Engineering Knowledge Building: The bridge between research, practice and teaching

Caroline Baillie

Integrated learning centre, Faculty of Applied Sciences, Queens University, Ontario

Introduction

Academic engineers appear to me to have parallel lives. They spend much of their waking hours measuring, modelling, discovering, theorising and debating their ideas with colleagues. This, they call research. They are learning new knowledge about the world they live in. The other part of their job involves teaching the students what they know about that part of the knowledge in their charge. They are helping the students to learn knowledge which is new for them. Learning is in fact the space in which these two, usually conflicting activities should coincide. However, one part of the Academic, the Researcher, believes that knowledge is negotiable and uncertain, to be discovered and rediscovered all their lives and beyond. The other part, the Teacher, appears to believe that knowledge has one truth and that this truth can be taught to willing recipients of this wisdom without negotiation.

Bowden and Marton[1] define learning on the individual level as what happens in the process of study and learning on the collective level as what happens through research. However, they are concerned that there is not enough relationship between these two processes of learning and see that the study of learning processes is now dealt with in separated disciplines from the knowledge to be learnt.

'Through the course of history, questions relating to how knowledge is formed have become separated from different domains of knowledge – of whatever kind.' (Bowden and Marton[1]p285).

For the purpose of this paper we will consider an intimate relation between learning and knowing or becoming knowledgeable about something. It is my belief that enabling engineers to reflect on the knowledge they negotiate and on the process of negotiation itself, they will be able to help students live the spirit of discovery. What students will learn within the University will then be more akin to how to be an engineer, rather than how to pass exams.

Certain educational researchers take the perspective that teachers need to help students think and reflect for themselves (personal constructivism) or that scientific understandings are constructed when individuals engage socially in shared tasks (social constructivism). Some researchers have discovered that both are necessary[2]. There is a lot of agreement across very different educational theories but not very much implementation into practice. There are not many practical suggestions or related training courses for scientific applications of such theories. Neither is there a suggestion that the engineering being discussed can have more than one understanding, or that the engineers need to reflect on their own process of learning the subject matter itself, as well as the process of teaching it to the students. The 'reflective practitioner' is one who thinks about how they teach and continually researches their own practice, it does not usually refer to a reflection in the subject matter itself. That is left to the 'research', even when it is the same person doing both activities. John Cowan[3] suggests that there are several modes of reflection that we can and do engage in but we need to remain conscious of those thoughts and take an active response to our ideas.

There are two steps to the process I am proposing. The first one would be to identify the basic units of knowledge which constitute a particular branch of science/engineering that the student might want to learn in the course of a degree. The second step would be to bring into the undergraduate course some of the important aspects of the knowledge negotiation process, which is learned behaviour of engineers after graduation.

For the first step, we need to discover what key concepts constitute necessary knowledge, the network of simplest units of knowledge within a discipline. It is well known that too much knowledge impedes creative thinking[4] and it is more important to help the students work with ways of exploring the knowledge than by telling them 'all'. But what is this basic unit? Is it a fact? Ravetz[5] (pp. 233-234) tells us that

'The investigation of a problem, (…) is accomplished by the use of tools, applied with tacit craft skills (…). On being submitted to a community, the result is tested, first formally and then informally; and if it shows significance, stability and invariance under changes in its objects, it becomes accepted as fact (…). The particular fact survives only because it is capable of breeding hardy descendants'

It is the testing by the community and the debate of these 'facts', which is so often studied. This paper does not attempt to re-present such analysis but intends to explore the link between the two major activities of a University, that of new scientific factual knowledge production (research) and knowledge sharing (teaching), through 'learning' or 'knowledge negotiation'.

'Facts' or knowledge as 'created' by the researcher can be thought of in three distinct levels. The first level, is that of the 'Effect' which is observed or measured during the course of an experiment. This Effect is then understood by research teams in various ways and 'Phenomena' are developed to explain the Effect. An example of this might be the observation, under a microscope, of a small spherical structure growing within a molten plastic . This would be an 'Effect'. It is understood by the 'Phenomenon', 'crystallisation'. At this level there are many ways of understanding these concepts. Researchers from different disciplines, e.g. chemistry or physics, with different personalities and different cultures will interpret and understand the Effects and related Phenomena in different ways. Each one of these multiple understandings are valid. At this stage the researcher continues to explore, hypothesise and negotiate during conferences and within journal papers etc. Models, formulae, theories and all manner of explanations and rules are developed by the researchers in order to manage the knowledge of these Effects and Phenomena, and in order to use the knowledge. These are knowledge 'Constructs', as they are created by the researcher and they have only one understanding and one meaning. It is possible to hold misconceptions about these. As they were created by one person or a small group of people, who determine how they are to be understood, the 'Objective' nature of the knowledge becomes apparent. In fact this knowledge is the farthest from reality despite being the most reliable and testable and there is one way of understanding it. Effects are the closest to reality and can be understood in many ways.

