Introduction

Student-centredness has long been considered an ideal condition for maximizing the learning of students in all disciplines, including engineering education. Definitions of the concept vary from concise to much more detailed and specific. According to Blackie, Case and Jawitz (2010) ¨in the teacher-centred approach the focus is on delivery of material whilst the student-centred approach focuses on how the student understands the material.¨ McCabe and O´Connor (2014, p. 351) go into more detail, stating that ¨a student-centred approach emphasizes four fundamental features: active responsibility for learning, proactive management of learning experiences, independent knowledge construction and teachers as facilitators.¨

Discussions of the student-centred approach often read as if it is a simple off-the-shelf pedagogical alteration that can be made by the teachers themselves, regardless of the institutional and curricular structures they are working within, or the nature of the subject matter that is being taught. The literature about student-centred instruction tends to give much more room to discussing the affordances of the approach than to the complex task of *how the change from traditional approaches can or should be achieved.* As will be discussed herein, the literature is yet to sufficiently address the realities of the classroom and the contextual complexities of the teaching task, as well as the importance of content for disciplines such as engineering. It is necessary also to recognise demands on the expertise of the teacher, which is increased rather than decreased when student-centredness is the goal. It is argued herein, that we require a more sophisticated understanding of the skills and circumstances that can bring student-centredness to life. This is necessary if engineering teachers are to be supported in pursuing this principle in their practice.

Background

Understanding this challenge must begin with some discussion of the ontological and epistemological bases of (higher) education, both traditionally and in more recent times:

> *According to the model that has dominated higher education for centuries (positivism), absolute knowledge (¨objective reality¨) exists independently of human perception. The teacher´s job is to transmit this knowledge to the students – lecturing being the natural method for doing so – and the student´s job is to absorb it. (Prince & Felder, 2006, p. 124)*

It is the legacy of this positivist tradition that engineering curricula still rely heavily on didactic approaches to teaching (primarily through lecturing) with a transmission view of learning, in which the role of the student is to be the ´tabula rasa´ on which objective facts are to be written. The prevalence of this view is especially strong in engineering which tends towards a positivist epistemology because of the role of Engineering Science as foundational knowledge for the discipline (Jolly, Jolly & Brodie, 2013). It is the presence of this theoretical knowledge that necessitates a content-heavy curriculum, according to traditional views, which many academics can still be seen to adhere to.

However, in recent decades understanding learning in terms of the principles of constructivism has become more accepted in higher education, precipitating a shift towards approaches such as student-centred instruction. For example, the Bologna Declaration of 1999 emphasised the need ¨to stimulate active, not passive learning, and to encourage students to be critical, creative thinkers, with the capacity to go on learning after their college days are over (cited in McCabe & O´Connor, 2014, p. 350). This constitutes a shift towards a constructivist epistemology of learning because:

> *The basic premise of constructivism is that knowledge is obtained and understanding is expanded through active construction and reconstruction of mental frameworks. Learning is not a passive process of simply receiving information – rather it involves deliberate, progressive construction and deepening of meaning. (Killen, 2007, pp.4-5, 7)*

In this view, the process of education necessarily focuses on the construction of meaning, rather than on the transmission or acquisition of facts (or 'scientific knowledge', in the positivist sense). This epistemological stance rejects the *tabula rasa* view of learning which has been common in engineering education in the past. Whilst engineering itself is still founded in positivist engineering science, learning about engineering is a different matter. Instead, this stance holds that *to know something about learning* is to know something about how learners come to understand and make meaning from interactions and events. This epistemological shift is profound. It requires that engineering educators fundamentally transform their beliefs and values about learning and about the teaching of their discipline, because:

> *A constructivist approach to teaching and learning does not deny the importance of factual knowledge, but it does emphasise that the best way for learners to retain and apply this knowledge is to 'put it into a larger, more lifelike context that stimulates learners to reflect, organise, analyse and problem solve. (Borich & Tombari, 1997, p. 180, cited in Killen, 2007, p. 9)*

