The competence dilemma in engineering education: Moving beyond simple graduate attribute mapping *

J Walther † and DF Radcliffe
The University of Queensland, Brisbane

SUMMARY: *A decade ago, major reviews of engineering education in Australia and the USA resulted in a new, outcomes-based approach to program accreditation in engineering. These outcomes are based on a set of Graduate Attributes derived to meet the perceived needs of industry into the future. However, recent reports suggest that engineering graduates may not have the competencies required for contemporary practice, even though program outcomes have been designed to meet the stated needs of industry. This observable gap between education and practice points to a set of underlying causes that we call the competence dilemma in engineering education. This paper reviews the fundamental assumptions on which outcomes-based education is built, in a way that was not considered at the time of the earlier changes to program accreditation. It also critically examines the nature of this perceptual gap between the Graduate Attributes that universities are striving to produce in their graduates and the competencies needed in practice in order to perform satisfactorily in industry. This entails the inclusion of the students' attitudes and self-concept in the conception of professional competence. This analysis of this competence dilemma suggests a more holistic view of competence formation. On this basis, the paper presents the results of an exploratory study into identifying alternative ways in which students' competence is formed and influenced in education. The analysis of the empirical study leads to a multi-scale systems model of engineering competence, where the attitudes and self-image are located on a meta-level, and organise and contextualise the individual's particular set of competencies in a specific work situation. At a time when authorities in both countries are reviewing the operation and success of outcome based education in engineering, this paper points to an evidence-based way forward to address the competence dilemma.*

1 INTRODUCTION

Since the early 1990s, engineering education has seen a significant paradigm shift from what was previously an input, content and process orientation towards a system based on educational outcomes. Prominent examples for this development in the context of the drastic social, economic and technological changes are both the 1994 ASEE report "Engineering Education for a Changing World" (ASEE, 1994) and Engineers Australia's 1996 review "Changing the Culture: Engineering Education into the Future" (Engineers Australia, 1996). These reports led to the development of ABET's Program Outcomes (ABET, 1995; 2004) in the US and the Australian Graduate Attributes (Engineers Australia, 2005), respectively. Both systems of educational outcomes brought two fundamental changes in engineering education. Firstly, this development changed the underlying instructional principle of engineering education. More specifically, the aspirational attributes postulated in the respective reports were turned into binding outcomes of the educational process. In the paradigm of outcomes-based education, the teacher selects and delivers specific learning activities which can be mapped to the achievement of defined attributes or competencies – we call this targeted instruction (Walther et al, 2006b). Secondly, the scope of education was extended to encompass the broader aspects of engineering practice, such as cultural and social awareness (eg. Graduate Attribute vii in Engineers Australia, 2005), and an explicit commitment to the preparation of students for current professional practice (Engineers Australia, 1996). This trend of reclaiming the preparation of students for professional practice was recently confirmed in an editorial for the

* Reviewed paper originally presented at the AaeE 2006 Conference, Auckland University of Technology, 10-13 December.

† Corresponding author Joachim Walther can be contacted at j.walther@uq.edu.au.

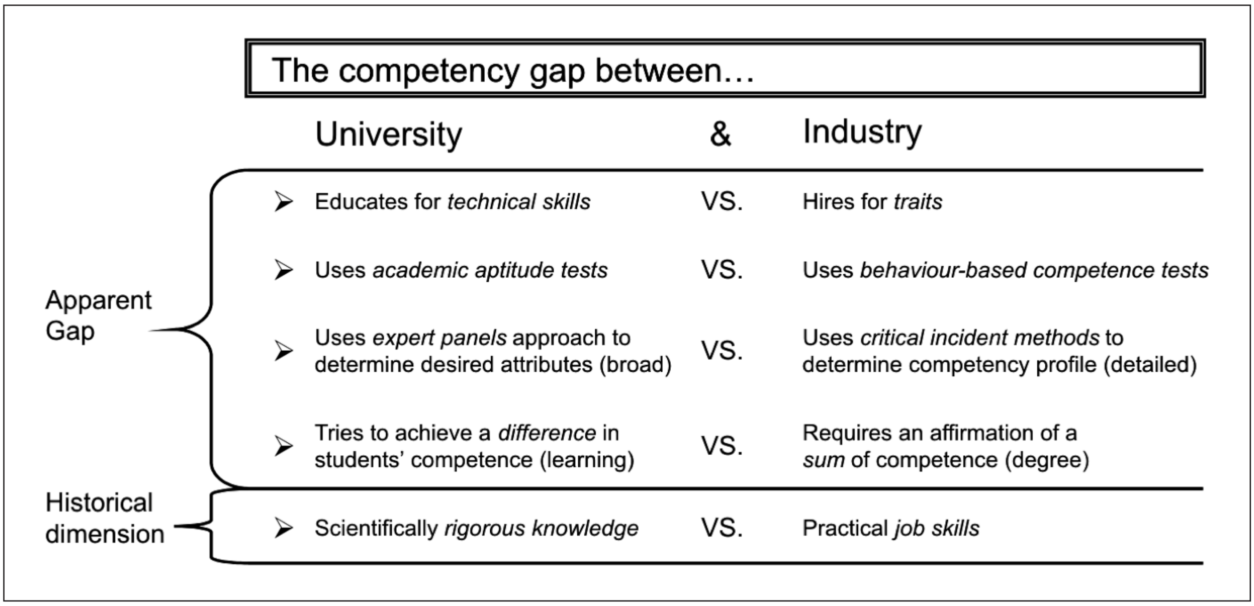

Figure 1: Aspects of the competency gap between university and industry.

