Education Theories on Learning: an informal guide for the engineering education scholar
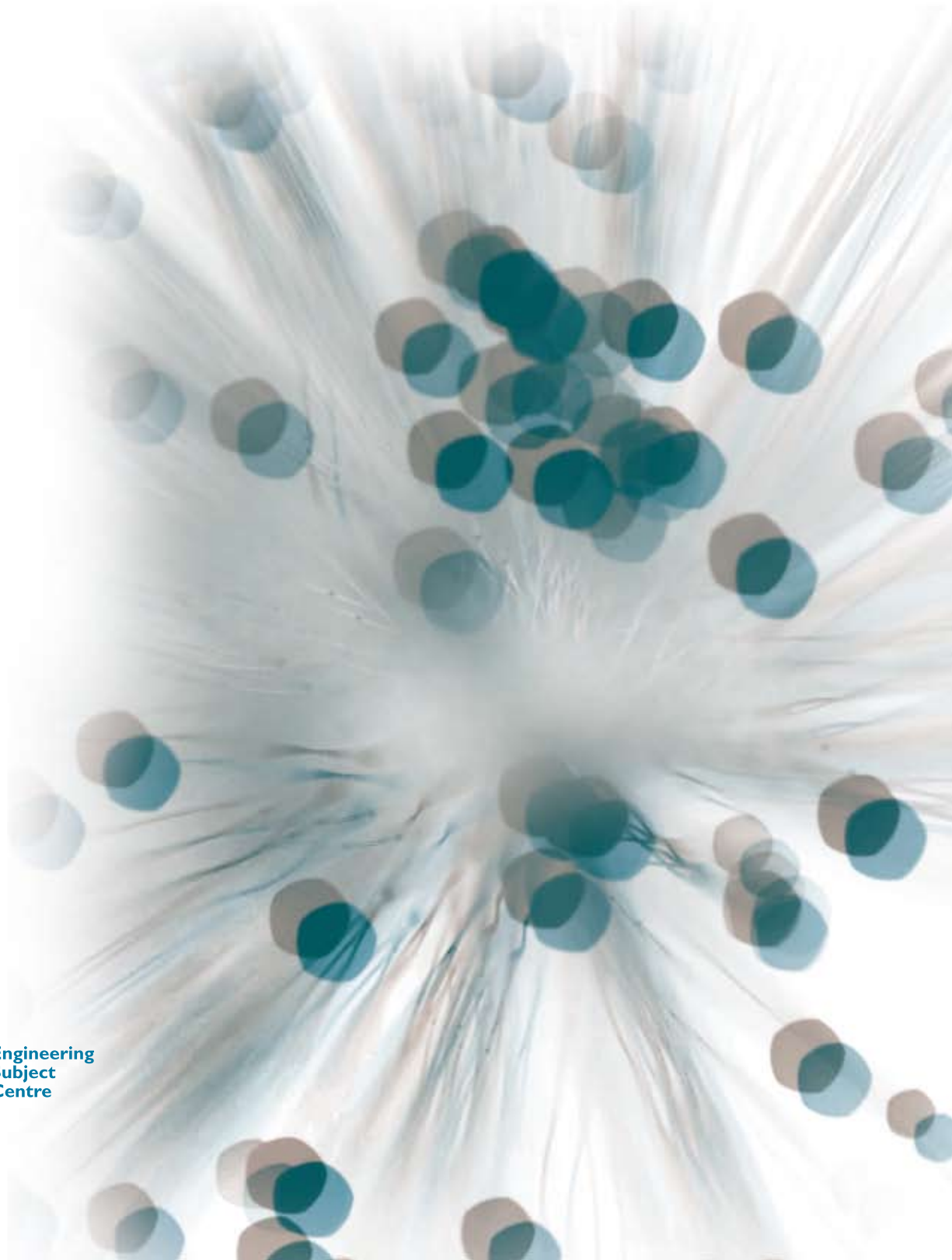
an **Engineering Subject Centre** guide by
Jenni Case

Author's biography

Jenni Case is Associate Professor in the Department of Chemical Engineering at the University of Cape Town, South Africa, and a former director of the Centre for Research in Engineering Education (CREE), University of Cape Town. Researching students' experiences of learning in order to improve the quality of student learning in science and engineering programmes has been a key focus of Jenni's work to date.

Education Theories on Learning: an informal guide for the engineering education scholar

Overview

This guide has been produced to complement and develop the Engineering Subject Centre's existing range of resources about learning and teaching theory. It is aimed at newcomers to the field, such as:

- engineering teachers who want to be able to use education theory and research findings to inform their teaching; and

- aspiring engineering education researchers who want to launch their own projects.

Using a view of a theory as a set of 'thinking tools', the guide offers a selection for building up a tool kit. Six 'tools' have been identified. The selection is the author's personal choice and the tools were chosen for their usefulness in engineering education research. Tools 1-3 broadly cover learning as acquisition, tools 3-6 look at learning as participation:

Tool 1: Concepts

Tool 2: Ways of experiencing

Tool 3: Approaches to learning

Tool 4: Community of practice

Tool 5: Identity

Tool 6: Discourse.

The guide has an informal tone to make it as accessible as possible for those who are new to education research. Each section provides a brief introduction to the tool, including a case study example and further reading. Wherever possible, references and further notes on terminology are in the footnotes. A detailed reference section is provided at the end of the guide. This structure enables the reader to engage with the text on either an introductory or more theoretical level, depending on their needs.

A view on theory in education

In the world of engineering there are theories that can be used for building a bridge, designing a chemical reactor or improving the aerodynamics of an aeroplane. It is probably then quite reasonable to assume that education theory will deliver some straight answers on how to conduct teaching or how to improve learning. If this were possible then this guide would offer you a set of rules to apply to your teaching and you could head off happy and secure. However, if you have spent any time working with students, for example giving a lecture and then seeing what students write in a test, you will already have that nagging feeling that improving teaching might in some odd way be more complex than designing an aeroplane.