Comprehending the phenomenon of learning is therefore outside the scope of a strictly positivist epistemology, and by extension, so too is the development of teaching expertise towards a more student-centred approach. Without some epistemological flexibility, and the right contextual conditions that can help to bring about epistemological change, engineering educators are not sufficiently equipped to develop student-centred approaches without support. It is easy to argue from the available literature that any curricular and institutional change is so far insufficient (Graham 2012), meaning that so far, engineering educators are left largely without support in the endeavour for student-centredness. As the subsequent sections will show, their ability to meet this challenge depends directly on their specific skills for teaching, as well as the unique position they find themselves in terms of their context for teaching. The ability to control these factors may be outside of their control.

Data from the research project

This paper draws on data collected for the PhD *Understanding Pedagogical Content Knowledge for Engineering Education: the role of field and habitus.* Data for this project were collected in a staged research design culminating in a series of ethnographic case studies, with a focus on the observation of teaching in context using the PCK model. Data from these comparative case studies provide a rich picture of engineering teachers´ differing preparedness for creating student-centred learning environments. The cases were selected following pilot and survey stages of data collection for how they represent different possibilities for practice within the field. Each case study was conducted by following the participant for week and recording all aspects of their role. Data were then analysed using constant comparative method in the NVivo program, and according to the theoretical and conceptual frameworks described below.

The ethnographic data from these cases clearly show that the ability to provide opportunities for student-centred learning goes beyond an approach to instructional design, and instead is closely linked to the teacher´s own cognitive constructions of their subject matter *and how to teach it for their students*. Teachers that are better able to create a student-centred learning environment are those that have a clear and current picture of their students´ own understanding of a specific topic or concept. Such teachers organise and present content and conceptual knowledge and structure activities according to their students´ ability to build cognitive conceptions, rather than according to their own. Furthermore, such teachers can be seen to integrate knowledge from a greater range of component knowledge areas in reflective process of teaching. This skill of integration and reflection facilitates their ability to understand and respond to their students concepts of what is being learned.

However, it can also be said that teacher´s ability to develop this specific form of PCK is dependent on their own *habitus* and position in the *field* (Bourdieu, 1990, p. 77). That is to say that where the participant´s habitus was not compatible with the uptake of a constructivist epistemology for teaching engineering (and by extension a student-centred approach to instruction), this was largely due to how they were positioned in the field, and the strategies that they used for achieving that position. In a few cases it can be argued that it was the nature of the field and the capital within that field that caused the participant to take up such a position and strategies.

Pedagogical Content Knowledge

Park and Oliver define PCK as:

> *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, PCK is seen as dynamic and contingent on the possibilities and limitations that the context for teaching allows. Park and Oliver (2008) propose a construct for how practice-oriented knowledge areas are interrelated and interdependent. These component domains of PCK interact variably to comprise teachers' overall bodies of pedagogical content knowledge and are 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 forms of knowledge are mobilized and applied in instances of practice through two important processes, which Park and Oliver (2008) identified as reflection and integration. Because of the applied nature of the engineering discipline, the present research added another category of knowledge to this construct, that is, knowledge of *teaching for practice* in the discipline, in which teachers use knowledge of how to teach about the nature practice in industry, and the skills required in professional practice, including knowing how to establish links to and demonstrate the relevance of teaching topics to future professional practice.

In summary, the PCK model developed from Park and Oliver (2008) has eight interactive and interrelated components identifiable through observation. These are defined in detail in Table 1, which also served as a code book for observation and analysis of the PCK construct in instances of practice. This model of PCK was used as an observational tool in the present study in order to reveal the nature of teaching practice for a variety of participants who were situated differently in terms of their position in the field and their habitus. Two of these participants will be compared here in order to show their differing preparedness for teaching within a student-centred approach. The data from each of these cases were extensive, and not all of them can be presented here. The conclusions that were reached for each case depended on a wide range of contextual details that it is not possible to present in full. However the most relevant aspects of each will be presented below.

Table 1 - Components of PCK (adapted from Park & Oliver, 2008, p.