Vygotsky (1962 in Panofsky et al[6], p.251) proposes that the relationship (of a scientific concept) to an object is mediated from the start by some other concept (…) the very notion of scientific concept implies a certain position in relation to other concepts i.e. a place within a system of concepts

Hence after defining our basic Effects, Phenomena and Constructs we must also consider the relations between them and their influence one on the other.

We confuse students by suggesting, through our manner of teaching, that all knowledge should be treated in the same way, that is: all scientific or engineering knowledge is the same as reality and it can be understood in one way.

Hence the first step is to encourage a community of researchers to reflect within their specialist areas on what are the most important Effects and Phenomena to be learnt by students. They then need to create collectively an 'outcome space' for each, which contains their many different ways of understanding these. The 'outcome space' then becomes the 'fact', which may be explained, labelled and tested, using the many and varied 'Constructs' developed by the different skill sets and perspectives of the researchers from the far corners of the earth.

In this paper, I will present the findings of a study in which I have explored one Phenomenon, the 'Interface' in Composite materials (e.g. Reinforced Plastics), from my own research community of Materials Engineers. I will demonstrate the outcome space of this knowledge concept and show how it has developed and been accepted by the research community itself. This demonstrates the principle explained above and indicates that the same might be done for all areas of research. What follows would be the responsibility of the research community to own their role as the 'Guardians' of the knowledge they discover. At present there is no sense of awareness of this guardianship. The community decides what constitutes acceptable knowledge through peer review of grant applications (for the initial production of knowledge) and of journals and conference papers (for the dissemination of such knowledge) as well as through the text books and courses created for the next generation of scientists. However what constitutes this knowledge' base and the acceptance of the notion of a negotiated knowledge is not explicitly discussed.

The second step involves considering the processes by which learning or knowledge building occurs, through interaction between scholars, ways in which this process is blocked and ways in which we might recognise knowledge building when it happens. In this paper I develop a map or outcome space of experienced ways of knowledge building which can be used to help teachers build up a course in which students learn to negotiate the outcome space of the knowledge through their own way of seeing the world. By this process I hope to encourage the essence of knowledge building whereby the acts of knowing are seen as negotiation and the object of knowledge as negotiated.

The interface

The interface is one of the most important aspects of a reinforced composite material. It is the ‘interface’ which allows for the transfer of stress from the matrix material, to the reinforcing material, so that it can do its job. This sounds very simple in essence. We teach students about ‘interfacial adhesion’ and how we would like the interface to be strong, for composites to have high static strength, as well as fatigue strength. Unfortunately, if the interfacial bonding is too strong, this tends to mean that any deviant crack, will pass straight through the material, breaking fibres as it goes, without the need to meander along a pathway between fibre and matrix, (debonding). If the interface is duly weakened then the crack will happily propagate at 90^o and wander all over the material, absorbing healthy quantities of energy and thus toughening our composite.

What we tend not to mention to students is that within the research area of interfaces in composite materials,there is a constant concern that we don’t know very much and are not getting very far in sorting out this obvious dichotomy.

The present study was originally initiated in order to take a step back and look in a fresh way at the issues facing the interface community. A research specialisation ‘phenomenography’ was selected for this study which aims at revealing the qualitatively different ways in which people make sense of various phenomena in the world around them. Experts in the field were interviewed about their understandings of the phenomenon 'interface’. There were two proposed outcomes intended for this work. The first was to develop the commmunity’s shared understanding of the phenomenon in question. The second, the subject of this paper, is to take the different ways of understanding the phenomenon and make use of this diversity to help students understand the concepts from their own unique perspectives.