In the field of social science where education finds itself there are indeed some who would claim to have formulated universal and general rules. The problem is not that these aren't true, but that when you are working in this mode you tend not to come up with particularly interesting or useful insights. For example, it has been shown that schools with students from poorer socio-economic backgrounds[1] have, on average, poorer academic outputs compared to those with students from wealthier backgrounds . Most teachers already know this. But how can we start to understand what is happening here so that we might be able to subvert the inevitability of such outcomes? Here we need to make different demands of theory.

There can be considered to be two types of theory in the social sciences[2]. Firstly, there is the kind of theory that we are familiar with in the natural sciences and engineering: a set of general statements about the world that we can either prove or disprove empirically. As noted above, this kind of theory is often not terribly helpful in education. The second kind of theory is described as a set of 'thinking tools', concepts or heuristics that one can use to offer new ways of looking at the world, to suggest new lines of enquiry or action. Here we do not have a set of right answers waiting for passive transfer to new contexts; each new user of this thinking tool will have to put it to use in solving their own problems. You need to consider your own situation, look into the guide and choose the tool that seems best suited to your needs. On the one hand this can be daunting; on the other hand anything less than an academic engagement would be an unlikely way to go about your work as an engineering academic.

Further insight as to why the 'engineering model' of theory is not necessarily applicable to teaching can be found in the observation that teaching is 'practical' rather than 'technical' in nature: 'it is a matter of making judgements rather than following rules'[3]. There might be some educational problems that are amenable to technical solutions but most are not. It has been suggested that 'enlightenment' rather than 'engineering' could work as a model for how we should think productively about education theory[4].

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[1] For a detailed meta-analysis of these studies see White (1982).

[2] (Mouzelis, 1995)

[3] (Hammersley, 1997, p. 147)

[4] It is also acknowledged here that many of the traditional ways of thinking about science and engineering knowledge have been contested in recent times, and it can certainly be argued that good engineering solutions are highly contextual and not simple transfers of theoretical knowledge from one domain to the other.

Building on the assertion that teaching is about making insightful judgements rather than applying technical solutions, this guide focuses primarily on learning theory. It is student learning that is at the heart of our enterprise, and any starting point for improving teaching needs, therefore, to focus on learning[5]. This is not to discount the value of theorising teaching, curriculum, institutions, etc., but merely to assert that thinking about learning is a good starting point, especially if you are aiming to develop new insights into what is happening in your classroom and course.

So we now have an invitation to engage with education theory, to find those thinking tools that seem most applicable to our context and to use these to develop our teaching practice, to understand our students and to design our educational systems. 'There is nothing so practical as a good theory' was stated by the social scientist Kurt Lewin[6] and this will be a useful mantra for the journey.

Who is this guide intended for?
This guide is intended for newcomers to the field:

- for engineering teachers who want to be able to use education theory and research findings to inform their teaching; and

- for aspiring engineering education researchers who want to launch their own projects.

It is worth noting that much current published literature in engineering education does not proceed from an explicit theoretical basis. This I feel is a great pity and a real limitation to what can be achieved in this area. The intention is that this guide will go some way towards encouraging more scholars to utilise education theory in guiding their work.

If you are planning to conduct your own research, once you have made the theoretical choices that this guide is focused on, you will also have to select or design an appropriate research methodology. There are many helpful texts on this topic. [7]

A note on writing style
I have endeavoured to make this guide as accessible as possible for those who are new to educational research. From my own experience and those of colleagues, I know that it can be difficult to find your way into educational literature. This guide therefore uses a very informal style and is deliberately different to what you will find in the average journal article. Wherever possible, references and further notes on terminology are in the footnotes. For a first read through you can simply ignore the footnotes and stick with the main text. For a first excursion into this area it was judged most important to get to grips with the new ideas and how one might use them, rather than having an exhaustive treatment on the theoretical provenance of these tools. If you are enticed to go further you will need to read further, so bear in mind that what you have here is simply a starting point. In selecting articles to illustrate the tools, as well as offering further reading, I have kept to journal articles which are easily accessible. In many areas you will need to get to the source books if you want to go deeper and in engineering education you will also find that many research studies are only presented at conferences, especially in the USA.

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[5] (Ramsden, 2003)

[6] (Lewin, 1951)

[7] A classic text here is Cohen, Manion and Morrison's Research Methods in Education (2000). There is also a useful Higher Education Academy guide to conducting education research in the physical sciences which is very relevant for those starting out in engineering education research. Go to http://www.heacademy.ac.uk/resources/detail/SNAS/snas_708.

The structure of this guide

Using a view of a theory as a set of 'thinking tools', this guide offers a selection for building up your tool kit. Six 'tools' have been identified. The selection is obviously personal and I have picked out those tools that I have found particularly useful in my own research in engineering education. However, these also do follow general trends in education thinking and can be separated into two general groups. Sfard (1998) identifies two broad metaphors which underpin thinking about learning. The first metaphor centres on a notion of learning as acquisition, and the first three tools fit broadly under this heading[8]. The second metaphor is about learning as participation and this describes the next three tools.

Learning as acquisition…

> If I had to reduce all of educational psychology to just one principle I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.
>
> (Ausubel, 1968, p. vi)

In working with tools 1-3 we will be focusing in different ways on 'what the learner knows'. These tools will help us develop a range of different explanations for student success or failure that go beyond simply labelling some students as able and others as not. We will look at 'concepts' and 'ways of experiencing' in order to analyse conceptual understanding. With approaches to learning we will develop a theory which explains why some students are developing conceptual understanding and others not. Although these tools have different theoretical underpinnings they all basically build on a perspective which sees learning as the acquisition of something, be it conceptual understanding or a way of experiencing. They offer us a means to get to know our students in order to be able to improve teaching and learning.

