 8 cited in Fernandez-Balboa & Stiehl, 1995, p. 293). It is this process of transformation of knowledge into knowledge-for-teaching that most definitions focus on, and they tend to include some variation on three main areas of knowledge. These are: knowledge of discipline content (subject matter); knowledge of general pedagogy; and, knowledge of instructional context (for example student characteristics and needs) (Abell, 2008).

Importantly, the influence of the discipline being taught; that is, the nature of the content knowledge and the underlying epistemologies that the discipline involves, is known to be a strong determinant of teachers’ PCK. This is also closely related to teachers’ own enduring beliefs and conceptions of learning for their discipline, which derive from their own experiences of learning in their discipline:

> *Stark (2000)…found that faculty members’ disciplinary beliefs about knowledge in their disciplines were the strongest influence on planning at the course and lesson levels. In a reciprocal fashion, teachers’ expectations about how students learn and what they should learn directly affect their teaching approaches, even within a tightly defined subject matter context... Faculty [also] indicated strong links between the subject matter and the method for teaching, often suggesting that a particular discipline, whether their own or another’s, should be taught in a particular way. (Major & Palmer, 2006, pp. 622, 626-627)*

However, as established in the previous section, the PCK construct also needs to capture the wider context in which teaching takes place. Having completed a comprehensive review of the PCK literature, Park and Oliver (2008) developed a more broad-reaching and comprehensive definition of PCK which is able to account for the contextualised nature of teaching practice:

> *In the end, reviews and analysis of the literature on PCK contributed to what we believe to be a comprehensive working definition…PCK is teachers’ understanding and enactment of how to help a group of students understand specific subject matter using multiple instructional strategies, representations and assessments while working within the contextual, cultural and social limitations in the learning environment. (Park & Oliver, 2008, p. 264)*

In this definition, teaching practice is seen as contingent on the possibilities and limitations that the context for teaching allows. Park and Oliver (2008) propose five categories of interrelated and interdependent knowledge areas which interact to comprise teachers’ overall bodies of pedagogical content knowledge. Each of these areas of knowledge is influenced by the teachers’ own prior experiences, the context in which they work and teach, as well as the disciplinary structures which define the subject matter being taught. These five categories are outlined in Table 1, below:

Table 1 - Components of PCK (Park & Oliver, 2008, p. 266)

Orientations to Teaching the Discipline
Knowledge of Students’ Understanding in the Discipline
Knowledge of Discipline Curriculum
Knowledge of Instructional Strategies and Representations for Teaching the Discipline
Knowledge of Assessment of Discipline Learning

The application of PCK to engineering education

Park and Oliver developed and tested their model for application to the teaching of Science in high school (in particular, Chemistry), and it therefore remains to be seen how useful it proves to be for application in higher education settings. The work of Fernandez-Balboa and Stiehl (1995), which Park and Oliver have drawn on in the construction of their model of PCK, offers some insight here. In their study of the pedagogical content knowledge of college professors across a variety of different disciplines and faculties, it was found that the PCK construct and its components is relatively independent of discipline. Although these authors use different labels to describe the components of the PCK, these components are more or less analogous to those of Park and Oliver (2008). It seems reasonable to conclude, therefore, that this model will prove valid for application in tertiary settings.

For useful application to understanding teaching practice in engineering education specifically, we also need to account for how educators manage to teach *for* practice in engineering industry. Cameron et al (2011) assert that teachers' professional experience in industry is necessary for preparing students for work in the field. This assertion is supported by the findings of Graham (2012), who highlighted the important role of faculty members who have industry experience in ensuring the success of curricular and pedagogical innovations. It is therefore reasonable to conclude that some aspect of teaching *for* practice will be involved in engineering teachers PCK, however this needs to be empirically explored.

The work of Shreeve (2010) suggests that this aspect of PCK is likely to be quite complex and contingent on other aspects of teachers' PCK. She shows that the relationship between teachers' industry experience and how they teach for practice is not straightforward (Shreeve, 2010). In a phenomenographic study designed to address variation in approaches to teaching *for* practice, Shreeve (2010, p. 694) derived from observation "five distinctly different categories of variation in experiencing the relationship between practice and teaching." These categories describe a spectrum of approaches, from a transmission model in which knowledge of practice is seen as simply being passed on to students, to an integration model, in which the teacher's knowledge-of-practice and knowledge-of-teaching interact to create a simulation of the role of a practitioner for students to experience in the classroom (Shreeve, 2010). Clearly, the teaching practices involved in operating at one end of this spectrum would be very different from those involved in operating at the other. This has significant implications for understanding PCK for engineering education:

> *Understanding that the relationship between practice and teaching may need to be addressed, rather than assumed as a natural outcome of expertise, may lead to…improvements in the way that students learn about practice-based subjects…Assuming that relations are only significant statistically or one-dimensionally ignores the complexity of the lived experience of education and the impact this can have on learning. (Shreeve, 2010, p. 701)*