European Journal of Engineering Education. In this article, Denis Lemaitre (2006) expresses the view that the preparation "of students for professional competence has always been the ultimate goal of engineering curricula" (pp. 45).

However, several authors indicate that engineering education still falls short of the goal of preparing students adequately for professional practice. A recent report of the Business Council of Australia (BCA, 2006), an organisation representing the leading 100 corporations in Australia, claims that engineering graduates have deficiencies with respect to crucial job skills such as "problem-solving, communication or entrepreneurship" (pp. 14). With respect to the situation in the US, Wulff (2002) observes that "many of the students who make it to graduation enter the workforce ill-equipped for the complex interactions … of real world engineering systems" (pp. 35). These are indications that industry requires a more adequate preparation of graduates for the job tasks of real-world engineering. Conversely, "much of the energy in teaching and learning in universities is still focused on developing the observable skills and knowledge dimension" (Radcliffe, 2005), rather than the less easily observable attributes required by industry. This disconnectedness shows that the concept of outcomes-based education in today's application to engineering education has not been able to fully prepare students for the changing demands of professional practice and also that broader aspects of competence have not found their way into the wider practice of education.

This problem is not simply an issue of the quality of instructional design and teaching delivery. This paper shows that the roots of the problem lie at a more fundamental level, which we call the competency dilemma in engineering education. On the basis of a theoretical analysis, results of research into alternative forms of competency acquisition suggest a more holistic view of competence. As a result of the empirical study, a multi-scale systems model of engineering competence is proposed. Finally the usefulness of this systems model of learning and competence in overcoming the described dilemma is discussed.

2 THE COMPETENCY GAP BETWEEN ENGINEERING UNIVERSITIES AND INDUSTRY

The disconnectedness described above manifests itself in a competency gap between university and industry. Figure 1 illustrates the various dimensions of the competency gap.

Industry expects graduates to have the skills and knowledge specified in the learning outcomes (ABET, 1995; Engineers Australia, 2005). Accordingly, teaching at universities largely focuses on developing skills and knowledge in students. Even the broader social dimensions of the Graduate Attributes are traditionally approached through course content or even isolated in one particular course (Radcliffe, 2005). This focus on the domain of knowledge and skills does not take into account the competency dimension of traits, motives and self-concept. However, this dimension of the personality is seen as crucial in current competency research (Spencer et al, 1993; McClelland, 1998). Competence is conceptualised as an iceberg where the skill and knowledge domain form the tip, visible above the waterline, and traits, self-conception and motives make up the base of human competence (Spencer et al, 1993). More specifically, this means that these person variables were identified as a far more reliable predictors of long-term job performance (McClelland, 1973; Spencer et al, 1993; McClelland, 1998).

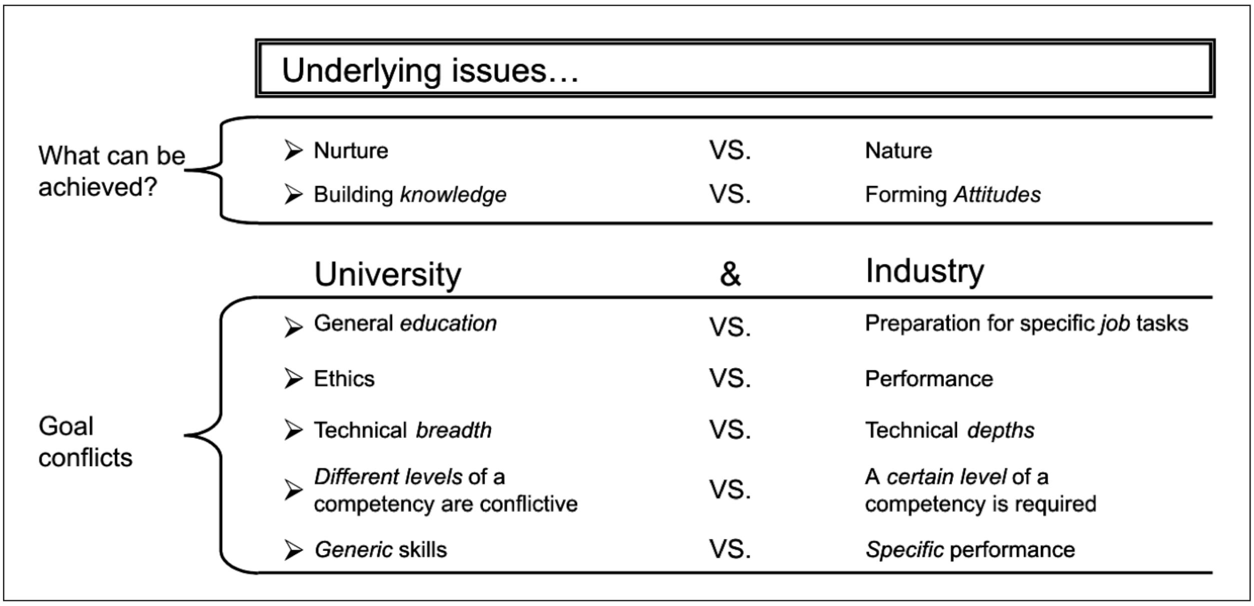

Figure 2: Underlying causes of the competency dilemma in engineering education.

Accordingly, companies tend to focus on the person variables when recruiting graduate engineers. This method of behaviour-based competency assessment with a predominant focus on the parts of the "competency iceberg below the water line" differs significantly from assessment methods employed in education. At university, students generally experience a range of traditional academic aptitude tests, such as exams, which focus on knowledge and skills. Radcliffe (2005) identifies this "Graduate Attribute Paradox" as the reason why the attempt of "developing graduates with those attributes stated by industry may not result in the type of engineer that industry requires" (pp. 197).