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[8] If you want to go further you might need to get to grips with the key theoretical differences amongst the three theories in this group, especially between conceptual change theory (tool 1) which rests on a dualist constructivist epistemology and phenomenography (tool 2) which espouses a non-dualist position.

TOOL 1: CONCEPTS

What are we talking about here?

In thinking about the learner's existing knowledge in terms of **concepts**[9] we are putting forward an idea of mental structures in someone's head[10]. The aim of teaching and learning is to change these mental structures, hence the term 'conceptual change'.

One thing that has been demonstrated repeatedly in research studies is that students' prior conceptions are surprisingly resistant to instruction. Even after scoring high marks in formal assessment, when faced with conceptual type questions successful students, even at the tertiary level, can display concepts that are not in agreement with science[11].

An important idea which has recently emerged in higher education research is that of a 'threshold concept': those key ideas in a discipline which need to be mastered in order to see the world in a different way[12].

What does this mean for engineering education?

Most of the research on concepts and conceptual change has been in the natural science disciplines of physics and chemistry, some of this work with university students. Given that these are the disciplines which form part of the foundation for engineering studies, there is much here that can be applied directly to engineering education. For example, the Force Concept Inventory (FCI)[13] is a test which can be administered to students both before and after instruction to determine to what extent conceptual change has taken place.

There is considerable scope to extend this work into the foundational concepts in the engineering sciences. For example, a concept inventory has now been established in the area of fluid dynamics[14].

In what ways might this be a useful thinking tool?

The focus on students' concepts both before and after instruction was a major step forward in education theory – rather than simply stating that a student 'got it wrong', one started to take an active interest in the wrong answers. This has proved to be a very productive angle both for research and also for teaching. Teaching which elicits students' prior conceptions means that instruction can be focused directly on what students are struggling with.

More recently, teachers are using the idea of 'threshold concepts' to unpack overloaded curricula and decide what are the really key ideas that students need to focus on.

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[9] This perspective comes from cognitive science. Much science education research in this area builds on the studies of Piaget, and this is sometimes referred to as a 'constructivist' theory of learning (cf. Matthews, 1998).

[10] Other terms which have been used instead of 'concept' include conceptual structures, phenomenological primitives, conceptual ecology and mental models (Leach and Scott, 2003).

[11] An extensive bibliography by Pfundt and Duit (1994) details the literally thousands of science education studies which describe 'alternative conceptions' across a wide range of topics. A popular demonstration of this idea can be seen in the film 'A Private Universe' in which Harvard University graduates gave their answers to two simple questions about the causes of the seasons and the phases of the moon (Scheps and Sadler, 1988).

[12] A very helpful overview by Glynis Cousin on threshold concepts can be found at http://www.gees.ac.uk/planet/p17/gc.pdf, published by the Geographical, Earth and Environmental Sciences (GEES) Subject Centre of the Higher Education Academy.

[13] See Saivinainen and Scott (2002) for a useful overview of the FCI.

[14] (Martin, Mitchell, and Newell, 2003)

Show me an example…

Carew, A. L., and Mitchell, C. A. (2002). Characterising Undergraduate Engineering Students' Understanding of Sustainability. *European Journal of Engineering Education*, **27** (4), 349-361.

In the context of new requirements for engineers to 'understand' sustainability[15], Anna Carew and Cynthia Mitchell set out to investigate the understanding of a group of third year engineering students who had just completed a module on sustainable development. To do this they chose to use the SOLO Taxonomy: a scheme for characterising students' conceptual development[16]. This scheme proposes that conceptual development can be analysed according to five stages of increasing conceptual sophistication. At the bottom of the scheme is the 'prestructural' stage which essentially involves no real understanding. This is followed by 'unistructural' and 'multistructural' stages in which the student displays knowledge of one or more items of content knowledge, but with no interrelations. In the 'relational' phase the student interrelates different items and in 'extended abstract' the student is able to use critical reflection to generate new ideas.

Carew and Mitchell asked students to provide written responses to the question 'in your own words, what is sustainability?' They then classified these responses into the five different SOLO levels. What was notable was that 65% of these students displayed responses at the pre- or unistructural stages, despite having just completed a module on this very topic!

Based on these findings, Carew and Mitchell suggest that we need to move beyond general statements advocating students' understanding in this area and we need to give more detailed guidance on what levels of understanding we should be expecting from our undergraduates. We may also need to rethink our teaching methods if we wish to develop conceptual understanding in our classes.

Where can I read further to learn more about this tool?

Leach, J., and Scott, P. (2003). Individual and Sociocultural Views of Learning in Science Education. *Science & Education*, **12** (1), 91-113.

As noted above, research into students' conceptions and conceptual change has been very prominent in science education research. John Leach and Phil Scott represent the research group at the University of Leeds which led much of this research. In this 2003 paper they provide a very helpful mapping out of the territory, summarising the work of key scholars in the area. This paper covers both 'individual' perspectives on learning, which focus on the theory outlined in this 'thinking tool', and 'sociocultural' perspectives which will be dealt with in tools 4-6. Because the aim of their paper is to argue for the necessity of combining these perspectives they include critiques of work that focus only on individual conceptual change. However they also point out salient theoretical positions in this area and they do argue for the value of this work.

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[15] This was based on the latest accreditation requirements from the Institution of Engineers in Australia, in particular a requirement similar to statement E-3 in UK-SPEC.

[16] (Biggs and Collis, 1982)

A very influential theory on conceptual change suggests that learners will only adopt new conceptions if they become dissatisfied with their existing conceptions and find the new conceptions to be intelligible, plausible, and fruitful[17]. Leach and Scott caution against a purely 'rational' view on learning which sees students checking new ideas against their sensory perceptions. Adopting a new idea has a lot to do with the social context in which this takes place and teachers play a key role in persuading the learners of the viability of new ideas.

