2006-1889: ENGINEERING EDUCATION: TARGETED LEARNING OUTCOMES OR ACCIDENTAL COMPETENCIES?

Joachim Walther, University of Queensland

JOACHIM WALTHER graduated from The Darmstadt University of Technology (Germany) with a Bachelor in Mechanical and Process Engineering and a "Diplom" in General Mechanical Engineering. As a PhD student he is now member of the Catalyst Research Centre for Society and Technology at the University of Queensland. His research interests lie in the areas of cognitive and social aspects of engineering design and education.

David Radcliffe, University of Queensland

DAVID RADCLIFFE is the Thiess Professor of Engineering Education and Professional Development in the School of Engineering at the University of Queensland. His research draws on and involves collaboration with the social sciences including education and anthropology. David is co-director of the Catalyst Centre and Director of Professional Development in the School. He was a National Teaching Fellow, in 1994 and a Boeing- A.D. Welliver Fellow, in 1999.

Engineering education: Targeted learning outcomes or accidental competencies?

Abstract

This paper presents preliminary results of research into the nature of engineering competence. Data was gathered in focus groups with participants from Australia, Germany and the US using critical incident techniques. The study has found evidence to suggest that some crucial engineering competencies are not predominantly achieved through targeted education. The first part critically analyses the history of the competency movement with special regard to the application of learning outcomes in engineering education. The two problems identified in this context are the lack of a conclusive definition of competency and the gap in the understanding of engineering competency between education and practice. On this basis, the concept of Accidental Competencies is introduced. Accidental Competencies are not achieved through intentional forms of learning but emerge from the coaction of curricular elements and other aspects of the educational process. Illustrative quotes from the focus groups are presented and analyzed with regard to Accidental Competency formation. Subsequently, a contextual model is introduced illustrating the coaction of elements surrounding the educational process in the formation of competencies. The potential advantages of the concept of Accidental Competency as a unique mode of enquiry into the nature of engineering competence are then discussed. Finally details of the direction of the further research are outlined.

Introduction

In the last decade global economic, technical and social changes have led to a sustained transformation of the discipline of engineering. Pressing issues such as increasingly intense international economic competition, the changing role of engineers in society and cross-disciplinary influences on traditional engineering pose an enormous challenge to engineering education programs.

The wide-ranging implications of those changes were already anticipated in both the 1993 ASEE report[1] "Engineering Education for a changing world" and Engineers Australia's 1996 review[2] "Changing the culture: Engineering education into the future". Both advocated fundamental changes in engineering education and the recommendations subsequently resulted in the development of ABET's Program Outcomes[3] and Engineers Australia's Graduate Attributes[4] (AMEA), respectively (For a comparison of the two systems see Mann & Radcliffe[5]). This initiated a paradigm shift in engineering education from the previously input-, content- and process-oriented system to an outcomes-based approach.

The concept of outcomes-based education defines a set of educational goals in the form of attributes, or competencies, which are to be achieved through the learning activities of the course. Adopting this approach in engineering education and specifically in the accreditation of programs was seen to serve a dual purpose: defining an educational goal or a set of attributes without specifying process with which the are to be achieved was seen as a means of fostering diversity of engineering programs[2] whilst ensuring that "Graduates from an accredited program are adequately prepared to enter and continue the practice of engineering"[2]. This meant in particular that new attributes especially in areas of multidisciplinary teamwork and communication (Graduate Attributes ii and vi in AMEA[4])

and social and cultural understanding (Graduate Attribute vii in AMEA[4]) could be explicitly incorporated.

Program Outcomes and Graduate Attributes serve as a guideline for accreditation of engineering courses both in the United States and Australia. Furthermore the concept is currently being adopted in other countries around the world as one possible answer to the challenges described above. Recent examples are the development of an Malaysian outcomes-based model[6, 7] or discussions on adopting an outcomes-based approach to accreditation and mutual recognition within the framework of the European Bologna process[8].

