The Centre for
Engineering and Design Education

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

a guide by **Jennifer M. Case**

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Author's biography

Jenni Case is 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.

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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. 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 improving the design of an aeroplane.

The term 'theory' in fact has a range of possible meanings in education research (Hammersley, 2012). Here we want to focus on theory as a set of 'thinking tools' (Mouzelis, 1995), each of which offers a way of looking at the world. The complexity of the social world means that what we have at hand are a range of different tools, each of which simplifies this complex reality along particular lines (Ashwin, 2009). We need to emphasise that not any way of theorising the world is necessarily going to work: the social world is in fact governed by its own mechanisms and thus it is all too easy to land up with what can be called 'chaotic conceptions' (Sayer, 2010) which may appear to make common sense, but which incorrectly represent the relationships that are present in the social world. The theories outlined in this guide are well established positions that have strong conceptual and empirical grounding.

Learning is a complex phenomenon. In what is a huge literature there have been a couple of highly productive ways of theorising learning and which arguably each give us a dimension of a 'recognisable reality'(Parlett and Hamilton, 1977). 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 (Ramsden, 2003). 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 (1951) 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 and even in higher 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, a classic being Cohen et al's *Research Methods in Education* (2000). A recent book focusing specifically on

researching learning in higher education is Cousin's *Researching learning in higher education: An introduction to contemporary methods and approaches*. 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 (Reid, 2006).

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. 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, where possible, 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.

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. Two broad metaphors have been identified which underpin thinking about learning (Sfard, 1998). The first metaphor centres on a notion of learning as the acquisition of knowledge, and the first three tools fit broadly under this heading. (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.) The second metaphor is about learning as participation in a social setting 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)

This famous quote by the psychologist Ausubel directs us towards an investigation of 'what the learner already knows'. How can we think about knowledge and what the learner knows? In working with Tools 1-3 we will be focusing on different theories that have been put forward to help conceptualise learning as the acquisition of knowledge. 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 knowledge. They offer us a means to get to know our students and their engagement with knowledge in order to be able to improve teaching and learning.

TOOL 1: CONCEPTS

What are we talking about here?

In thinking about the learner's existing knowledge in terms of concepts we are focusing on conceptual knowledge as an important dimension of disciplinary knowledge, with concepts as the key organising entities in this knowledge base. 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 (Matthews, 1998). Other terms which have been used instead of 'concept' include conceptual structures, phenomenological primitives, conceptual ecology and mental models (Leach and Scott, 2003). At a basic level, concepts function as categories, thus learning starts with assigning objects to categories, but also significant is getting to understand the relationships between categories. Recognising that in many conceptual areas, learners are not blank slates (see Ausubel quote above), the aim of teaching and learning is thus to change the conceptual structures that a learner has at their disposal, 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. 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).

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. A helpful overview by Glynis Cousin (2006) on threshold concepts was published by the Geographical, Earth and Environmental Sciences (GEES) Subject Centre of the Higher Education Academy. For an exemplar of research in science/engineering using threshold concepts see Park and Light (2009) and Kabo and Baillie (2009).

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) (Saivinainen and Scott, 2002) is a test which can be administered to students both before and after instruction to determine to what extent conceptual change has taken place.

More recently there has been much expansion of 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 (Martin et al, 2003; Fraser et al, 2007) and work on a heat and energy concept inventory is discussed below.

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', researchers started to take an active interest in the wrong answers. This has proved to be a 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 the really key ideas are that students need to focus on.

Show me an example…

Prince, M., Vigeant, M. and Nottis, K. (2012). Development of the heat and energy concept inventory: Preliminary results on the prevalence and persistence of engineering students' misconceptions. *Journal of Engineering Education*, **101** (3), 412-438.

Michael Prince and colleagues note that concept inventories have been popular in engineering education research since they are easy to administer and lend themselves to quantitative analysis. The work reported in this article builds on earlier work in developing a test to assess engineering students' understanding of heat transfer. This test focuses on four specific areas that were identified in previous work as posing challenges for students: 1. Temperature vs. energy, 2. Temperature vs. perceptions of hot and cold, 3. Factors that affect the rate vs. amount of heat transferred and 4. The effect of surface properties on thermal radiation. The goal in developing this instrument was to achieve a high degree of reliability. In this article they outline in detail the steps taken in developing and testing this inventory. The final version of the instrument consists of 36 multiple choice questions, divided into four subscales representing the four conceptual areas outlined above. More than 300 students (at ten institutions) completed the inventory both before and after they received instruction in a course on heat transfer. The analysis of these responses firstly demonstrated the internal reliability of the tool, but also, significantly, showed the persistence of students' misconceptions in the targeted concept areas.