Leach and Scott have a strong interest in using the results of education research for designing teaching which can foster conceptual change. They review a number of studies which suggest that teaching methods which take no more time than conventional methods can have the desired effect. They do however note that improved research methodologies are needed to properly justify these claims.

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[17] (Posner, Strike, Hewson, and Gertzog, 1982)

TOOL 2: WAYS OF EXPERIENCING

What are we talking about here?

From this perspective learning involves a new 'way of experiencing', something which might sound quite similar to concepts and conceptual change. We are again interested in what learners know both before and after instruction – but there is one key difference that we need to note. With the term 'ways of experiencing a phenomenon'[18] we are not saying that students have concepts in their head, but rather that learning is a relationship between a person and a phenomenon[19].

If you want to uncover the different ways students are experiencing a phenomenon (a topic) then you need to conduct open-ended interviews with them and get them to talk about the phenomenon. You can then analyse the interview data using standard qualitative techniques[20] to sort it into different categories. These categories are then considered to represent the full set of possible different 'ways of experiencing'. It has been found from many such studies that there are always a limited number of such categories. Strictly speaking, one can't assign a 'way of experiencing' to a particular individual since the categories are arrived at often by using fragments of interview data from various individuals. It is better to think of the set of categories as representing the full range of ways of experiencing in a group of individuals.

What does this mean for engineering education?

Although the purists would perhaps not agree, it is possible at this stage to see many links between this tool (ways of experiencing) and tool 1 (concepts). The underlying theory is different, but in both cases one is able to investigate a range of different 'prior ideas' as well as unpack 'wrong answers'. One practical point is that where concepts and conceptual change have been very prominent in school level science education research, phenomenographic research which focuses on ways of experiencing has been widely used in research in higher education, especially in the UK, Australia and Sweden. At the very least you will come across papers which use these latter terms and so it is useful to know at least something of what they are talking about.

In what ways might this be a useful thinking tool?

A focus on 'ways of experiencing' does open up new perspectives on teaching and learning. It is especially useful in the ways in which it links an understanding of student learning to acts of teaching. In recent work the awareness of a range of different ways of experiencing a phenomenon has led to a strong focus on variation. Here there is a claim that variation in experience is a necessary condition for all learning[21]. When designing teaching one aims then to include variation, especially in what have been termed 'educationally critical aspects' of the object of study[22].

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[18] This comes from a field termed 'phenomenography' (Marton and Booth, 1997). In the text here for readability I have chosen to use the term 'ways of experiencing' wherever possible.

[19] This is termed a 'relational' perspective. Compared to constructivist learning theory, which implies a dualism between mind and body, this is a non-dualist perspective; concepts do not reside in a separate mind.

[20] For example, see Strauss (1987).

[21] See, for example, Pang (2003)

[22] See, for example, Linder ,Fraser and Pang (2006).

Show me an example…

Marshall, D., Summers, M., and Woolnough, B. (1999). Students' conceptions of learning in an engineering context. *Higher Education*, **38** (3), 291-309.

In this study Delia Marshall and colleagues focused on engineering students' ways of experiencing learning itself, also termed 'conceptions of learning'. The assumption is that the ways that students experience or conceptualise learning is an important determinant of their 'approach to learning' (see tool 3) in a given context. Most previous studies of conceptions of learning had focused on social science or humanities contexts and it was expected that things might be slightly different in engineering, as indeed they were.

The students that were interviewed were on an engineering foundation programme at a UK university. Five conceptions of learning were identified in this study. Compared to other studies of conceptions of learning they did not find a simplistic conception of 'increasing one's knowledge'. This could be taken to mean something positive about the engineering course context. The least sophisticated conception of learning which was identified focused on memorising definitions, equations and procedures, so at least the students directed their learning with some purpose. This was followed by a slightly more active conception which involved applying equations and procedures. A substantial shift was seen in the third conception of learning which focused on making sense of physical concepts and procedures. Here there is an introduction of a reflective dimension. Going further, a small group of students conceptualised learning as 'seeing phenomena in the world in a new way', and a final small group displayed the most sophisticated conception of learning which centred on 'change as a person'.

In considering the implications of these findings, Marshall et al. suggest that educators need to explicitly design curricula which foster these higher conceptions of learning. This, they suggest, will require a stronger focus on reflection, on the broader context for application of learning and more peer-level discussion.

Where can I read further to learn more about this tool?

Booth, S. (2001). Learning Computer Science and Engineering in Context. *Computer Science Education*, 11 (3), 169-188.

Shirley Booth has played a key role in the area of phenomenographic research, starting with her PhD on students who were learning to program in a computer science and engineering course[23]. She then co-authored a key text, *Learning and Awareness*[24], and has continued to be involved, especially in the application of this thinking in science and engineering education. In this paper she lays out a very practical argument for shifting from a 'transmissive' to a broadly 'constructivist' pedagogy. She argues that rather than depending on 'folk pedagogy', which is anecdotally derived, we need to ground our thinking in educational theory. In this paper she lays out and illustrates what it means to take a phenomenographic perspective.

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[23] (Booth, 1992).

[24] (Marton and Booth, 1997).

The context for this paper is a Computer Science and Engineering programme which underwent reform, prompted particularly by the low participation rates by women. The reform approach argued that improving the programme for women would also improve it for all students. This paper focuses on the introductory course for this programme which aimed to provide students with a particular orientation, termed a 'relevance structure', for the forthcoming programme. Building on phenomenographic theory, group work was implemented throughout the course to ensure a variation of perspectives.