Similarly on the level of professional accreditation Engineers Australia employ a competency-based approach to certify professional engineers. The system is based on the definition Stage 1 competencies for Graduate engineers[9] and Stage 2 competencies for Professional Engineers. The first level is achieved by obtaining a formal degree from an accredited engineering program. The achievement of latter is demonstrated through critical incident reports which show that the respective competencies were attained through work experience.

Preliminary results from an ongoing study at the University of Queensland into the nature of engineering competence indicate, however, that some competencies of recent graduates are not the result of the systematic instruction envisaged in the concept of outcomes-based education. Based on these findings this paper introduces the concept of Accidental Competencies. These are the competencies that graduates achieve through the co-action of several curricular elements and additional aspects surrounding the formal process of education. Accidental Competencies are therefore not a planned outcome resulting from curriculum design.

Critical Review of the Competency Movement

In order to understand this concept it is necessary to review the definition and underlying assumptions behind the idea of competencies, the foundation of outcomes-based education. As pointed out by several authors[10, 11], the philosophy of outcomes-based education goes back to the behavioral objectives movement promoted by Tyler[12] and Bloom[13] fifty years ago. In 1962, Mager[14] defined objectives as "the description of a performance you want learners to be able to exhibit, before you consider them as competent". As shown in Figure 1 Tyler prescribes four basic steps to instructional design[12].

In the first step the educator determines objectives which should be achieved in the course. Then appropriate learning experiences are selected to achieve the objectives as observable student behavior. In the contemporary application of this concept the learning activities are mapped to specific attributes they achieve – this concept will be referred to as Targeted Instruction (See Figure1). The next step is to organize the leaning experiences in a sequential and logical order and in the last step it is determined to which extent they have been achieved.
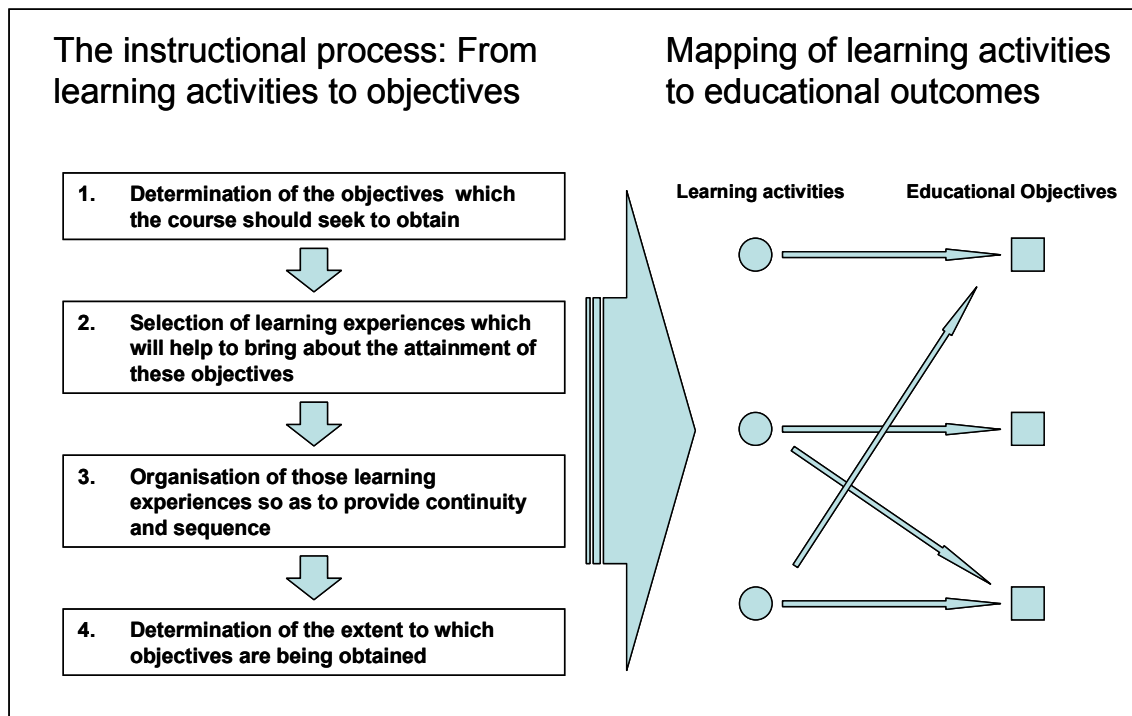
The instructional process: From learning activities to objectives