This difference between university and industry is also reflected in the respective practices of determining competency requirements. The Graduate Attributes were developed, with considerable input from industry, using an expert panel approach. This approach specified broad aspirational goals that point out a general direction for engineering education. However, in everyday practice of determining specific competency requirements in industry, expert panel methods have been shown to "only moderately agree with the competencies shown to be important by the data from behavioural event interviews" (McClelland, 1998). In contrast to the very general definition of the graduate attributes, competency studies in industry use critical incident techniques and arrive at very detailed competency profiles specific to a particular position in the organisation (Leiper et al, 1999; Rifkin et al, 1999; Robinson et al, 2005; Yang et al, 2005).

This discrepancy in methods of deriving competency requirements and their outcome also points to the fundamental difference in the function of the respective competency profiles. At university the Graduate Attributes serve as a future goal and the purpose ideally is to achieve a positive difference in students' competence through education. This is quite different from the view of industry. From this perspective it is of no concern how or even whether a difference in competence was achieved. Only the certification of a sum of competencies in the form of an engineering degree is required.

This aspect also connects with a historical or epistemological difference in the perception of competence between university and professional practice. Schön (1995) describes the historical development at the beginning of the last century when professional disciplines, such as engineering, were incorporated into research universities. In order to comply with the traditional standards of scientifically rigorous knowledge, the discipline had to explicitly separate itself from the ambiguous problems and inexact practices of professional engineering. This resulted in the fact that practical job skills, which are seen by some authors to be the heart of engineering (BCA, 2006; Spinks et al, 2006; The Royal Academy of Engineering, 2006), are still not considered as fundamental knowledge in today's universities.

3 UNDERLYING CAUSES AND GOAL CONFLICTS

In practice, the competency gap mainly emerges from two underlying causes (figure 2). Firstly, there is the question as to what is in principle possible in education. And secondly, there are a number of goal conflicts that arise from the necessity of preparing students in a general engineering course for very specific job tasks in a wide range of possible career paths and roles (Spinks et al, 2006).

Even though the specified learning outcomes are predominantly concerned with skills and knowledge, some aspects clearly concern deeper personal variables of traits self-concepts and motives. When considering the graduate attributes concerning ethical and social awareness it is evident that this can not be taught on the level of factual knowledge (Radcliffe, 2005). It is even disputed whether traits and attitudes such as these can generally be influenced in education. However, McClelland (1973) points out that contrary to common belief this level of the personality is not immutable – "there is no solid evidence that … any human trait cannot be changed by training or experience" (pp. 8). Even though the contribution of traits and motives to engineering competence is now being acknowledged in some areas of engineering (ASCE, 2004). The American Society of Civil Engineers also acknowledges that teaching with traditional means proves problematic: The report speaks of the facts that "relative to attitudes, knowledge and skills are typically more comfortably and frequently discussed by engineers" (pp. 31). This results in a "lack of focused attitude teaching and learning efforts in universities" (pp. 35). The concept of Accidental Competency formation discussed in the later section suggests that attitudes are in fact influenced and formed unintentionally in the context of traditional building of knowledge.

Engineering as a profession is becoming increasingly diverse with a wide range of career paths and engineering roles. Thus, engineering educators are challenged to prepare their students for this diversity of competency demands. This results in the goal conflict of general education versus the preparation for specific job tasks that can be analysed in a number of dimensions (figure 2).

The Henley Report for the Royal Academy of Engineering (Spinks et al, 2006) comes to the conclusion that the future roles of engineering graduates range from technical specialist to the engineer as a transdisciplinary integrator or to engineers in the role of creative change agents who shape the future of engineering industry. This poses the question of whether to equip students with a broad (and arguably shallow) knowledge base in many domains, or prepare them for specific job tasks and a contribution in a narrow subject area (technical depth). The two extremes each show distinct disadvantages. Defining very specific competency requirements (see industry view as described above) leads to an increasing inflexibility of future graduates. Thorstein Veblen (1918) stated at the beginning of the last century that specialisation in education "widens the candidate's field of ignorance, while it intensifies his effectiveness within his speciality" (pp. 152). However, a broad knowledge base does not qualify engineering graduates for the highly technical tasks of certain jobs. Similar difficulties result when implementing the competency goals in outcomes-based education: Specific requirements "loose sight of the forest of skilled competence for the trees of perfected performance" (Bruner, 1971, pp. 13). On the other hand Miles (2003) observes that learning objectives or competencies are often "too broadly framed", which makes them "impossible to implement" (pp. 73).

Outside the domain of traditional engineering knowledge, the goals of general education and the specific performance requirements of industry can be especially opposing. Many engineering educators advocate the inclusion of elements of liberal education into engineering programs in order to support students' acquisition of the social and ethical awareness specified in the Graduate Attributes. However, it can be questioned if such an inclusion contributes to specific performance in the workplace. At the same time, it might seem to put even more strain on an already overfull curricula and thus further escalate the struggle between the aims of technical breadth or specific education.

Another problem that is commonly overlooked in the application of competence-based education is the requirement of different levels of a competency in different contexts (Spencer et al, 1993). With a number of competencies, especially on the attitudinal level, it is not the case that the graduate will be more successful in the workplace the more of this competence she acquires. Different job situations require different levels of a competency as a basis for performance. To illustrate this, we might consider a competence such as an engineer's attitude towards risk. Whereas one particular job might require a risk-tolerant person, a risk-seeker, another situation might require a risk-averse attitude to ensure success (Hillson et al, 2005). However, as learning outcomes, these two extreme levels of risk attitude are incompatible.