Research Methodology

Interviews were conducted with ten selected key researchers of interfaces, from eight different countries. The first author, an interfacial researcher for over thirteen years conducted the interviews, and as such a mutual understanding of the issues discussed were possible. The discussion lasted between 30 – 60 min and questions were posed aiming at exploring their understanding of the interface and current issues and phenomena of relevance to the field. The interviews took place in the laboratories of the interviewees or interviewer, or during international conferences, where the two could meet mid-way between labs. They were semi-structured sessions, with probe questions planned, such as ‘What do you understand by the ‘interface’ in composite materials?’. If the interviewee responded ‘ its bonding between fibre and matrix’, then they were further probed with a question, ‘what , for you, is this ‘bonding’? Often a simple question such as ‘Can you give me the definition of ‘interface?’, would result in a ten minute speech. Causing the interviewee to focus and to specify particular meanings for particular expressions was the main purpose of the session. This way, any assumed knowledge is dispensed with and a mutual understanding of the same terms builds between the interviewer and interviewee.

The manner of interviewing is quite specific in the phenomenographic tradition[1] Marton[7] indicates the style of conversation that takes place:

'interviewing has been the primary method of phenomenographic data collection. What questions are asked and how we ask questions, of course, are highly important aspects of the method. For present purposes it will be suffice to say that we used questions that are as open –ended as possible in order to let the subjects choose the dimensions of the questions they want to answer. The dimensions they choose are an important source of data because they reveal an aspect of the individual's relevance structure. Furthermore, though we have a set of questions at the start of the interview, different interviews may follow somewhat different courses'.

The original method adopted for interviewing is slightly adapted in the current research as the interviewer is also involved in research of interfaces. This means that the dialogue becomes more detailed than is possible when researching more general phenomena. It is expected that the interviewer and interviewee will build an understanding between them. It may in fact be possible for new understandings to be reached for both parties in such a discussion. More usually this will arise from the collation of all interview transcripts.

One aspect of this kind of research which is often questioned is the relatively small numbers of interviews. This is a method which does not rely on statistical reliability of data. It is important that the interviewees from whom the data are collected are appropriate, representing a cross section of views. It is always possible that there may be a unique, unexpressed view which has not been captured. Nevertheless, the purpose of the research is not to state categorically that these are the only views, but only that they represent the most common ways of experiencing the phenomena. Additionally it is important to note that the 'ways' expressed are not meant to be 'the way' that the interviewees understand. When they express a way they indicate that they are capable of doing so, on this occasion, in this situation. Hence several different ways of understanding are possible for the same person. To be aware of this range of ways of seeing the phenomena will already be a large step towards the aims of the study. To ensure as wide a range of views as possible, interviewees were selected who were key personnel within their country and would thus know of most ways of thinking in their own community. A wide range of continents were selected, and professional backgrounds (physics, materials science, chemistry, chemical and mechanical engineering and manufacturing)

The way the interviews are analysed is explained by Bowden et al[8]

'All interviews were transcribed and the transcripts subjected to rigorous phenomenographic analysis. This involved one member of the research team taking responsibility for reading all transcripts related to a given question and devising a draft set of categories of description drawn from the transcripts. ..an iterative process was used to produce final descriptions …'

The categories are not determined beforehand as in classic content analysis but are developed from the data and tested against it. The way in which the categories of description relate to one another forms the 'outcome space'. A limited set of ordered categories are found which depict the space of possible (represented by the key researchers explored in the present community) meanings of interface. This space is structured through 'dimensions of variation' which present ways in which understandings vary.

Results – Dimensions of variation

Dimension 1 Scale focus • Focus on one scale level without reference to the need to consider other scale levels • Focus on the issue of scale itself and the necessity to work at different scales • Focus on the relation between scales Dimension 2 Focus • Interface is described in terms of a modified fibre or a modified matrix • Interface is described in terms of the sum of or difference between matrix and fibre • Interface is described as more than the sum of the parts, e.g. a new material Dimension 3 Concept and Object • Interface is an object e.g. interphase with four or five layers • Interface is a concept which can be measured by association with measurable objects e.g. chemical bonds as a measure of 'interfacial adhesion', strain in the fibre as a measure of 'stress transfer efficiency'. Interfacial properties are often defined in terms of the testing method. • Interface is a concept which cannot be measured because the object is not well defined e.g. it is referred to in terms of cracking, but the crack does not run along one boundary • Interface is a concept which is transferable to other contexts e.g. in nature • Interface is a concept e.g. it may not exist, or it may be expressed indirectly as having quality Dimension 4 Value and Purpose • Value of the interface is related to purpose of the interface and technical application of the composite via the interface itself e.g. there is no point measuring the properties of the interface or knowing what it is to do, without knowing the conditions which the composite material will be subjected to. • Value of the interface is related to the purpose of the interface and technical application via the composite as a whole and the particular composite system, e.g. the interface properties are directly related to the composite properties which in turn influence the conditions of use of the material. • Value of the interface is related to the purpose of the interface with no consideration of technical application e.g. determining the 'strength' of the interface which is required to transfer stress, for the sake of the development of knowledge in materials science, with no application.