Only one study so far has been undertaken to explore PCK in engineering education. In this small-scale study, the design of the study did not have the capacity to meet its stated aim: "to discover the essential characteristics of engineering teachers' pedagogical content knowledge" (Viiri, 2003, p. 353), because it did not seek to comprehensively describe the PCK constructs of the teachers that were studied. Rather it constrained itself to examining "teachers conceptions of their students' ideas of moment" (Viiri, 2003, p. 353). Whilst this undoubtedly gives insight into one aspect of teachers' pedagogical content knowledge, it does not allow for a full description of the range of "essential characteristics", or components of PCK that teacher's possess, or how these components interact to affect actual teaching practices. Thus, the need to develop and test a model of PCK for engineering educators remains a necessary research agenda if we are to understand how actual teaching practice comes about. Given the need to pursue this research agenda, this paper proposes the modification of Park and Oliver's (2008) model of PCK to include a sixth component: "teaching *for* practice." How this extra component affects teaching practice is expected to have a significant effect on how the PCK construct can be used to understand engineering teaching, with an ultimate view to improving the teaching practice of engineering educators.

Illustrations from the ALTC data

The application of this model of PCK to engineering education will require validation using a purpose-built, empirical study. The necessary methodology for such a study is discussed in the next section. However, examination of data from an existing ALTC study yields some initial insights into the usefulness of the construct. The study in question examined the first year engineering project-based courses of thirteen different universities across Australia and New Zealand (final reports for this project are still in preparation). Its primary purpose was to discover the aspects of course design and instruction that were most useful for achieving the courses' various purposes within the project-based course model. The research design yielded a range of data from both students and instructors which can be brought to bear on the question of instructors' teaching practice, and what it shows about their underlying bodies of PCK.

In one site in particular, three instructors teaching in the same course demonstrated notably different approaches and priorities in interactions with their students. Each instructor was involved with the learning activity of building a prototype for a water filtration system for improving water quality in a third world community. In questioning students about their prototype, each instructor demonstrated a slightly differing conception of the relevant learning outcomes associated the prototyping process. One instructor seemed to be primarily concerned with how well the prototype practically demonstrated the theoretical concepts that the students had applied. A second was mostly interested in how well the students could describe how the prototype would be scaled up for full-size use. The third was concerned with the students' explanations of how the system would be understood, accepted and utilized by the third world 'clients.' It was theorised that each instructors' teaching priorities were influenced by their background and experiences before entering teaching. The first instructor had a strongly theoretical background, the second a strong industry background, and the third a background in working for the organisation Engineers Without Borders, who liaise with community groups and NGOs to develop engineering projects in third world contexts.

To explore the relationship between each of these instructors' backgrounds and how they chose to teach, follow up interviews were conducted with each instructor to uncover how they understood their own practice. It was hypothesised that if their background experience was directly causing them to prioritise certain learning outcomes, this would be visible in how they discussed their decisions and actions in their teaching practice. Despite the reasonableness of this hypothesis, no evidence of causation was found in interviews with any of the three instructors. If their prior experiences were causing their current teaching priorities and actions, the instructors were not themselves conscious of this link. When questioned about what was influencing their decisions and actions in teaching practice, all three instead spoke about the curricular and course design structures that they were working within, and the influence of this on how they went about teaching.

Although the causal link between teachers' backgrounds and their priorities for learning may still be established, this finding shows that the pattern of causation is complex rather than simple, and is mediated by other mitigating factors such as curricular and institutional structures. Further elucidation of this relationship requires a complex model to explain the factors and variables which interact to determine teaching practice. This lends weight to the usefulness of the PCK construct and its capacity to explain engineering teaching practice as a complex and contingent set of thoughts, attitudes and behaviours. Although a wide variety of other data from the ALTC project is revealing of similar conclusions, it is outside the scope of this paper to discuss them in depth. However, it is clear from this discussion that the application of the PCK construct to engineering education is warranted.

Appropriate methodologies for further research

This discussion also highlights that the exploration of the PCK construct for engineering education will not be straightforward. This is partly due to the nature of PCK itself, because "beyond the issues of interpretation, the high level of specificity of PCK with respect to instructional variables such as students' characteristics, subject matter, contexts and pedagogy…makes the task of defining PCK more challenging (Park & Oliver, 2008, p. 262). However, there are theoretical frameworks which, when used to underpin an appropriate methodology, allow research to capture patterns in thoughts, attitudes, behaviour and action, and their relationships to context and wider social structures.