As a way out of these contradictions, generic, key or meta competencies have been frequently suggested (Scott et al, 2002; Male et al, 2005; The Royal Academy of Engineering, 2006). A key competence is defined as "a central competence which could be applied to solve different problems in different situational contexts"(Weinert, 1999). However, key competencies are sometimes disputed as to their validity as a psychological concept. Weinert also shows that key of generic competencies are difficult to "implement pedagogically" (pp. 12), since such skills would always be embedded in the learning context. Finally, even if they could "be acquired through planned instructional programs" (pp. 12) their contribution to specific performance is very limited.

4 CONSEQUENCES OF THE COMPETENCY DILEMMA IN ENGINEERING EDUCATION

The above analysis shows that introducing of outcomes-based education in engineering broadens the responsibility of engineering educators

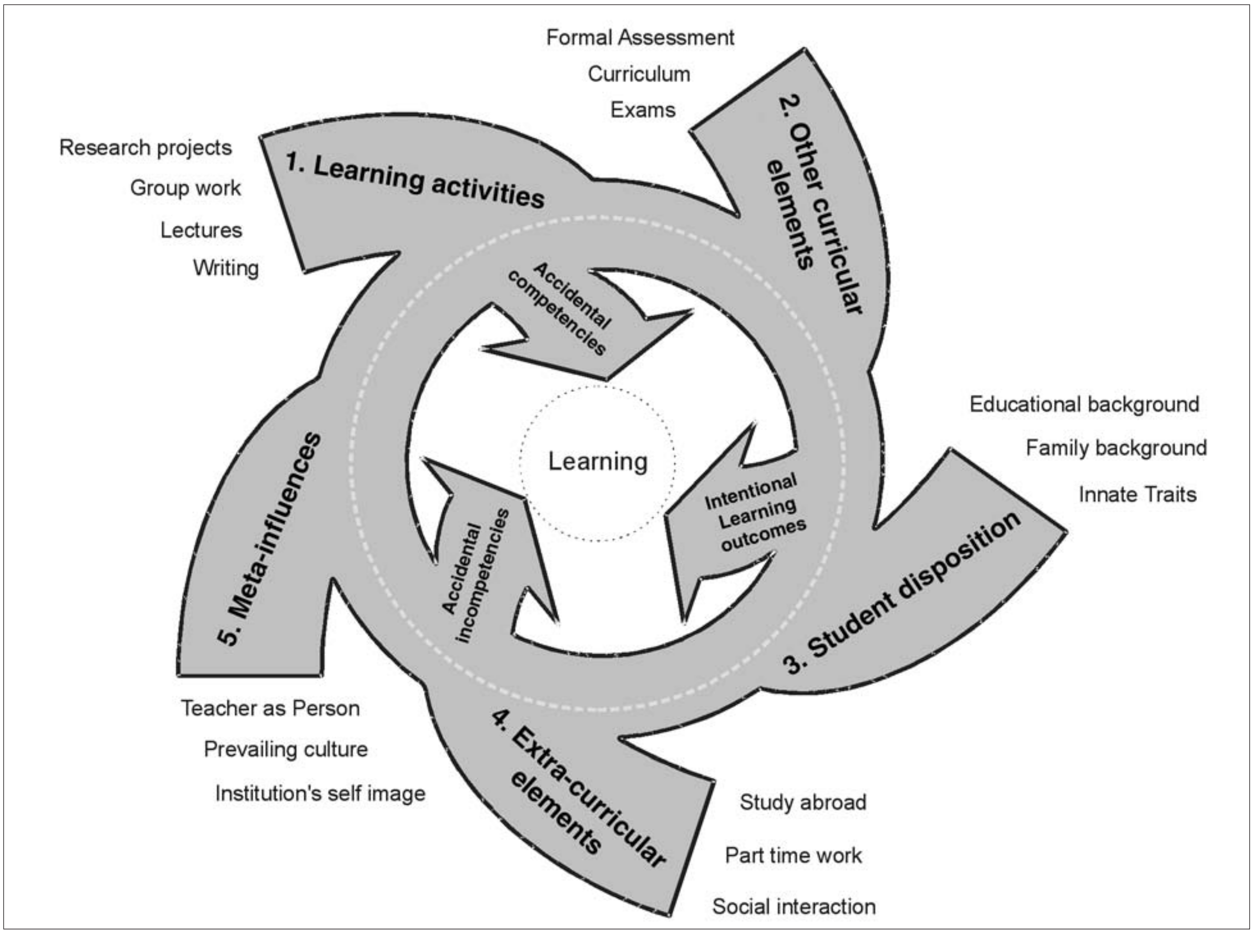

Figure 3: The Spiral Model of competency formation.

considerably. Firstly, this means that learning outcomes become binding deliverables of the education process. Secondly, engineering education assumes the responsibility for preparing students for professional competence. Thirdly, the definition of the learning outcomes suggests that a more holistic understanding of engineering competence is needed, which explicitly includes the level of attitudes and traits. The extent to which attitudes are the concern of education is determined by the definition of professional competence, since this is the declared goal of education. The Graduate Attributes speak of students' ethical and social awareness of the implications of engineering work. An OECD project on human competence, however, suggests an even broader model of competence that extends to attributes "for a successful life and a well-functioning society" (Salganik et al, 2003). With this range of holistic conceptions of competence, the instructional approach in engineering education ironically fragments learning into narrowly defined learning activities (Walther et al, 2006b) and also breaks up the understanding of competence into a list of desired attributes. This discrepancy has the consequence that the problems described cannot be approached in the current instructional paradigm since available strategies, such as key or meta competencies, prove to be of limited usefulness. In order to investigate this discrepancy the following section presents research into holistic understanding of learning, which also points to a holistic conceptual view of competence.