Table 1 Dimensions of variation of ways of understanding the 'interface'

Four dimensions of variation were found and these are given in Table 1.

Discussing the Dimensions

In order to understand the complexity of the above descriptions, we need to imagine an outcome space which has four directions of reference as shown below in Figure. 1. A relationship exists between the four directions, between the dimensions of variation, and each researcher may then expect to hold a view or several views which lie somewhere on this outcome space.

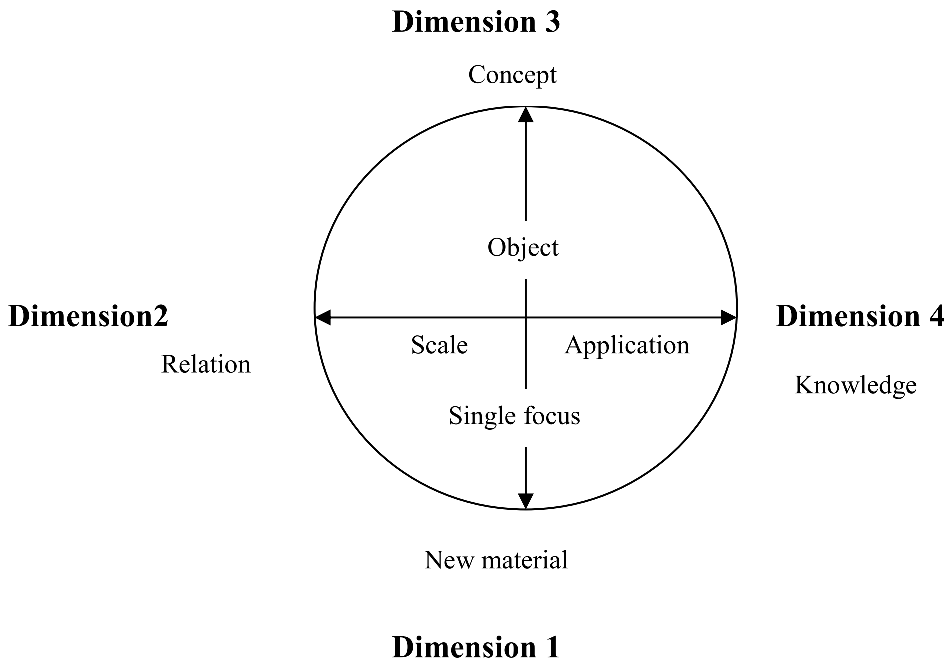

Figure 1 Outcome space for Interface described by four dimensions of variation

Dimension 1 ranges between seeing the interface through one **single focus** of fibre or matrix, to viewing the interface as a **new material**.

Dimension 2 ranges between seeing the interface through one **scale** level to focusing on the need to see the scales in **relation**ship to one another.

Dimension 3 ranges between seeing the interface as an **object** with specific properties to seeing the interface as an elusive **concept** but to which parallels can be made in all areas.

Dimension of variation 4 ranges between work carried out for a particular **application** to that work carried out for materials **knowledge** development.

LINKING DIMENSIONS OF VARIATION TO MODELS OF LEARNING AND TEACHING

In exploring the potential use of this outcome space, we need to reflect on what we mean by teaching and what of learning. Olsen and Bruner[9] building on the work of Tomasello et al[10] suggest that we can distinguish four models of learner's minds that are held by theorists, educators, and children, in their 'Folk Pedagogy' or inherent beliefs about teaching and learning. In order to place the current study in a useable framework, and make reference to more traditional approaches to teaching, these models will now be applied to the present situation, that of adult learners, learning about the interface (all quotations taken from Olsen and Bruner[9]).