Mapping of learning activities to educational outcomes

1. **Determination of the objectives which the course should seek to obtain**

2. **Selection of learning experiences which will help to bring about the attainment of these objectives**

3. **Organisation of those learning experiences so as to provide continuity and sequence**

4. **Determination of the extent to which objectives are being obtained**

Learning activities   Educational Objectives

Figure 1: Instructional Design according to Tyler[12] – Targeted Instruction in outcomes-based education

The main controversy surrounding this theory has been centered on the question of what constitutes a learning objective. Bloom[13] systemizes Tyler's objectives in three domains of learning. He describes the domains for objectives as follows: the Cognitive Domain which includes knowledge in the form of facts or information; the Psychomotor Domain refers to performance through physical skills; and finally the Affective Domain relates to feelings and attitudes. However, with its focus on observable behaviors this theory of learning objectives is grounded in the tradition of behavioral psychology. Human behavior is understood to be a deterministic chain of stimulus and response[15] under a specific condition. Thus internal states of the mind or occurrences in Bloom's Affective Domain are entirely attributed to the stimulus response mechanism. Learning processes are seen as "conditioning a reflex response associated with a specific environmental stimulus"[10]. This view has found its way into modern approaches to vocational training such as the Australian TAFE (Training and Further Education) competency-based training approach where tasks are split up in numerous behavioral elements which have to be mastered by the learner[16, 17].

The omission of internal states in the behaviorist conception was the main source of criticism[18] from cognitivist scientists. In response this antagonistic movement developed internal computer-like models of cognition[19] as information processing. Within this framework of cognitive architectures, learning is understood as the acquisition of fine-tuned routines[20]. This concept of expertise solely focuses on cognitive processes and its application is mainly limited to the investigation of more complex mental tasks. Occurrences in Bloom's affective domain, however, remain largely unconsidered.

Between those diametrically opposed theories practical disciplines, such as human resource management, tried to resolve the contrasts into a pragmatic and applicable approach to competence and learning. While the discipline comes from a background which is grounded in the tradition of behavioral objectives, analyses in the field of human resources management touch on cognitive job tasks. Hence the necessity arises to incorporate this