5 THE SPIRAL MODEL OF ACCIDENTAL COMPETENCY ACQUISITION

The concept of Accidental Competency views competence acquisition holistically as a complex system (Walther et al, 2006a). This complex systems view depicted in the contextual model of Accidental Competencies (figure 3) is based on the results of a preliminary enquiry that we previously reported (Walther et al, 2006b). Accidental Competencies are abilities important to performance in professional practices that are not linked to targeted instruction of the stated learning outcomes of the course. Engineering students acquire these competencies through the complex interaction of traditional forms of learning and other elements surrounding the formal educational process.

The outer circle contains different clusters of the elements that constitute the complex system of education and thus contribute to the formation of students' competencies. The elements of the traditional concept of targeted instruction are grouped in the category of learning activities (category 1), comprising lectures, group work or research projects. The cluster of general curricular elements (category 2) contains formal assessment procedures or other regulatory curricular elements. The student disposition (category 3) is concerned with the individual student on a personal level. Factors like innate traits or the educational background can have a significant impact on how the other elements interact to form competency. The student's disposition accounts for their extracurricular activities (category 4), but can also strongly influence how the learning activities themselves (category 1) are received and lead to competency formation. The fifth category of meta-influences includes elements such as the culture or self-image of the institution, but, on a more specific level, also the teacher as a role-model. In the complex systems view of competence formation, all elements of these categories potentially interact on several levels (indicated by the arrows in figure 3) and lead to intentional learning outcomes through formal learning processes, but also to Accidental Competencies and Incompetencies.

6 AN EMPIRICAL STUDY OF ACCIDENTAL COMPETENCIES

In order to investigate the problematic competency gap between university and industry, this paper draws on a pilot empirical study on Accidental Competency acquisition that we have previously reported (Walther et al, 2006b). From the set of critical incidents collected in this study, two examples are presented in the following section in the form of illustrative quotes. The analysis is intended to foster a deeper understanding of this holistic model of learning beyond the contextual model presented in figure 3.

6.1 Critical Incident 1 (from the transcript of an individual interview)

> *"I studied engineering because I have always had the urge to shape my environment around me so that it would be pleasant. Then I came to university and there were bleak buildings with no personalised or pleasant space. For academics, it was obviously enough to select another desktop background for their computer now and then. I thought engineering was about shaping a pleasant environment for yourself and others. At that point I asked myself: is everyone here so different that they do not need that?"*

This quote illustrates how the prevailing culture at an institution influences students' competence on the attitudinal level. The American Society of Civil Engineers refers to this effect as the "teaching and learning of undesirable attitudes to the detriment of all" (ASCE, 2004). Correspondingly, the respondent describes how his study environment had a negative influence on his self-perception or self-efficacy as an engineer. (Ponton (2001) has identified this aspect as a crucial element in the development of engineering competence.)

The respondent explains how he perceived engineering as a creative role that is aimed at the shaping the technological environment in a social way. However, the study environment at the institution contrasted with this view and the respondent reports his difficulties of reconciling these perspectives. Accordingly, this influenced the respondent's development of his professional identity. He commented on the fact that later during his professional life he was sometimes left with insecurity as to how to view his engineering role.

6.2 Critical Incident 2 (from the transcript of a focus group discussion)

> *"During my degree, I gave up asking questions. It just was not encouraged. Today, when I work on interdisciplinary projects, I have encountered situations where it would have been better if I had asked."*

This example also illustrates the development of an Accidental Incompetency on the attitudinal level – the inability to use appropriate ways to access information in a complex socio-technical working environment (Compare "Ability to function effectively in multidisciplinary teams" (Engineers Australia, 2005) or "the ability to network" (Gundling et al, 2000; Scott et al, 2002)).

The mechanism of competency acquisition in this case can be partly attributed to the overall cultural imprint of the educational context. On one level, the respondent describes how in particular courses the teachers did not appreciate questions or even viewed them as a sign of the student's incompetence. Overall, this created an image that "as an engineer, one does not ask questions". The participant then explains how this attitude had a very negative effect in a later project in an interdisciplinary team environment. He gives the example that the other team members made frequent use of their subject specific acronyms. With the initial tendency not to ask for explanation, this led to a point were the discussions were already too far advanced for the respondent to finally request clarification.

7 CONCEPTUAL MODEL OF COMPETENCE

On the basis of such critical incidents and drawing on the existing literature, figure 4 presents a multiscale systems model of engineering competence. Simply put, the systems view in this context means that overall competence is more than the sum of individual competencies. Typically complex systems