B1 - Orientations to teaching and learning	The participant´s beliefs about the purposes, goals and methods for teaching in the discipline, founded on their epistemology of teaching and learning, and of teaching engineering
K1 - Knowledge of students´ understanding in the discipline	Knowledge about students´ characteristics, what they know and likely areas of difficulty. Also including likely areas of student misconceptions about topics or concepts, and characteristics of a cohort or group of students
K2 - Knowledge of discipline curriculum	Knowledge about the horizontal and vertical curricula for a subject, including the teacher´s understanding of the importance of topics relative to the curriculum as a whole, enabling teachers to identify core concepts, modify activities, etc.
K3 - Knowledge of instructional strategies and representations	Subject specific and topic specific strategies that are consistent with the goals for teaching for this teacher
K4 - Knowledge of assessment of disciplinary learning	Knowledge of the dimensions of disciplinary learning that it is important to assess, and knowledge of methods by which it can be assessed, including knowledge of specific instruments, approaches and assessment activities
K5 - Knowledge of teaching for practice in the discipline	Knowledge of how to teach about the nature of practice in industry, and the skills required in professional practice, including knowing how to establish links to and demonstrate relevance of teaching topics to future professional practice
P1 - Reflection on action	Knowledge is elaborated and enacted through ¨reflection on action¨ after teaching practice is completed and concerning the need for expansion or modification of the participant´s planning or repertoires for teaching a particular topic
P2 - Integration of component PCK knowledge areas	Integrating multiple components of PCK and enacting them within a given teaching context

Participant A – The learning-focussed habitus

Participant A was uniquely positioned in the field by her significant prior experience in industry combined with her independence and ability to leave the field if she wished. Having achieved tenure in her position, this participant´s main focus in her role was on teaching her students in a way that could best prepare them for their future life as professional engineers. The participant explicitly stated that her main interest in her job was in teaching; specifically, to improve her students´ learning outcomes: ¨I want to one day teach a course where no one failed, that´s my goal every year.¨ However, this focus also limited her ability to accumulate capital and control her position in the field.

The university in this case had a considerable reputation based on its research output, and as such was considered a research intensive institution, with academic staff generally expected to undertake ongoing research activities. Despite this, the participant pressed little interest in the research aspect of her role, choosing instead to undertake increased contact hours with students in order to be able deliver her courses more effectively and to directly improve her students´ learning. For this participant, whilst promotion was a goal that she was willing to work for, she refused to focus on it exclusively or at the cost of being able to spend time on developing her teaching. Because she was able to leave the field if her job was no longer interesting or fulfilling, her choices were a lot more free than those of other academics, who depended on ongoing employment and promotion. She was able to accept a higher level of risk for taking an alternative approach to teaching than many other academics.

When discussing her goals for teaching the discipline, the participant consistently presented a clear focus on the skills required for engineering:

> *To learn to be able to exercise judgment, justify, these are all the learning objectives...this is about them being able to go and find the information, because your employer…will say go and investigate x, y, z and come back and tell me what my options are. You will have never heard of x, y and z before, you are going to have to develop those skills.*

Even when the class being taught was theoretical (such as for first year Static), her focus and approach was clearly on helping the students to actively construct and reconstruct their conceptions of the topics to be learned:

> *So in the first tutorial class, before I had even done the concept in lectures, we did the concept of a moment in the hands on class. So, I bought 18 muesli bar boxes and chopsticks and they made little three dimensional axes out of chopsticks and blu-tac, and they put their muesli bar boxes on the table and they had to actually think if I push it this way it is rotating that way... so I actually physically [work through the concept].*

This participant´s approach was clearly predicated on a constructivist epistemology of teaching and learning, in that she saw the role of the teacher as to help students to arrive at an appropriate and workable understanding of the relevant topics and concepts by developing their own schemata. She did so based on an extensive knowledge of students´ conceptions and misconceptions of topics and concepts, developed through years spent on practice and reflection on practice. She was frequently able to discuss the exact nature of student understanding in reference to a specific concept to be learned or a specific learning objective for engineering, but also talked about the amount of time and sacrifice in other areas of her role that was required to be able to develop her teaching in this way.