The evaluation of this course was also conducted using a phenomenographic approach. The aim was to identify the different ways in which students experienced the course. This was firstly with regard to the intended 'relevance structure' and here it was found that many students had ways of experiencing that were at odds with the planned course direction. Secondly, given the importance of group work in the course design, they sought to identify students' ways of experiencing group work. This was also quite surprising. Only a small group of students adopted the collaborative perspective that was intended. These evaluation findings were then used to modify the way in which the course was delivered, and in subsequent years it was found that a greater proportion of students (and tutors) were experiencing the course in the manner in which it had been intended.

TOOL 3: APPROACHES TO LEARNING

What are we talking about here?

Approaches to learning describe what students do when they go about learning and why they do it. The basic distinction is between a deep approach to learning, where students are aiming towards understanding, and a surface approach to learning, where they are aiming to reproduce material in a test or exam rather than actually understand it[25].

A critical assumption here is that approaches to learning are strongly determined by students' perceptions of the educational context and not only determined by students' backgrounds[26]. There is therefore no such thing as a 'deep learner' or a 'surface learner' – the same student can take different approaches depending on the educational context[27].

What does this mean for engineering education?

If approaches to learning are determined by the student's response to an educational context then the challenge for educators is to create environments which foster deep approaches to learning[28]. This is not as straightforward as one might guess, especially in engineering programmes which have high workloads and 'high stakes' assessment[29].

Research with engineering students has also uncovered a more detailed range of approaches to learning, with 'procedural approaches' in between the classic deep and surface approaches[30]. Procedural approaches involve students focusing on solving problems, and this can be with either 'surface' or 'deep' intentions. This suggests that we need to think about the traditional advice given to engineering students to 'do loads of problems and understanding will come later'. From marking examination scripts and design reports most teachers know what happens when students have focused on learning problem solving procedures at the expense of understanding what they are doing.

In what ways might this be a useful thinking tool?

Context is everything in approaches to learning theory. You can't simply 'blame the student' – you have to try and understand how the educational environment is being perceived. This is not as difficult as it might sound. Many people like to use inventories to identify students' approaches to learning (for example, Ellis et al., 2008) but it has also been argued that simple qualitative studies using student interviews can generate useful contextual results[31].

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[25] This original research is described in the book The Experience of Learning, now in its second edition (Marton, Hounsell, and Entwistle, 1997). Although out of print this book is available free online at http://www.tla.ed.ac.uk/resources/EoL.html. The field of phenomenography (described in Tool 2) developed from the original study which identified approaches to learning (Marton and Säljö, 1976).

[26] (Ramsden, 2003)

[27] This is a crucial difference between approaches to learning and learning styles (for an overview of learning styles in engineering education, see Felder and Silverman, 1988).

[28] Biggs calls this 'constructive alignment' (Biggs, 1999).

[29] See, for example, Case (2004).

[30] (Case and Marshall, 2004)

[31] (Case and Marshall, in press).

Show me an example...

Ellis, R. A., Goodyear, P., Calvo, R. A., and Prosser, M. (2008). Engineering students' conceptions of and approaches to learning through discussions in face-to-face and online contexts. *Learning and Instruction*, **18** (3), 267-282.

Robert Ellis and colleagues conducted their investigation with third year engineering students at an Australian university. They focused their study on conceptions of learning (see tool 2) and approaches to learning, building on the assumption that conceptions of learning are likely to influence approaches to learning. They were interested to see how these ideas might apply in the context of an innovative course which used both face-to-face and online discussions.

They conducted both a qualitative study using a phenomenographic approach (see tool 2) and a quantitative analysis using student learning inventories. They obtained similar results from both analyses, showing relatively strong correlations between 'cohesive' conceptions of learning and deep approaches to learning. They concluded that it is important for lecturers to help students develop approaches to learning in which discussions (both face-to-face and online) are seen as important sites for building understanding.

Where can I read further to learn more about this tool?

Biggs, J. B. (1999). What the student does: teaching for enhanced learning. *Higher Education Research and Development*, **18** (1), 55-75.

John Biggs is one of the key scholars in this area of research. His early results with his 'Study Process Questionnaire'[32] were surprisingly similar to those arising independently from the work by Marton, Entwistle and colleagues mentioned earlier. His writing is practical and highly accessible and a good starting point for anyone wanting to explore this area further.

In this paper, Biggs responds to concerns currently raised about how to meet the needs of the diverse range of students now entering higher education. In describing two hypothetical students, Susan and Robert, he provides a useful illustration of what deep and surface approaches mean in a particular course. He then puts forward his idea of 'constructive alignment' which involves creating educational environments where teaching and assessment are aligned with desired educational outcomes, such that more students will be likely to adopt deep approaches.

Biggs then backtracks a little to provide a very useful history on approaches to learning research. He uses these ideas together with the ideas of conceptual change (see tool 1) to formulate an approach to teaching which focuses on 'what the student does'. This, he argues, is more effective than trying to cater to individual students' varying requirements. To achieve constructive alignment one needs to ensure that learning objectives, teaching methods, and assessment are all focused towards the same thing. In discussing learning objectives he uses the SOLO taxonomy described under tool 1. He also provides a useful range of teaching methods for consideration, as well as assessment tools. This paper is really a helpful overview of a progressive and practical way to rethinking teaching in higher education.

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32 (Biggs, 1978)

Learning as participation…

> Learning is not merely a matter of acquiring knowledge, it is a matter of deciding what kind of person you are and want to be and engaging in those activities that make one a part of the relevant communities.
>
> (Brickhouse, 2001, p. 286)

In working with Tools 4-6 we will draw on a very different perspective on what it is to learn[33]. Here we focus on learning as participation. This is not any sort of activity: students are learning to do the activities associated with the professional community of engineers.

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[33] This can be termed a sociocultural perspective on learning (Cobb and Bowers, 1999).