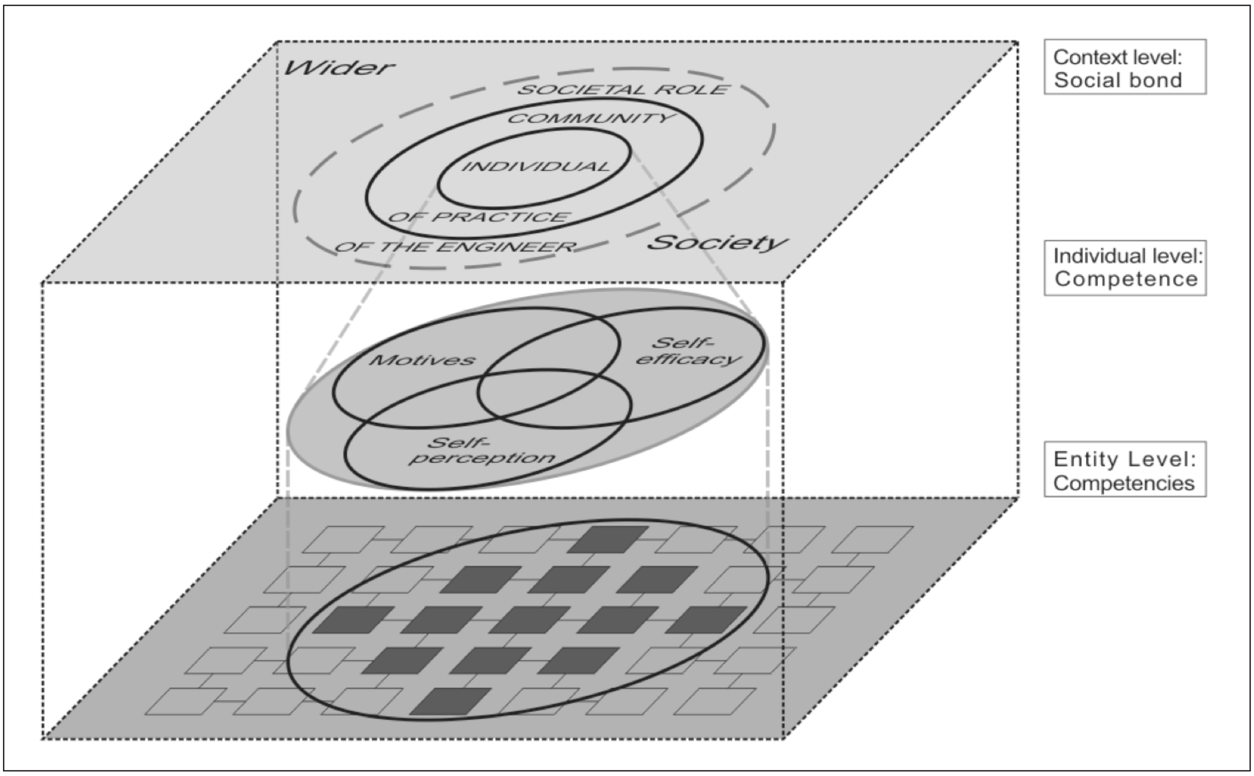

Figure 4: Multiscale systems model of engineering competence – competence emerges from the interaction of the context and the entity level through the mediation of elements on the individual level.

span several levels of scale from a micro view to a large-scale macro perspective (Bar-Yam et al, 2004). In the context of engineering, the competence model distinguishes between the entity, individual and context level. These levels are connected through a rich interaction of their respective elements and this interaction determines how competence emerges in a particular context. This model of competence allows a synthesis of aspects of several conceptual views that are employed in different disciplines concerned with competency research.

The context level (upper level in figure 4) illustrates how the individual is embedded in a social bond and how this context influences individual competence. Research in the area of communities of practice (Wenger, 1998; Stonyer, 2005) describes this aspect of competence formation as apprenticeship learning. However, the interaction goes beyond the community of practice and includes the wider society in general.

The entity level (lower level in figure 4) describes the micro view of engineering competence. It contains the individual competencies in the form of an interconnected network. This view is similar to the conceptual understanding of the Graduate Attributes (Engineers Australia, 2005), which sees competence in terms of a number of constituting elements. The list of Graduate Attributes does, however, not acknowledge the connectedness of competencies and their mutual influences.

The competencies on the entity level are not independent from the context. Influences from the context level are mediated by elements on the individual level (middle level in figure 4). These regulatory mechanisms include the individual's self-perception (social view of competence (Sandberg, 2000)), their motives and their self-efficacy (Ponton et al, 2001). These overarching elements are shaped by the interaction of the individual in the social context and, in turn, organise and contextualise the competencies on the entity level, depending on the situation. In contrast to the concept of competence underlying the Graduate Attributes or the iceberg model, the regulatory elements on the individual level cannot be treated as additional entities on the lower level. Hence, they could not be added to a list of desired competencies and educated in isolation.

8 DISCUSSION

In order to illustrate the proposed multiscale systems model of competence, we return to the example of Accidental Competency acquisition presented in the second critical incident. From the transcript it became evident that the respondent has the ability to communicate in a social network. Other reported critical incidents show that he is also resourceful in finding information and solving technical problems. For the purpose of this example, we consider those abilities as the set of competencies available to the graduate on the entity level. During the educational process, the context level shaped his self-perception in a way that as an engineer he would be hesitant to ask questions. Hence, in the described interdisciplinary team situation, the respondent makes no use of the ability to communicate or use peer support in a social network and does not ask for clarification of the unknown terms. His self-perception as an engineer marshals from the entity level the ability to independently research information – a quality that is held in high regard at university. Unfortunately in this situation, this is to the detriment of the graduate since he must realise that he should have asked his colleges for clarification. Hence, it is not sufficient in the professional context that the graduate obtained the set of competencies mentioned above. The fact that his self-perception will determine how the competencies come to bear in a particular context shows that even if engineering education achieved all desired individual attributes, this does not necessarily mean the students display competence in a job situation.

This example shows that the multiscale systems model of competence can be used to locate and analyse one example of a holistic learning, and relate this to the requirements of professional practice. Beyond that it needs to be discussed, on a general level, to which extent this understanding of engineering competence can contribute to overcoming some of the aspects of the competency dilemma in engineering education.