aspect in the underlying concepts. In his seminal paper[21] McClelland defined competencies as traits that lead to superior job performance. This idea of linking competency to job performance was later on developed by Boyatzis[22] and Spencer[23] into a model of competence that is broader than, but includes, educational objectives[10].
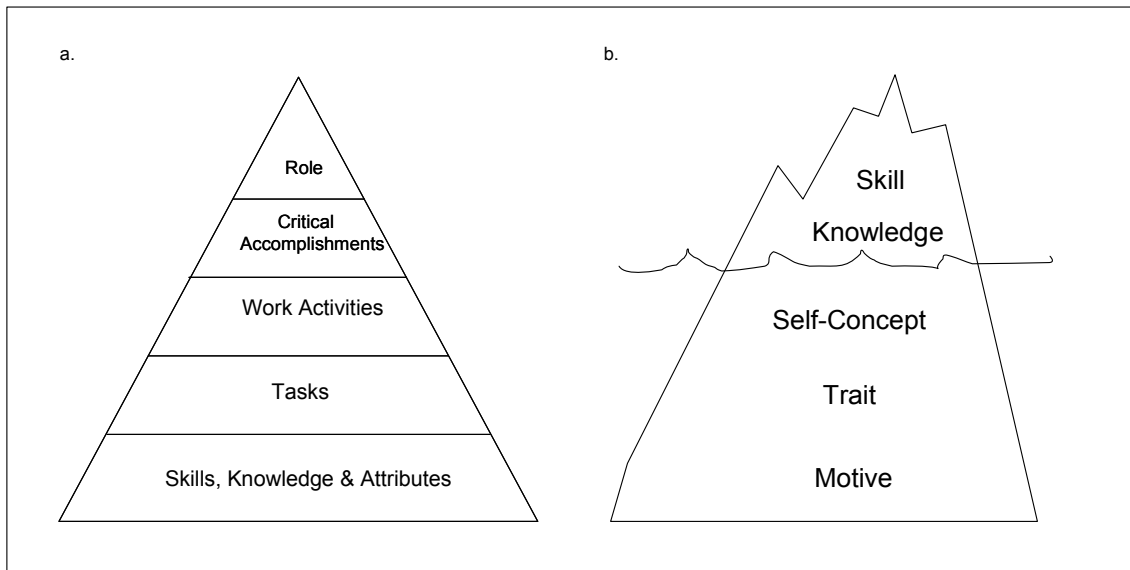

Figure 2: Levels of investigation of competencies adapted from Plonka[24]– and Iceberg model of layers of competency according to Spencer[23]

As illustrated in Figure 2b Spencer[23] defines various levels of competencies. Skills and knowledge form the upper part of the iceberg model relating to the classical academic conception of competency[21], thus encompassing Bloom's cognitive and psychomotor domain. Accordingly self-concept, traits and motives describe a very basal level of performance expectation and include what Bloom defined as the Affective domain. Subsequent studies[22, 23] indicated that these underlying or "invisible competencies"[25] have a more crucial impact on job performance. In practical application, however, competency studies face the problem that those underlying levels are difficult to empirically access. Hence most investigations do not seem to explore those elementary concepts and are mainly concerned with the analysis on the task level[26] (See Figure 2a).

In summary this shows that despite its wide-ranging application in education and training the concept of educational outcomes or competencies is difficult to define in a coherent theoretical framework. There are large variations especially with regard to the depth of the analysis (See Figure 2a: role to task level) as well as the elements of competency taken into consideration (Compare Fig. 2b: knowledge to attribute).

Educational Objectives in Engineering Education

The conceptual difficulties described in the previous section apply to the use of educational outcomes in engineering education. However, there are a number of additional concerns arising from the fact that engineering education is the preparation of students for professional practice. Table 1 list several fields where tensions or goal conflicts exist between education and practice.

The fundamental objective of an engineering course is the education of students (Refer to Table 1). In several aspects this can be quite different from the demands of employers in industry, since human resources management links competence to job performance[22, 23]. As an example for the tensions that might arise from this difference, the following might be considered. Universities are required to devote teaching time and effort towards the achievement of outcomes such as an "understanding of the social, cultural, global and environmental responsibilities of the professional engineer"[4]. However, issues pertaining to this broader concept of professional responsibilities might have no implication on the performance criteria an individual is measured against in the workplace. Hence, in industry some the qualities or attitudes postulated in Engineers Australia's Graduate Attributes are not explicitly measured insofar they are not related to job performance.

The second predicament results from the fast changing nature and increasing diversity of professional practice. Universities are confronted with the task of preparing students for a multitude of career paths, each of which demands performance in very specific technical areas. In this context the focus on meta or core competencies is seen as one possible solution[25] to equip students with qualities that are useful across a wider range of job demands. However, the benefits of this approach are not undisputed since investigations[27] show that the more general a competency is the less useful it is in a specific situation.