Despite the theoretical nature of Statics, this participant was often seen to be asking the students questions and supporting them in answering instead of simply transmitting content. Even when tasking with delivering lectures for the Statics class, her style remained Socratic and was peppered links to future professional practice, as wells as links to previously learned material or future learning. In one example, this was seen when the participant presented a new topic by giving an example from industry of the ¨Angel of the North¨ sculpture, built by an engineering firm in the UK. In discussing this example (shown in detail in Table 2), the participant was able to involve the students in the process extensively, even in a lecture session. This was done in two ways. First, the students were asked questions in place of being simply provided with the content. They were expected to answer those questions themselves but could work together to theorise about them and derive an answer from their existing understandings. The concepts being discussed were also related to the role of being a professional engineer as well as previous and future learning. Each of these pedagogical choices can help to involve the student in an active process of learning, as well as supporting them in building a workable schemata for the concept being learned, both key tenets of a student-centred approach. This approach also coincided with the participant´s ability to integrate multiple elements of PCK knowledge in one instance of teaching practice, each being seen to strengthen the others.

Whilst this example may seem straightforward, the skill involved in creating such an interaction around a piece of core material to be learned should not be underestimated. The case study as a whole consistently pointed to extensive levels of time and effort to develop her Pedagogical Content Knowledge to be able to teach in such ways. She did so by consciously collecting feedback from her students and reflecting on it in topic specific ways. She also spent considerable time redeveloping courses and teaching sessions in light of this feedback.

Table 2 - Example data from ´Angel of the North´ example showing alignment with student-centred principles

Student-centred principles	**Data from observational notes on Statics lecture**	**Aspect of PCK demonstrated**
	¨*Now we will be moving towards some simple design to give you some context.*¨	- Previewing future learning (K3)
- Relating concepts to the future professional life of students	Uses Angel of the North sculpture as an example structure to consider. Participant tells students that she used to work for the company that built the sculpture. Gives some context of the site, height, weight, wing span (bigger than a 767). Points out that engineers on the project probably wouldn´t have expected to work on a project for a sculptor. Shows pictures of it being assembled.	- Real world example and context (K3) - Teaching for practice (K5) - Real world example and context (K3) - Teaching for practice (K5)
- Active process for students because they need to answer the questions - Requiring student to construct their own mental frameworks for the concept	Asks students ¨*What type of structure is this? How does it stand up? What are the design loads?*¨ Points out that it doesn´t fall under any codes. Participant gives students examples of types of structures they have seen. Students discuss questions in groups as well as how they think they will build it.	- Socratic orientation to learning (B1) - Linking with previous learning (K3)
- Small group collaboration and discussion - Active process for students because they need to answer the questions	During group discussion Participant shows pictures of the sculpture being built and assembled, transport, scaffolding, etc. After students have discussed amongst themselves, Participant asks again what type of structure it is. ¨*What do we think it is? What does it have to be? You have done all of this...*¨ After a few prompts a student says cantilever. Participant asks ¨*what is going to give it it´s fixed connection?*¨ Students don´t answer. Shows slide of the structure underneath the ground. ¨*Essentially this structure down here acts as the moment of connection*.¨	- Real world example with rich contextual information (K3) - Teaching for practice (K5) - Linking with previous learning (K3) - Socratic orientation to learning (B1)
- Active participation by students	This example is referring back to theory/concepts already learned. ¨*Design would have required geotechnical engineers, structural engineers to...*¨ ¨*Design loads - what sort of design loads were important for this structure?*¨ Student answers wind.	- Linking with previous learning (K3) - Real world example with rich contextual information (K3)
- Relating concepts to the future professional life of students	Participant discusses aspects of the problem of wind - stresses on the ankles of the sculpture. Goes on to discuss more design load issues in terms of the actual structure, including self-weight, thermal issues, lightning, snow load.	- Real world example with rich contextual information (K3) - Teaching for practice (K5)
- Relating concepts to the future professional life of students	¨Critical design load was building it...Construction when it has got only one arm on it - a common problem with load during construction.¨ L says there was a one in 1000 year storm on the night of construction. ¨This is what engineers get to do, and this is what we will look at the basics of over the next few weeks.	- Teaching for practice (K5) - Linking to future learning (K3)