In planning such a study it is important to attend to two important factors. First, it is essential that such an approach has the capacity to reveal the relationship between patterns of individual agency, and patterns of institutional culture:

> *[In terms of determining teaching practice,] one may have carefully and critically reflected on one's beliefs, assumptions and strategies, and ended up with an understanding of the complexities of learning and teaching that one would also be able to make real in one's practice. However, curricular structures and organisational conditions may bring about constraints that do not necessarily leave enough space for the implementation of teaching in [this manner]. (Postareff et al, 2008, cited in Mälkki & Lindblom-Ylänne, 2011, p. 45)*

Second:

> *As Kagan (1990) argued, the complexity of teachers' knowledge cannot be captured by a single instrument. Particularly, assessment of PCK requires a combination of approaches that can collect information about what teachers know, what they believe, what they do, and the reasons for their actions (Park & Oliver, 2008, p. 267)*

The theoretical framework offered by the work of Pierre Bourdieu allows for both of these requirements of the research to be met. Research in terms of Bourdieu's theory of Practice offers insights and understanding [for educational questions that are] not readily visible in other approaches" (Grenfell & James, 1998, p. 2). The particular strength of Bourdieuvian theory is in describing how individual agents' patterns of habitual disposition (*habitus)* interact with patterns in the wider social context (*field)*:

> *For Bourdieu (1992, pp.72-73)., a field is a 'configuration of relations between positions objectively defined, in their existence and in the determinations they impose upon the occupants, agents or institutions.' The medium of these relations, these determinations, is capital, which is hence both product and process within a field. All capital – economic, social and cultural – is symbolic, and the prevailing configurations of it shape social practice. (Grenfell & James, 2004, p. 510)*

For the case in point, the relevant field is engineering education, and patterns discernible within this field will therefore have an effect on the teaching practice of its educators. How educators operate within the field to position themselves and accumulate *capital* will be revealing of the field itself. The purposes, decisions and actions of engineering educators; their individual agency (although itself contingent on the structure present within the field), can be discerned and explained in terms of Bourdieu's notion of habitus:

> *The habitus, as a system of dispositions to a certain practice, is an objective basis for regular modes of behaviour, and thus for the regularity of modes of practice, and if practices can be predicted…this is because the effect of the habitus is that agents who are equipped with it will behave in a certain way in certain circumstances. (Bourdieu, 1990, p. 77)*

In another explanation of this notion of habitus, Reay (2004) explains that:

> *Bourdieu views the dispositions, which make up habitus, as the products of opportunities and constraints framing the individual's earlier life experiences. They are: "durably*

inculcated by the possibilities and impossibilities, freedoms and necessities, opportunities and prohibitions inscribed in the objective conditions" (Bourdieu, 1990a, p. 54). As a result, the most improbable practices are rejected as unthinkable, but, concomitantly, only a limited range of practices are possible. (Reay, 2004, p. 433)

This description of habitus is explanatory of much of what we know about what influences how teachers go about teaching, for example, the role of prior conceptions about teaching and learning, the epistemological basis of a discipline which is being taught, and the effects of the contextual and institutional conditions in which teaching takes place. This makes the theory of field and habitus particularly useful for explaining teaching practice, as it allow us to do so without divorcing thought and action from the context in which it takes place. Thus, in studying engineering education and engineering educators in terms of field and habitus (respectively), patterns in PCK (and consequent teaching practice) may be established and predicted.

This approach is supported by Grenfell and James (2004, p.514), who argue for an overall need for a "*relational* approach to educational questions, emphasising the mutual interdependence of social constraint and individual agency." In contrast to substantialist approaches, a relational way of thinking:

accepts that such 'activities and preferences' as the research uncovers are understandable in terms of social spaces, positions and relationships pertaining in a particular time and place…Thinking relationally…[means] seeing [learning and teaching] in relation to people, organisations, times and places…; in other words, the field site or context. (Grenfell & James, 2004, p.515)

In an educational research project that Grenfell and James (2008, p. 515) discuss, such a relational approach yielded findings that challenge the notion that "good teaching has characteristics that are broadly common across situations (and can therefore be defined in standards and through parts of inspection frameworks)". This finding lends weight to the need to understand teaching practice in terms of teachers' bodies of PCK, and that PCK in turn can only be understood relationally: as a form of *habitus* within a *field.*

Conclusions

Ultimately, the aim of the research agenda that has been proposed herein needs to ultimately address improving teaching practice, so that students' learning outcomes in engineering education can also be improved. Understanding engineering teachers' bodies of PCK and how they are comprised and developed is a vital step in this process. This is especially true given that it is known that:

[Teachers'] notions of disciplinary structure also influenced a [their] readiness and willingness to broaden their pedagogical knowledge bases…This is somewhat different from the traditional notion of 'teachers teaching as they were taught'; the Private faculty also suggest that teachers teach as they had learned. (Major & Palmer, 2006, p. 627)

Thus, until we understand *how* engineering teachers' beliefs about teaching in their discipline (among other variables) affect *how* they teach, we cannot address how to successfully undertake wide scale and successful change in teaching practice. Further,

Research…shows that acquired pedagogical content knowledge and developing methods different from what teachers themselves experienced as students requires learning opportunities for teachers that are more powerful than simply reading and talking about new pedagogical ideas (Ball & Cohen, 1996). Teachers learn through studying, by doing and reflecting, by collaborating with other teachers, by looking closely at students and their work, and by sharing what they see. (Major & Palmer, 2006, p. 621)

Understanding engineering education contexts as *fields*, and understanding how they influence the practice of educators, will be vital for realising these kinds of opportunities for change within institutional structures and professional development programs. These change processes are necessary if the barriers to innovation that have been identified in studies such as Graham’s (2012) are to be overcome. This topic approach will therefore comprise the research for the primary author’s doctoral dissertation.

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