1. Seeing Learners as Doers: The Acquisition of Know-How
'When an adult deliberately provides a demonstration or a model of a successful or a skillful action, that demonstration is premised on the adult's belief that the learner does not know how to do x, and on the further assumption that the children can learn x by being shown'

2.Seeing Learners as Knowers: The Acquisition of Propositional Knowledge
This is the basis of belief in didactic teaching, that 'pupils should be presented with facts, principles and rules of action that are to be learned, remembered and then applied. This pedagogy assumes a certain theory of mind – namely that the learner 'does not know that p' that he or she is ignorant or innocent of certain facts, rules or principles that can be conveyed by telling. What is to be learned by the pupil is conceived of as in the minds of teachers as well as in books…'

3.Seeing Learners as Thinkers: The Development of Intersubjective interchange
The teacher, according to this view, is concerned with understanding what children think and how they arrived at what they believe…Pedagogy is thought of as helping children understand better, more powerfully, more relevantly with respect to their other interests..their understanding is fostered through discussion and collaboration'

4.Learners as Knowledgeable: The Management of 'Objective' Knowledge
'What this fourth perspective offers is a way for learners to grasp the distinction between personal knowledge, on the one side, and what is taken to be known by the culture on the other. Not only to grasp the distinction but to understand its basis, as it were, in the history of knowledge. …..we can ask how that conjecture got settled into something more solid over the years – what are the reasons for that belief…The child is seen as possessing beliefs and theories that are formed and revised on the basis of evidence: Pedagogy is a matter of assisting them in evaluating their beliefs'.

In the first case, the student learning about the interface, will be faced with the lecturer, who knows that 'becoming an engineer requires more than knowing the theory' and demonstrates ways of testing the strength of an interface. All engineering degrees will include some aspects of models 1 and 2. Most lecturers will agree that you have to 'know how' to be an engineer as well as having knowledge about scientific facts. This often takes the form of practical classes whereby the student will follow recipe like instructions and mimic the techniques of the lab 'demonstrator'. The second model forms the larger part of the traditional engineering lecture ethos where it is assumed that the lecturer can take their 'knowledge' about the interface, from inside their head and give it to the student, by telling it to them.

The final two categories represent more useful models of teaching and learning. From the studies which concern themselves with the learner's perspective, as model 3, we have come to understand how we must provide an environment conducive of a 'deep' approach to learning [7]. Relating to model 4, we can see that helping students see that there are many ways of understanding the 'interface', will improve the students appreciation of the interface. If students are asked to explain what they understand by this phenomenon, and this is shared and discussed, it is expected that they will form a deeper understanding of what an interface is, as well as relating it to their own experiences. What students learn and what engineers 'know' are conceptualised as 'ways of seeing' and it is assumed that every way of seeing contributes to our collective understanding of any phenomenon [1].

Bowden and Marton[1] go further to discuss the 'phenomenographic' way of understanding teaching and learning as presented in this paper. Not only do they consider the model of the learner's mind and the relationship with the knowledge but they consider a non-dualistic model. 'A phenomenographic way of looking at learning involves a non dualistic ontology, a relational position. ..We do not see subject and object, person and world, and experience and experienced as separate. We see them intertwined …Reality is, in our view, *constituted* through the mutual and intertwined emergence of humans and their world' [1].

Learning means ' not so much replacing one view of a phenomenon with another, more correct one, but a widening of the space of different views available to the individual…. When assisting other people to develop new insights about the world, the best thing we can do is to learn about their way of thinking..'[1]

The 'ways of understandings' developed in this study are somewhat hierarchical in that, certain ways are seen as inclusive of others. e.g. we might suggest that understanding the interface as a new material is inclusive of understanding it as a modified fibre, because the first way contains the second. Now learning can be related to a direction. It is about gaining more complete, more inclusive ways of understanding. Furthermore, teaching is about opening up for variation in the critical aspects and exposing students to variations in these aspects. Without variation they can't discern anything.

In this study we ask established experts in the field to readdress the basic building blocks of the engineering 'knowledge' that underlies the formation of current ways of thinking about the 'interface'. These ways are made explicit and then represented as a continuum or Dimension of a way of thinking. In this way the students enter the minds of the scientists past and present, as much as the scientist/lecturer enters the minds of the student.

In the next stage of this work, we might exemplify a teaching / learning approach by the following exercise: students will be presented with the above Dimensions, together with the extracts from transcripts which exemplify each case. They will be asked to discuss the apparent conception of the interface held within a series of published papers. They will be asked to critique the papers in a very different manner to any previous approach. Students will then present their critiques to one another for discussion.

During the1999 IPCM[11](Interfacial Phenomena in Composite Materials) conference the data above was presented in a more complete form as technical data representing interfacial categories. The intention was to contribute to the research community knowledge about the interface as opposed to knowledge about teaching the interface. The paper was well accepted and intrigued researchers commented in the days after this presentation

'This paper has made the most impact in this conference'
'It was good watching other's reactions'
Several were overheard asking the question
'Where are you on the diagram?'