Further recent key studies on conceptual change in engineering education:

Engelbrecht, J., Bergsten, C. and Kågesten, O. (2012). Conceptual and Procedural Approaches to Mathematics in the Engineering Curriculum: Student Conceptions and Performance. *Journal of Engineering Education*, **101** (1), 138-162.

Sahin, M. (2010). The impact of problem-based learning on engineering students' beliefs about physics and conceptual understanding of energy and momentum. *European Journal of Engineering Education*, **35** (5), 519.

Montfort, D., Brown, S. and Pollock, D. (2009). An Investigation of Students' Conceptual Understanding in Related Sophomore to Graduate-Level Engineering and Mechanics Courses. *Journal of Engineering Education*, **98** (2), 111-129.

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

Streveler, R. T., Litzinger, T., Miller, R. and Steif, P. (2008). Learning conceptual knowledge in the engineering sciences: Overview and future research directions. *Journal of Engineering Education*, **97** (3), 279–294.

In this article Ruth Streveler and colleagues provide a very helpful overview of this research field, specifically aimed at the engineering education community. They firstly provide a very helpful and up to date overview of fundamental research in cognitive psychology. Here they touch on the central debate on whether students' naïve conceptual knowledge exists in an organised and coherent structure, or whether it comprises fragmented 'facets'. A further important area for fundamental research is on why some 'misconceptions' prove so resistant to instruction, as mentioned above. A

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particularly useful new line of research suggests that this tends to occur in conceptual areas where causality is not direct but rather emergent; the observed phenomenon is emergent from the underlying processes but not directly causally related. This is the case for many physical phenomena including electrical current, diffusion, and so on.

This article then moves on to survey current applied research which looks to map student conceptual knowledge in particular knowledge domains. There are many different methodologies for approaching this empirical work although the best known for engineering education researchers are the concept inventories mentioned above.

Finally, this article provides detailed and up to date research findings in three conceptual areas of significance to engineering science: mechanics, thermal science, and direct current circuits.

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. The term 'ways of experiencing a phenomenon' comes from a field termed 'phenomenography' (Marton and Booth, 1997); in this text for readability I have used the shortened 'way of experiencing'. Here we are not focusing on the conceptual structures that students have acquired, but learning is rather seen as a relationship between a person and a phenomenon. 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.

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 (for example, see Borrego et al, 2009) 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 often arrived at 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 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 (Pang, 2003). When designing teaching one aims then to include variation, especially in what have been termed 'educationally critical aspects' of the object of study (Linder et al, 2006).

Show me an example…

Thuné, M. and Eckerdal, A. (2009). Variation theory applied to students' conceptions of computer programming. *European Journal of Engineering Education,* **34** (4), 339-347.

Noting that many engineering students find challenges in learning computer programming, this research by Michael Thuné and Anna Eckerdal from Uppsala University set out to find out the variation in students' experiences of learning to program. In this study, fourteen students, at the end of an introductory computer programming course, were interviewed with a semi-structured interview protocol which encouraged them to talk about their experiences from different perspectives. A phenomenographic analysis of the data generated five categories of description, each describing a different way of experiencing learning to program. To give a sense of these categories, the least sophisticated one is only directed towards the actual programming language, while the most sophisticated one sees computer programming as a way of thinking and a mode of solving problems. The authors note that this study builds on earlier seminal work by Shirley Booth (featured below) who conducted a similar study with computer science majors.

A further layer of analysis in this study characterised the dimensions of variation along which these categories vary. This was then used to design a teaching activity which focuses on bringing about variation in the experiences. The article reports on a pilot study which tested out some of these teaching ideas and showed improved understanding by the students who participated.

Further studies to consider:

Carew, A. L. and Mitchell, C. A. (2008). Teaching sustainability as a contested concept: capitalizing on variation in engineering educators' conceptions of environmental, social and economic sustainability. *Journal of Cleaner Production*, **16** (1), 105-115.

Fraser, D. M. and Linder, C. (2009). Teaching in higher education through the use of variation: examples from distillation, physics and process dynamics. *European Journal of Engineering Education*, **34** (4), 369-381.