This constituted a considerable sacrifice of time spent on research and the participant acknowledged the detrimental effect this might have on her ability to go for promotion. If she wasn´t relatively independent of the field, in that she could leave it if she wished, this may have posed an unacceptable degree of risk for her, leading her to use different strategies to compete for a different position in the field. Further it should be acknowledged that this approach was made possible by an inherently constructivist epistemology of learning and of teaching engineering. This epistemology was preserved despite being contrary to the generally held epistemology of teaching that was present at her institution; that is, that academics in the engineering faculty were seen to add to their disciplinary expertise through theoretical research, and as a result were recognised as being more prepared for teaching in their area of expertise than before. Whilst of course it is a tenable position that theoretical research can and should inform teaching, it does not follow that this replaces the need for the forms of expertise involved with teaching itself. This is essentially a reversion to the positivist approach to learning, in which the students are passive receivers of wisdom from disciplinary but not teaching experts. The problem with this view is that:

> *University teachers who focus on their students and their students´ learning tend to have students who focus on meaning and understanding in their studies, whilst university teachers who focus on themselves and what they are doing tend to have students who focus on reproduction. (Prosser & Trigwell, 1999, p. 142)*

The following case gives an example of what it looks like when teachers accept this positivist epistemological stance, and when the institution continues to reward and preserve this position.

Participant B – The ´canon-of-knowledge´ habitus

Participant B was selected for the case study as the result of working at an institution with an alternative curricular structure and a suite of published educational policies surrounding alternative approaches to student learning. The institution in question structures its engineering program to include internships during the degree, so that students get on the job engineering experience as they progress. This approach is based on the view that engineering is an applied discipline and therefore requires the development of workplace-based, applied and practical skills in students, in order for them to develop the requisite graduate attributes. The university also espoused a student-centred approach to teaching, and had developed a program of educational innovation that was intended to shift teaching away from traditional models more in line with a constructivist approach. In its own words, the institution stated that ¨[this program] highlights the importance of focussing first and foremost on how students come to learn and then on what teachers should do to support that.¨

Within this institutional context, a participant was chosen who had a strong theoretical research background, and a teaching portfolio that involved teaching highly theoretical courses. The purpose of this case was to see if an institution that espouses an alternative epistemological approach to teaching and learning would have an effect on dislodging the traditionally positivist view of teaching engineering for a theoretically focussed teacher. Despite this espoused shift away from a traditional approach to curriculum and pedagogy at the institution, Participant B was seen to hold fast to traditional views of learning, teaching and curriculum. As such had a very different conception of the nature of teaching and learning in engineering to Participant A.

First, his view of the nature of the discipline was not founded in a skills focus, but on knowledge. In his view, to master the discipline, adequate foundational knowledge was required before professional skills became relevant:

> *In engineering definitely you should …start from [the] basic and build up your knowledge, otherwise if you're in upper levels, but nothing in foundation, you have missed some part… believe me sometimes if a student for some reasons has…not performed well in that basic part we see immediately … in engineering I believe we develop any equation or explain any concepts definitely, definitely in fact this source base of that concept should be explained and*

> *they should understand why later on what they will remember just that concepts again they can rebuild it.*

Second, he was sceptical of the value that too much practical experience could have for students. In discussing the role of the internships in the curriculum at his institution, he stated:

> *And they try to balance I believe, but of course even to me [the current internships] should be adequate, you shouldn't go more than that for let's say practical by the rest will be in fact gained by graduate engineer.*

In discussing his perception of the university program to make learning more student-centred, his view was that this initiative was about leaving the student to take on more of the process themselves and without support:

> *Students should be somehow trained that she or he does not need to face-to-face let's say lecturing be able to provide all what the student needs from internet … We put everything whatever they need- additional papers, additional sources, additional software they may use or they may not use… going towards that students centred - in fact student can manage their education.*

In this view of student-centredness, students are left with relevant materials, but without help as to how to use them to develop knowledge and understanding of the necessary concepts or their relevance. This participant was not comfortable with releasing this level of control over what and how the student would learn of the subject matter, at least for his own subjects. This a common misapprehension about student-centred approaches for engineering education.