TOOL 4: COMMUNITY OF PRACTICE[34]

What are we talking about here?

Community. Just another buzzword? Here is a thinking tool that invites you to consider the educational context as a 'community of practice'. A community of practice is defined by the joint activities in which its members are engaged[35]. Students are 'newcomers' to the community and they get inducted by participating in these joint activities[36]. Even though the newcomers are at the margins of the community they do need to be involved in 'legitimate' (i.e. meaningful) activities. The teachers (and more experienced peers) are the 'oldtimers' in the community and they interact with the newcomers and also model the activities in the community. As students advance in their ability to carry out the relevant activities they become full members of the community of practice.

This perspective might sound more appropriate to an apprenticeship context than a formal educational setting, but many education scholars have now started to apply these ideas to what can be termed a 'knowledge community'[37]. The activities of the knowledge community comprise specialised ways of thinking, writing, talking, problem solving and so on.

What does this mean for engineering education?

This view on learning with a focus on 'communities of practice' has in fact always been implicitly present in engineering education. Our students spend periods in industry, they do practical investigations that get them to work with small scale versions of engineering equipment and our final year assessment is often in a design project which is supposed to model engineering practice. Taking on board 'community of practice' as an explicit thinking tool might help us to run these activities more effectively as learning experiences. In many engineering schools the practical and design courses receive less attention than the lecture-based theoretical courses, perhaps at least in part because these are not the courses that have high failure rates. We might be able to use these courses more effectively as key sites of learning which also energise and excite students.

But the 'community of practice' thinking tool can also be used to drive a more radical rethink of what we do. Perhaps we need to move 'authentic' activity to a more central place in our curriculum. This is what is being advocated by the Problem Based Learning (PBL) movement[38]. This involves fully taking on board the central importance of students' active participation to ensure effective learning.

More recently there are a number of scholars who have productively applied this thinking tool to designing and researching online communities of practice[39].

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[34] The learning theory that encompasses this thinking tool is called 'situated cognition' (Brown, Collins, and Duguid, 1989) or 'situated learning' (Lave and Wenger, 1991)

[35] (Wenger, 2000)

[36] This is termed 'legitimate peripheral participation' (Lave and Wenger, 1991)

[37] (Northedge, 2003b)

[38] For a valuable review of the suitability of PBL to engineering education see Perrenet et al. (2000).

[39] See Johnson (2001).

In what ways might this be a useful thinking tool?

What is the community of practice? Is it your classroom? Your department? The professional community of engineers? One can apply this thinking tool to communities at different levels. But if you consider your course or your programme then you need to think about what would be the appropriate activities that define your community of practice. You would also need to consider whether students are getting a chance to do meaningful activities and whether the classroom works as a community to support this learning.

Show me an example…

Case, J. M. and Jawitz, J. (2004). Using situated cognition theory in researching student experience of the workplace. *Journal of Research in Science Teaching*, **41** (5), 415-431.

Jenni Case and Jeff Jawitz used the idea of 'community of practice' to explore engineering students' experiences of industrial vacation work. They sought to investigate whether students experienced 'legitimate peripheral participation' (meaningful activity) or not. Engineering vacation students are traditionally in a difficult place, being only part way through their programme and on a short assignment, and it is generally considered difficult for managers to find useful things for them to do. Also considering issues of race and gender and the inherent conservatism of many engineering workplaces it was likely that access to the community of practice might be further complicated.

The study shows that access to meaningful activity is indeed a central determinant of whether the students have a productive learning experience or not. It was noted that the engineer assigned as mentor to the student played a key role in facilitating this access. In many cases the mentoring engineer was able to act as an advocate for the student's status as a legitimate participant in the workplace.

Where can I read further to learn more about this tool?

Wenger, E. (2000). Communities of practice and social learning systems. *Organization*, **7** (2), 225-246.

This paper is focused generally on organisational contexts (and not directly on formal educational settings) but in it Etienne Wenger lays out very clearly how he sees the concept of 'communities of practice' which he originally devised together with Jean Lave. He helps us answer the question posed above – what makes for a community of practice? And all along the way he provides good examples to illustrate his concepts.

In this paper he suggests that we can have different forms of belonging to a community of practice: engagement (doing things together), imagination (constructing an image of ourselves) or alignment (making sure our activities are aligned with those of others). He goes on to make some interesting points about the importance of focusing on the boundaries of communities and looking at ways to broker knowledge between different communities. He also gives a good summary of his way of thinking about identity (see thinking tool 5).

This is a very practical paper for anyone wanting to apply the idea of 'community of practice' to their own context. He gives lots of questions and useful organisational matrices for structuring your investigation.

TOOL 5: IDENTITY

What are we talking about here?

Identity might seem to be a topic more suited to the clinical psychologist than the engineering educator: "I don't need to know if my first years are well-adjusted 18 year olds, I just need to worry about whether they are learning any engineering!" It is therefore important to note that the view on identity that we wish to consider for inclusion in our guide does not focus on internal psychological makeup but is much more about how you present yourself to the world and how the world recognises you. In engineering education we are continually assessing whether our students are able to display engineering skills and knowledge with confidence. This is basically what we are talking about when we focus on identity.

There are a number of key assumptions that underpin this view of identity:

- MULTIPLE: we all hold multiple identities and deploy different identities depending on where we are and who we are interacting with at that time.

- SHIFTING: our 'suite' of identities changes over time: we take on new identities and we might sometimes choose to drop a particular identity. Some new identities might require us to do this and we might be in a dilemma if we don't want to drop that identity.

- PRODUCED: there is nothing passive here. To be recognised as holding a particular identity, you need to talk and act in a way that others will recognise you as such.

What does this mean for engineering education?