On one occasion this was met by a stony silence to which the questioner responded
'You're obviously a point in the middle'
Several started a discussion on how this approach could be applied to any object of study and in fact asked of each other
'Is a fibre a concept or an object? Can this be applied to other things like a chair? Is a chair a concept or an object?'

If it is possible to induce the researchers themselves to question their own notions of knowledge and make explicit to them that their assumed knowledge is in fact not mutual within the community, it does indeed seem probable that students can enter into similar discussions, with the benefit of reaching into the minds of the collective interfacial research community.

It is obvious that all researchers cannot conduct such studies into their own fields, in order to generate such a 'Collective Consciousness' for their students. However, it is anticipated that lecturers and students alike would profit from text books which explore the subject matter from this very different perspective and to offer multiple views on scientific 'facts'. They could present the pathway of discovery of those understandings, rather than a traditional presentation of a 'fait accompli' and aim for a negotiated 'objective' knowledge

At the Integrated learning Centre of the Faculty of Applied Science, Queens University, Ontario, I have been applying some of these ideas to my training of Engineering Faculty. We have been exploring first year concepts and the variation of understanding of these concepts. In workshops, we have considered ' energy', 'force', 'equilibrium' etc. and it has been surprising to the faculty to see how many different and yet valid descriptions arise. We have then gone on to explore how this can help students broaden their base of possible conceptions, thus deepening their understanding of the concepts and revealing misconceptions. Students may find one description in a text that is different from their lecture notes. This approach will relieve that confusion. Through the training workshops we are hoping that many faculty will take up these ideas and build them into existing courses. This paper is intended to induce further consideration and discussion of the application of the notion of knowledge building within engineering education, as the link between research, practice and teaching.

Acknowledgements

I would like to thank the interviewees for their time and patience, Ference Marton, Jonas Emanuelsson and the Dept. of Education and Educational Research, Gothenburg University, The Trecentenary Foundation of the Bank of Sweden and the 'AGORA' project Wissenschaftskolleg, Berlin, for supporting this study.
Bibliography

1..J.Bowden, and F.Marton., *The University of Learning* Kogan Page, (1998)
2.Driver, Rosalind/Asoko, Hilary/ Leach, John/ Mortimer, Eduardo/ Scott, Philip, (1994) "Constructing Scientific Knowledge in the Classroom", *Educational Researcher*, **23**, Issue 7, pp.5-12
3.JohnCowan *Beyond reflection where next for curricula which concentrate on capabilityin Baillie and Moore* (Eds) (2003) Effective learning and teaching in engineering, Routledge
4.Dewulf, Simon/ Baillie, Caroline, (1999) *CASE: Creativity in Art, Science and Engineering. How to foster creativity,* London:Imperial College
5.Ravetz, Jerome (1996), *Scientific knowledge and its social problems*, New Brunswick,

6.Panofsky, Carolyn/John Stenier, Vera/ Blackwell, Peggy (1994), “The development of scientific concepts and discourse”, in: Vygotsky and Education: Moll, Luis (ed), *Instructional implications and applications of sociohistorical psychology*, pp.251-267
7.F.Marton, Phenomenography – a research approach to investigating different understandings of reality. *Journal of thought*; **21** (3) 42 (1992)
8.J.Bowden, G.Dall’Alba, D.Laurillard, E.Martin, F.Marton, G.Masters, P.Ramsden, A.Stephanou, E.Walsh, Displacement, velocity and frames of reference: Phenomenographic studies of students’ understanding and some implications for teaching. *American Journal Physics* **60** : 263 (1992)
9.D.Olsen, and J.Bruner, Folk Psychology and Folk Pedagogy *in The Handbook of Education and Human Development* Ed D.Olsen, N.Torrance, Blackwell (1998) Pages 9-27
10.M.Tomasello, A.Kruger, H.Ratner, Cultural Learning. : *Behavioural and Brain Sciences* **16**(3) 495-511 (1993)
11Baillie, C., presentation at Interfacial Phenomena in Composite Materials, 1999, Berlin

Biography

CAROLINE BAILLIE

Caroline is the Dupont Canada Chair of Engineering Education Research and Development at Queens University, Kingston, Ontario. Before moving to Canada Caroline was Senior Lecturer in Engineering and the Deputy Director of the UK Centre for Materials Education (UKCME) based in Liverpool – part of the national HEFCE funded Learning and Teaching Support Network whilst on study leave from Imperial College London.