In parallel with these views, observation of teaching sessions with this participant revealed an approach to teaching which focused almost exclusively on the material to be covered, with little or no attention given to how or how well the students were understanding it. Lectures were given with the participant facing the board and speaking over his shoulder. He only rarely faced the class. When he did ask questions, he provided his own answers almost immediately. In the few instances where students attempted to answer a question during one of his sessions, their response was not acknowledged and no feedback was given. One hundred percent of the talking was done by him, and speech was continuous, without pause or signposts among the different concepts being discussed.

During lecture sessions it was also apparent that the participant´s disciplinary knowledge seemed to be communicated according to how it was organised for himself. Things were mentioned as he remembered and understood them rather than being organised according to the students´ own schemata and their needs for conceptual change. Corresponding with this state of affairs, a number of elements of PCK were completely absent from observations of this participant´s practice, including using knowledge of students, of assessment practices, or using processes of reflection and integration. In fact, the only element of PCK that was well represented for this participant was knowledge of discipline curriculum, as is to be expected given his epistemology of teaching engineering.

Despite the problems with this approach, the participant was unaware of its drawbacks, and was unaware if students were having difficulty with the material. Despite being given the same opportunities as participant A to discuss his epistemology of learning and teaching and his approach to supporting his students´ understanding, he was not able to give a comprehensive response, and instead reverted to discussing the demands of the discipline in terms of mastery of subject matter. As such, whilst he stated that he was in support of student-centred approaches, he was likely unaware that his own epistemology was not compatible with such an approach.

At this point in his career as an engineering academic, this participant was yet to encounter any significant challenge to this epistemology and consequent approach to teaching. Despite nominally not supporting the paradigm of learning that the participant demonstrated, the institution continued to support his position, at least in the sense that it had not yet required him to change or adapt. As is commonly seen in the field, the participant believed that a focus on research in his site would give him the best chance of promotion, and focussed his efforts here rather than on developing his teaching. In this sense, in promoting research over teaching development, the structure of the field failed to prompt him towards developing practices that would support a more student-centred approach. For this participant, the skills that would be involved in this kind of teaching development were not apparent, and therefore would require significant time and support to cultivate. This would necessarily begin with developing some epistemological flexibility towards teaching and learning.

Conclusions

It is easy to discuss student-centred learning as a simple pedagogical approach to be implemented ´off the shelf.´ However, as we have seen herein, the concept requires much more interrogation to arrive at a clear picture of the skill and circumstances required to bring the principles of the approach to life. As was seen with Participant A, even where the field permits and promotes a traditional approach to teaching, well developed PCK can provide the skills which allow a teacher to take a student-centred approach, even during traditionally didactic activities such as lectures for theoretical courses. However, the degree of time and focus on teaching that this level of PCK development requires can pose a risk to the participant in competing in the field. Participant A was only able to accept this degree of risk due to relative independence within and from the field, and an ability and willingness to deemphasise her research activities.

Conversely, even when the institutional discourse about learning nominally promotes a student-centred approach to teaching, the field can act in such a way as to support didactic and transmission focussed approaches that do little to support students in their learning. Fundamentally, this comes down to the epistemologies of teaching and learning that the engineering education field supports and perpetuates through reward structures that privilege research at the cost of the development of teaching. For example, where theoretical research expertise is seen as analogous with teaching expertise, the didactic approach to teaching is seen to persist. For the field to change its fundamental epistemology, some commitment must be made by institutions to how they support and reward alternative approaches to teaching. Where rewards for research combined with a didactic teaching approach outstrip any rewards for constructivist, student centred teaching development, the traditional approach to engineering education will undoubtedly persist despite any isolated initiatives for change.

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