Zoltowski, C. B., Oakes, W. C. and Cardella, M. E. (2012). Students' Ways of Experiencing Human-Centered Design. *Journal of Engineering Education*, **101** (1), 28-59.

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 phenomenographic research, starting with her PhD on students who were learning to program in a computer science and engineering course (Booth, 1992). She then co-authored a key text, *Learning and Awareness* (Marton and Booth, 1997) 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.

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

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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.

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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. This original research is described in the book *The Experience of Learning*, now in its second edition (Marton et al, 1997). Although out of print this book is currently available free online. The field of phenomenography (described in Tool 2) developed from the original study which identified approaches to learning (Marton and Säljö, 1976).

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 (Ramsden, 2003). 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. 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).

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. Biggs (1999) calls this 'constructive alignment'. This is not as straightforward as one might guess, especially in engineering programmes which have high workloads and 'high stakes' assessment (Case, 2004).

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 (Case and Marshall, 2004). 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 but it has also been argued that simple qualitative studies using student interviews can generate useful contextual results (Case and Marshall, 2009; Tormey, 2013).

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.

Further studies to consider:

Gynnild, V. and Myrhaug, D. (2012). Revisiting approaches to learning in science and engineering: a case study. *European Journal of Engineering Education*, **37** (5), 458.

Jungert, T. (2008). A longitudinal study of engineering students' approaches to their studies. *Higher Education Research & Development*, **27** (3), 201 - 214.

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' (1978) were surprisingly similar to those arising independently from the work by Marton et al mentioned earlier. His writing is practical and highly accessible and a good starting point for anyone wanting to explore this area further. Although now slightly dated, this article is still a classic and thus included here.

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 rethink teaching in higher education.

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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. This can be termed a sociocultural perspective on learning (Cobb and Bowers, 1999). 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 which of course centrally involves engaging with engineering knowledge and knowing.

TOOL 4: COMMUNITY OF PRACTICE*

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 (Wenger, 2000). Students are 'newcomers' to the community and they get inducted by participating in these joint activities. This is termed 'legitimate peripheral participation' (Lave and Wenger, 1991). 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' (Northedge, 2003b). 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 (for a valuable review of the suitability of PBL to engineering education see Perrenet et al, 2000). 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 (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.

*The learning theory that encompasses this thinking tool is called 'situated cognition' (Brown et al, 1989) or 'situated learning' (Lave and Wenger, 1991)

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.

Working together with a colleague Jeff Jawitz, in this article, we 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.

Further studies to consider:

Donath, L., Spray, R., Thompson, N. S. and Alford, E. M. (2005). Characterizing Discourse Among Undergraduate Researchers in an Inquiry-Based Community of Practice. *Journal of Engineering Education*, **94** (4), 403-417.

Pascual, R. (2010). Enhancing project-oriented learning by joining communities of practice and opening spaces for relatedness. *European Journal of Engineering Education*, **35** (1), 3.

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

Johri, A. and Olds, B. M. (2011). Situated engineering learning: Bridging engineering education research and the learning sciences. *Journal of Engineering Education*, **100** (1), 151-185.

The perspective on learning outlined in this tool can also be termed 'situated learning' and in this article Aditya Johri and Barbara Olds provide an extensive overview of the fundamental research in learning sciences that underpins this theory on learning. Here they show how the situative perspective can be traced back to original work by John Dewey but also draws in socio-cultural psychology and activity theory. They write that "a central aim of the situated perspective is to understand learning as situated in a complex web on social organisation rather than as a shift in mental structures of a learner"(p.160).

Following this introduction the article has a very interesting structure. It outlines three key concerns in situated learning: social and material context, activities and interactions, and participation and identity. It then invites expert researchers in each area to provide a commentary based on their current research.

In conclusion they specifically point to productive areas for the incorporation of these perspectives in engineering education. They also outline a number of useful directions for future research.

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. A useful exploration of the disciplinary identities on offer in engineering education is given by 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. 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 (Seymour, 1995). 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 (Woolnough et al, 1997). Some insights have been delivered, but we still seem to 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'" (Gee, 2001). 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…

Tate, E. D. and Linn, M. C. (2005). How does identity shape the experiences of women of color engineering students? *Journal of Science Education and Technology*, **14** (5), 483-493.

Building on literature which shows the limitations of considering race and gender separately, in this article Erika Tate and Marcia Linn consider the experiences of individual women students of color (their choice of terminology as US authors). They focus their work on the multiple identities that students inhabit, based on their memberships of different communities. Three kinds of student identities were identified in this study: academic identity (associated with perceived success in academic activities), social identity (how does society perceive me?) and intellectual identity (related to identification with the career).