Learning engineering is not simply a matter of 'acquiring knowledge'; engaging with engineering is an act that has implications for how others will see you. Students come to engineering with some identities already in place that they use in the home, at school, with their friends. Taking on the new identity associated with learning engineering will either merge seamlessly with these other identities or else there might be a clash. A clash between these identities could result in academic failure or ultimately not choosing to follow a professional engineering career.

It is important to note here that we are not suggesting that undergraduate students are in a position to take on a full professional identity as an engineer. They are not yet able to behave in such a way that those in the engineering community would recognise them as an engineer. So we need maybe to call this the identity of being 'an engineering student'. This is a broad concept that goes all the way from engaging in certain academic activities in class to a certain way of engaging with campus life. There may be a number of different identities available to your students that all, to some extent, can be used to successfully 'pull off' being an engineering student. But you can probably also think of some students who find themselves uncomfortable with or unable to take on these identities. Possibly more so than broad foundation degree programmes in the sciences or humanities, engineering as a 'professional' degree places strong demands on students around identity[40].

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[40] A useful exploration of the disciplinary identities on offer in engineering education is given in Matthew and Pritchard (2008). The edited book in which this chapter is found is also a useful resource on the topics of discipline, community, identity and discourse (Tools 4-6).

The engineering workplace involves a wide spread of practical engineering identities: some engineers focus on design, others on production, others on financial and managerial aspects of the business and so on. However, it seems that the tertiary institution offers a more narrowly defined range of identities and it is therefore possible that some students are not able to find an identity that 'fits' and thus either drop out or graduate without a productive identity to take into the workplace[41]. This could be at the root of the failure of engineering programmes to deliver an acceptable number of successful graduates.

In what ways might this be a useful thinking tool?

Many engineering educators are concerned about the involvement of students from 'non-traditional' backgrounds in engineering education, for example women and ethnic minorities[42]. These concerns centre on the choice to do engineering, success in engineering programmes and taking up engineering careers. Research in this area has often focused on trying to identify the 'factors' that underpin career choices and academic success[43]. Some insights have been delivered, but we seem to still be very far from having productive insights as to how to widen access to engineering. Research guided by a focus on identity, as defined above in the sociological tradition, has the potential to generate important new understandings of this situation that can be used to guide future interventions. This might allow for 'a more dynamic approach than the sometimes overly general and static trio of 'race, class and gender'[44]. Engineering education research using identity as a theoretical tool has tended to focus mainly on gender issues (see below) and so there is productive future scope for exploring other aspects of diversity.

Show me an example…

Walker, M. (2001). Engineering identities. *British Journal of Sociology of Education*, **22** (1), 75-89.

In this paper Melanie Walker reports on a project which sought to understand the experiences of male and female students in a large Department of Electrical and Electronic Engineering at a pre-1992 university. She interviewed six men and nine women in in-depth individual interviews. The data was analysed using a framework focused on identity.

She found that women tended to adopt what could be termed a 'resistance' identity in which they asserted their difference from other females and 'claimed to be ''more like the boys''' (p. 81). These identities offered a way of succeeding in engineering education but they did not challenge the dominant norms around ways in which one could be male or female in this environment. In fact, traditional ways of thinking resulted in women engineering students being stereotyped as more organised and hard working, something that the women didn't actually welcome, especially in terms of the work that would get assigned to them in a group. Furthermore, for male students who did not identify with the views of maleness that predominated, there was also little room to move. Thus, the dominant culture ended up disadvantaging a subset of both women and men. While noting that there have been major changes in women's opportunities in the world of engineering work, Walker notes that the engineering identities taken on by these students 'both challenge and leave dominant gender relations in place' (p. 86). Although she is reticent to prescribe practical solutions, her analysis suggests that we need to

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[41] This argument is laid out in Allie et al. (2007).

[42] See, for example, Seymour (1995).

[43] See, for example, Woolnough et al. (1997).

[44] Gee (2001, p. 99)

create spaces where both male and female engineering students can be free to create 'project identities' where they are able to build new identities that contribute towards a transformation of dominant gender relations in engineering.

Two further key studies on identity and gender in engineering education are:

Phipps, A. (2002). Engineering Women: The 'Gendering' of Professional Identities. *International Journal of Engineering Education*, **18** (4), 409-414.

Stonyer, H. (2002). Making Engineering Students - Making Women: The Discursive Context of Engineering Education. *International Journal of Engineering Education*, **18** (4), 392-399.

Where can I read further to learn more about this tool?

Gee, J. P. (2001). Identity as an analytic lens for research in education. *Review of Research in Education*, **25** (1), 99-125.

James Gee is well known for his work in sociolinguistics and discourse analysis. In this paper he presents his take on 'identity' which is sociologically grounded with a particular focus on discourse (see tool 6). Gee's writing is especially accessible for the non-specialist and this paper provides a useful mapping out of four different 'sources' of identity that we can recognise. This could provide a starting point for a research project into the engineering identities in your classroom. This paper is also a useful introduction to Gee's notion of Discourse (as well as a quick crash course if you feel like it on modernism and postmodernism from a sociological perspective!). Towards the end of the paper he presents a brief illustrative study. It is set in a primary school classroom but it is not too hard to imagine how a similar kind of analysis could emerge from research in an engineering tutorial session. In his analysis of possible identities on offer to African American children in this classroom he provides a hard hitting analysis of how the institution might constrain possibilities for success depending on one's social background.

TOOL 6: DISCOURSE

What are we talking about here?

With a focus on 'discourse' it might seem that we are focusing exclusively on written and spoken language – this might seem fine for the language teacher but only a part of what we are needing to think about in engineering education. In fact, the term discourse refers broadly to ways of using language, mathematical calculations, software, graphs, non-verbal gestures, artefacts and so on. It is the specialist discourse that characterises a particular community of practice (see tool 4). For example, the discourse of being an engineer will involve the practice of design to solve real world problems, and this includes collecting and analysing data, using empirical laws and correlations, doing mathematical calculations and modelling, as well as presenting one's results to a range of different audiences. From this point of view, successful learning involves using a discourse in order to be able to participate in this community.