If engineering education considers how the social surroundings influence the individual level of competence, students' attitudes become accessible in the educational process. The possibility of shaping attitudes is very limited in the traditional approach of targeted instruction. The wider understanding of education means that the function and possibilities of engineering educators go beyond selecting and administering learning activities. The critical incident presented shows that the teacher as a role model has an influence on the attitudes and self-perceptions of engineering graduates and ultimately on their professional competence in the work context. If this potential was used beneficially by engineering educators by, for example, modelling professional and ethical behaviour, this might be more effective than the attempts of explicitly teaching those elements through course content. This effect of purposefully using the social context in education also extends beyond the classroom. This would mean that some of the influences highlighted in the contextual model of Accidental Competencies (figure 3), such as student interaction with the community of practice in part-time work or internships, should be explicitly considered in education. This does not necessarily suggest dramatic changes. The empirical study shows that teaching and the way students are introduced to the community of practice does already create self-perceptions and attitudes. It would be a matter for engineering education to consciously shape this influence in a beneficial way.

The proposed model of competence takes into account the regulatory role of, for example, self-perception on competence. This describes an overarching element of competency that has been shown to be relevant for performance (Sandberg, 2000). As opposed to the concept of meta or key competencies, which relies on the transferability of those attributes, the regulatory mechanisms on the individual level draw on individual competencies and organise these in the practical context. This provides a way to overcome some of the goal conflicts discussed earlier. The difficulties posed by the conflicting necessities in education could be mitigated by raising students' awareness and helping them shape a professional identity. In case of the example of different risk attitudes discussed earlier, the student's awareness of her role in a specific job would help to select the appropriate risk attitude in that context. In this way, the explicit shaping of a professional identity could help students to select their desired individual competencies in a flexible curriculum and apply them purposefully in the professional context.

This proposed conceptual understanding of engineering competence and the holistic view of student learning can be used to derive some initial suggestions to overcome the competency dilemma in engineering education. On the other hand, it is equally apparent that this concept does certainly not offer a complete solution to the issues raised.

9 CONCLUSION AND OUTLOOK

The analysis presented brings into question some of the implicit assumptions that underpin the present methods of designing engineering programs based on graduate attributes. The competency dilemma in engineering education, where programs designed to meet the stated needs of industry, still seem to fail to produce graduates with the necessary competencies for successful performance in practice. In order to approach these difficulties, a systems view of competence formation is proposed that acknowledges both intentional and unintentional (accidental) learning outcomes. The results of an exploratory, empirical investigation into so- called Accidental Competency acquisition are reported. This leads to the proposal of a multiscale systems model of engineering competence to promote a more fundamental and holistic understanding of student competence formation. At a time when accreditation agencies and other authorities are reviewing the operation and success of outcome based education in engineering, the results presented here offer an evidence-based approach to how we might design and evaluate engineering programs in relation to engineering competence in practice. It provides a logical framework for moving beyond a simple process of deriving perceived graduate attributes (desired outcomes) and mapping these to programs.

What is proposed is more realistic, complex systems perspective for how we approach the design of engineering education programs, taking into account the formal educational perspective, while also acknowledging the many, subtle ways in which professional competence is developed.

REFERENCES

ABET, 1995, *Engineering criteria 2000 (EC2000),* Accreditation Board for Engineering and Technology.

ABET, 2004, *Criteria for accrediting engineering programs,* Accreditation Board for Engineering and Technology.

ASCE, 2004, *Civil engineering body of knowledge for the 21st century: Preparing the civil engineer for the future, Reston,* Virginia, American Society of Civil Engineers.

ASEE, 1994, *Engineering education for a changing world,* American Society for Engineering Education, Engineering Deans Council, Corporate Roundtable.

Bar-Yam, Y., Ramalingam, C., et al. 2004, *Making things work: Solving complex problems in a complex world,* Cambridge, MA, NECSI, Knowledge Press.

BCA, 2006, *New concepts in innovation – The keys to growing Australia,* Melbourne, Business Council of Australia.

Engineers Australia, 1996, *Changing the culture: Engineering education into the future,* Barton, ACT, Engineers Australia.

Engineers Australia, 2005, *Accreditation management system educational programs at the level of professional engineer.*

Gundling, E. & Porras, J. I. 2000, *The 3M way to innovation: Balancing people and profit,* Tokyo, New York, Kodansha International.

Hillson, D. & Murray-Webster, R. 2005, *Understanding and managing risk attitude,* Aldershot, Hants, England, Burlington, VT, Gower.

Leiper, Q. & Khan, T. 1999, "A competency-based system for assessment, training and development of engineers", *Proceedings of the Institution of Civil Engineering,* Vol. 132, pp. 151-155.

Lemaitre, D., Prat, R. L., et al. 2006, "Editorial: Focusing on competence", *European Journal of Engineering Education,* Vol. 31, No. 1, pp. 45-53.

Male, S. & Chapman, E. 2005, "Assessing the generic competencies of engineering graduates: Preliminary report from an ongoing research program", *Proceedings of the 4th Global Colloquium on Engineering Education,* Sydney, Australasian Association for Engineering Education.

McClelland, D. C. 1973, "Testing for competency rather than for intelligence", *American Psychologist,* Vol. 28, pp. 1-14.

McClelland, D. C. 1998, "Identifying competencies with behavioral-event interviews", *Psychological Science,* Vol. 9, No. 5, pp. 331-339.