The study, based on in-depth interviews with a convenience sample of five students, found that students distinguished between their social and academic peer groups. The women students who were interviewed were found to have strong academic identities and were fully engaged in their studies. They had developing social identities and their intellectual identities as engineers were starting to emerge. In conclusion the study suggests that a positive academic identity provided an 'anchor' for the development of the other identities.

Further key studies on identity in engineering education are:

Jungert, T. (2011). Social identities among engineering students and through their transition to work: a longitudinal study. *Studies in Higher Education*, **38** (1), 39-52.

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.

Stevens, R., O'Connor, K., Garrison, L., Jocuns, A. and Amos, D. (2008). Becoming an engineer: Toward a three dimensional view of engineering learning. *Journal of Engineering Education*, **97** (3), 355-368.

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

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

Allie, S., Armien, M. N., Burgoyne, N., Case, J. M., Collier-Reed, B. I., Craig, T., Deacon, A., Fraser, D. M., Geyer, Z., Jacobs, C., Jawitz, J., Kloot, B., Kotta, L., Langdon, G., le Roux, K., Marshall, D., Mogashana, D., Shaw, C., Sheridan, G. and Wolmarrans, N. (2009). Learning as acquiring a discursive identity through participation in a community: Improving student learning in engineering education. *European Journal for Engineering Education*, **34** (4), 359-367.

This article, written collaboratively by a team of engineering education researchers from the Centre for Research in Engineering Education at the University of Cape Town, draws together theoretical perspectives from across the three 'participation' Tools (4-6) outlined here, to focus on the development of 'discursive identity' as being the central outcome for engineering education. Discursive identity emphasises that students' emerging identities are constituted through the learning of engineering knowledge and practice, here conceptualised as engineering discourse (see Tool 6). What this perspective highlights is that taking on a new identity might not be totally unproblematic for the learner. The work of James Gee (2001) emphasises that students might experience conflicts with the identities they have brought with them from school and the home.

This perspective offers productive insights into how we might best support successful learning in engineering. A necessary requirement is that teaching makes explicit those aspects of the engineering discourse that are usually tacit.

The article closes with three exemplars of researchers in science and engineering who have redesigned courses to more explicitly support students' development of a disciplinary discursive identity.

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 is only part of what we need 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 (Kieran et al, 2001), 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? 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" (Jacobs, 2007). 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 (Northedge, 2003a).

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 (Gee, 2004). Taking on the new discourse will need to seem worth it.

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.

Further studies to consider:

Dunsmore, K., Turns, J. and Yellin, J. M. (2011). Looking Toward the Real World: Student Conceptions of Engineering. *Journal of Engineering Education*, **100** (2), 329-348.

Johnston, S., Lee, A. and McGregor, H. (1996). Engineering as Captive Discourse. *Philosophy and Technology*, **3-4** (1).

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

Airey, J. and Linder, C. (2009). A disciplinary discourse perspective on university science learning: Achieving fluency in a critical constellation of modes. *Journal of Research in Science Teaching*, **46** (1), 27-49.

In this article John Airey and Cedric Linder draw together a number of key perspectives in the literature to develop a notion of 'disciplinary discourse'. To this literature overview they add a significant new insight, which is that students need to become fluent in a 'critical constellation' of different modes of the disciplinary discourse. These modes include oral, visual, activities, tools and mathematics, and ways of relating between these modes. Their research with university physics students shows, firstly, that this fluency in the modes is only achieved with repetition, thus the significance of the practice element in science (and engineering) education at university level. Furthermore, they uncovered instances where students were apparently imitating the disciplinary discourse and only could exhibit fluency in some of the modes, not all of them that are required for the disciplinary way of knowing that the course intends.

The study that is featured in this article draws on interviews with students that asked them to talk about their experiences of learning physics, based specifically on lectures that had recently taken place and of which extracts were replayed to the students during the interview. The article gives a very clear description of how the analysis proceeded, which could be of particular use for engineering education researchers wishing to conduct analyses of students' fluency in disciplinary discourse.

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, put forward a compelling argument around what scholarship in the academy should entail (1990). 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' (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'. A range of definitions have been offered on what it means to be a 'scholar' of one's teaching (Kreber, 2001; Prosser, 2008). 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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