What does this mean for engineering education?

In engineering education we can therefore think of ourselves as working to produce 'technologically literate' graduates – with literacy used here in the broad sense of being able to use a particular specialist engineering discourse. What is worth noting is that discourse has been an especially useful thinking tool in mathematics education[45], which should be sufficient to persuade you that this is not simply the domain of the language teacher.

In what ways might this be a useful thinking tool?

So what's the big deal? If we are focusing on 'talking engineering' how hard can it be…[46] In fact being able to use engineering discourse successfully, so as to be recognised as a competent graduate engineer by the professional community, is not so straightforward, as we all know. There is no simple 'bluffer's guide' to see you through.

Discourse scholars have pointed out that learning a discourse is difficult precisely because so little is made explicit to the learner. Most of the key aspects of the discourse remain hidden. The task of the skilled teacher is to 'make the tacit explicit'[47]. How to do this? Teaching can be conceptualised as:

- helping to create shared specialist meanings with students

- leading the journey from familiar discourse into the specialist discourse

- coaching students in using the new specialist discourse[48].

It is important to recognise that taking on a new discourse often involves both loss and gain. Students might be required to give up something of their familiar ways of communicating and relating to the world[49]. Taking on the new discourse will need to seem worth it.

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[45] See Kieran et al. (2001).

[46] Leach and Scott (2003, p 9) point out that this is a misconception.

[47] Jacobs (2007).

[48] Northedge (2003a).

[49] Gee (2004).

Show me an example…

Kittleson, J. M., and Southerland, S. A. (2004). The role of discourse in group knowledge construction: a case study of engineering students. *Journal of Research in Science Teaching*, **41** (3), 267-293.

Julie Kittleson and Sherry Southerland research what happens in groups of mechanical engineering students who are doing their senior design project. What they had found was that, despite the lecturers attempting to promote collaborative work in student groups, there were very few instances of students grappling collaboratively with concepts. In trying to figure out why this was so they drew on discourse as a thinking tool.

They use a subtle distinction introduced by Gee which reserves the term discourse (with a little 'd') for students' actual use of discourse in stretches of text or calculations. The term Discourse (with a capital 'D') refers more broadly to ways of thinking, valuing, etc. So the observation that students rarely engaged in any negotiation of concepts came from an analysis of their use of little 'd' discourse. To build an explanation as to why this was happening they turned to an analysis of the big 'D' Discourses that seemed to be operating in the situation. Here they uncovered engineering students' views of group work which seemed to focus on using it for maximum efficiency and therefore dividing up work amongst the different group members and not working collaboratively. These Discourses were related to students' views of what it was to be an engineer. They believed that different members of the group had different strengths and so should take on different parts of the task.

Where can I read further to learn more about this tool?

Sfard, A. (2001). There is more to discourse than meets the ears: looking at thinking as communicating to learn more about mathematical learning. *Educational Studies in Mathematics*, **46** (1-3), 13-57.

Discourse analysis is surprisingly difficult to do for those of us who don't have a background in linguistics, but the best way to learn about it, or even to see if you want to pursue it, is to look at real examples of how it has been used. This article is particularly useful in that it presents two examples of classroom discourse and then leads you conversationally through how one could analyse these using an acquisition perspective and then taking a discourse perspective. The setting is a school mathematics classroom, so one can certainly judge transferability to engineering education contexts.

In this paper, Anna Sfard uses her analysis of these two 'episodes' of mathematics learning to spell out key aspects of this perspective on learning. She defines a 'communicational approach' which sees thinking as nothing more than our internal (not necessarily verbal) conversations[50]. By definition this is a process that embeds us in a social context. In helping to explain the meaning of 'discourse' beyond its everyday focus on reading and writing, Sfard provides a helpful description: discourse is 'anything that goes into communication and influences its effectiveness' (p 28). In considering mathematic discourse she notes that its 'mediating tools' are predominantly symbolic and that these are regulated by 'meta-discursive rules' which are often tacit.

This is a lengthy but very rich paper. It will take a long time to read through in one sitting (be warned!) but you will hopefully find it useful to return to various parts of it. It is really a complete manual for doing a relatively accessible and potentially very productive form of discourse analysis in engineering education.

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[50] This derives from the work of the Russian psychologist Vygotsky (1962; 1978).

Concluding comments

In recent times the idea of the 'scholarship of teaching and learning' has come to the fore. Ernest Boyer, who coined the term (1990), put forward a compelling argument around what scholarship in the academy should entail. He suggested that academics might aim to be scholars, not only in the traditional sense of researching in their discipline (what he termed the 'scholarship of discovery'), but also to engage in a 'scholarship of teaching'[51]. A range of definitions have been offered on what it means to be a 'scholar' of one's teaching[52]. These include being an excellent teacher, using the literature on teaching and learning to inform one's teaching, conducting research on the teaching of one's discipline, together with explicit reflection on and communication of one's work to allow for peer review. A significant aspect of this work therefore demands an engagement with education theory. This guide has presented a kit of 'thinking tools' which the scholar can skilfully apply to complex contexts. This has been merely a starting point and of course this kind of journey does not have an end; there is a lifetime of interesting reading and thinking ahead. Enjoy the ride!

If you have any comments or suggestions or other ideas that you wish to share, please contact me at jenni.case@uct.ac.za.

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[51] Subsequently also termed the 'scholarship of teaching and learning' (SOTL). Note here that Boyer proposed a total of four types of scholarship, including the 'scholarship of application' and the 'scholarship of integration'.

[52] (cf. Kreber, 2001).

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