Miles, D. H. 2003, *The 30-second encyclopaedia of learning and performance: A trainer's guide to theory, terminology, and practice,* New York, American Management Association.

Ponton, M. K., Edmister, J. H., et al. 2001, "Understanding the role of self-efficacy in engineering education", *Journal of Engineering Education,* Vol. 90, No. 2, pp. 247.

Radcliffe, D. F. 2005, "Innovation as a meta graduate attribute for engineers", *International Journal of Engineering Education,* Vol. 21, No. 2, IJEE Special Issue: The Entrepreneurial Engineer, pp. 194-199.

Rifkin, K. I. & Fineman, M. 1999, "Developing technical managers – First you need a competency model", *Research Technology Management,* Vol. 42, No. 2, pp. 53-57.

Robinson, M. A., Sparrow, P. R., et al. 2005, "Design engineering competencies: Future requirements and predicted changes in the forthcoming decade", *Design Studies,* Vol. 26, No. 2, pp. 123-153.

Salganik, L. H. & Rychen, D. S. 2003, *Key competencies for a successful life and a well-functioning society,* Cambridge, MA, Toronto, Hogrefe & Huber.

Sandberg, J. 2000, "Understanding competence at work: An interpretative approach", *Academy of Management Journal,* Vol. 43, No. 1, pp. 9-25.

Schoen, D. 1995, "New scholarship requires a new epistemology", *Change,* Vol. 27, No. 6, pp. 27-34.

Scott, G. & Yates, K. W. 2002, "Using successful graduates to improve the quality of undergraduate engineering programmes", *European Journal of Engineering Education,* Vol. 27, No. 4, pp. 363-378.

Spencer, L. M. & Spencer, S. M. 1993, *Competence at work: models for superior performance,* Chichester, UK, Wiley.

.Spinks, N., Silburn, N., et al. 2006, *Educating engineers for the 21st century: The industry view,* Oxfordshire, UK, Henley Management College, the Royal Academy of Engineering.

Stonyer, H. 2005, "Developing engineering education using a community of practice model", *Proceedings of the 4th Global Colloquium on Engineering Education,* Sydney, Australasian Association for Engineering Education.

The Royal Academy of Engineering, 2006, *Educating engineers for the 21st century: The industry view – A commentary,* London, UK.

Veblen, T. 1918, *The higher learning in America,* New York, BW Huebsch.

Walther, J. & Radcliffe, D. 2006a, "Accidental Competencies: Is engineering education simply a complex system?", *Proceedings of the 17th Annual Conference of the Australasian Association for Engineering Education,* Auckland, New Zealand.

Walther, J. & Radcliffe, D. 2006b, "Engineering education: Targeted learning outcomes or Accidental Competencies?", *Proceedings of the Educational Research and Methods Division – 2006 American Society for Engineering Education Annual Conference,* Chicago.

Weinert, F. E. 1999, *Concepts of competence,* Definition and selection of competencies (DeSeCo), Organisation for Economic Co-operation and Development (OECD).

Wenger, E. 1998, *Communities of practice: Learning, meaning, and identity,* New York, Cambridge University Press.

Wulf, W. & Fischer, G. 2006, "A makeover for engineering education", *Issues in Science and Technology Online,* accessed 17 August 2006, www.issues.org/18.3/index.html.

Wulf, W. A. & Fisher, G. M. C. 2002, "A makeover for engineering education", *Issues in Science and Technology,* Vol. 18, No. 3, pp. 35.

Yang, M. Y., You, M., et al. 2005, "Competencies and qualifications for industrial design jobs: Implications for design practice, education, and student career guidance", *Design Studies,* Vol. 26, No. 2, pp. 155-189.

JOACHIM WALTHER

Joachim Walther is a PhD student with the Catalyst Research Centre for Society and Technology at the University of Queensland. The objective of the centre is to create innovative, sustainable solutions to complex social and technological challenges facing industry and the community, through the fusion of social science and engineering perspectives.

Joachim's PhD research is in the area of engineering competence and particularly looks at the formation of accidental competencies in undergraduate education. The research involves a complex systems perspective to investigate how students' competence is formed through the interaction of learning activities and other influences from the wider educational environment.

Prior to this, Joachim graduated from the Technische Universität Darmstadt (Germany) with a Bachelor in Mechanical and Process Engineering and a "Diplomingenieur" in General Mechanical Engineering. During his undergraduate studies, he spent one year at the University of New South Wales in Sydney completing a bachelor research project in the area of computational fluid dynamics. In Darmstadt, he completed a one year master's equivalent research thesis investigating cognitive aspects of engineering design. This work in collaboration with engineers and cognitive psychologists comprised of an analysis of engineering design methods from the point of view of cognitive psychology.

DAVID RADCLIFFE

Professor David Radcliffe is the Thiess Professor of Engineering and Professional Development at the University of Queensland, and leader the Catalyst Research Centre for Society and Technology. He coordinates the Thiess-UQ Strategic Learning Partnership on a daily basis. This involves his spending at least three days per week with Thiess and remainder on campus at the university.

David is an engineer who has worked in various universities and with industry in Australia and the US over 25 years. His teaching and research interests span design, sustainable systems, engineering education and professional development and knowledge management. David was the Inaugural National Teaching Fellow, Australia, 1995 and a Boeing Welliver Fellow in the 1999, the first from Australia. He was principal investigator on the Australasian Virtual Engineering Library project since it inception in 1999 and he has lead the development of the Sustainability Knowledge Network initiative.

David is a Fellow of Engineers Australia and the immediate Past President of the Australasian Association of Engineering Education.