Table 1: The Competency Gap between Education and Engineering Practice

Aspect	University	Company
Objective of the organization	Education	Performance
Desired outcome	Preparation for a multitude of career paths	Contribution in specific areas
Focus in the formation and assessment of competency	Technical competence	Traits, self-concept, motive
Methods of assessment of competence	Traditional academic assessment	Behavior-based critical incident techniques
Methods for identification of competency requirements	Expert's panel	Behavioral competency studies

Despite the reforms of engineering education described above "much of the energy in teaching and learning in universities is now focused on developing observable knowledge and skills"[25]. Even though initial attempts to include the level of attitudes into the notion of learning outcomes were recently presented in the literature[28] those concepts have not yet found their way into the wider practice of education.

With regard to assessing competence or the achievement of educational outcomes, universities mostly employ traditional academic assessment methods. Companies on the other hand use behavior-based critical incident techniques[29] and hire for traits, attitudes and motives as a better predictor of job success. This phenomenon has been termed the "Graduate Attribute Paradox"[25].

Another area of substantial disagreement is the definition of competency requirements for education and professional practice, respectively. Similar to the assessment of competency in the selection process, human resource management uses critical event techniques to compare the traits of superior and average performers and derive job-specific competency profiles[22, 23]. Due to the specific nature of those competency studies the degree to which they can be

transferred into a general educational context is very limited. The approach of determining competency requirements in education and curriculum design is best described as an expert's panel method[23, 26]. Stakeholders from universities, the profession, industry and the larger community define competencies or attributes as desired educational outcomes[1, 2]. This procedure poses two risks: Even though the participants might have sufficient insight into engineering practice they are prone to contribute espoused beliefs[23] - or what they think useful competencies might be - to the inventory of desired educational outcomes. Additionally, by including attributes which are generally perceived as positive but not necessarily relevant in professional practice causes the competency requirements to grow too general to be useful in specific curriculum design[10, 27].

Accordingly the literature in the field of engineering research[30] shows that the two fundamentally different approaches described above come to a very limited agreement with regard to which competencies are required for engineers. This whole complex of discrepancies in the different views on educational outcomes will be referred to as the *Competency Gap between education and practice*.

Summarizing the above paragraphs it can be stated that there are two fundamental obstacles when applying an outcomes-based or competency approach to engineering education: The first is best summarized with Miles[10]: "Competencies are definitely very popular; the only problem is that almost everyone has a different notion of what a competency is". This stresses the need for a theoretically founded but pragmatic conceptual model of competence. The second refers to the competency gap between education and professional practice. It means that there is only very limited agreement with regard to which competencies are required in professional practice and should thus be taught at university.

The Concept of Accidental Competencies

For the reasons discussed above the point of departure for this study of Accidental Competencies must be an at least preliminary definition of the conceptual understanding of the term competency in the context of this research. Our working definition encompasses the areas of skills and abilities, attitudes, traits and motives as well as job tasks. This inclusive definition was chosen for the pragmatic reason of being able to capture a maximum of information in the later part of the study. However, for the purpose of usability of the concept in the educational context it will have to be refined, focused more sharply and continuously validated.

In order to define the term Accidental Competency it is necessary to step away from the very positivistic understanding of learning as described in the critical review of competency movement above (as illustrated in Figure 1) and view education holistically as a complex system. Complex systems are characterized by a large number of elements which interact on a multitude of levels. These local interactions of elements generally have a global impact and can lead to the emergence of properties on higher levels of the system[31]. Accordingly Accidental Competencies are defined here as attributes that are not achieved through targeted instruction. They are acquired through the unintentional coaction of curricular elements or aspects surrounding the educational process. In that Accidental Competencies can be included in the stated learning outcomes but can in some cases go beyond that scope.

Exploratory Study of Accidental Competencies

In order to be able to investigate the critical competency gap (Refer to Table 1) the investigation targeted graduate engineers and graduate students in the transition phase into professional practice. In two focus groups each of which comprised of three students or young professional engineers from different national backgrounds data was gathered using Critical Incident Techniques. The first focus group (No. 1) consisted of three mechanical engineering graduates currently enrolled in a PhD program; with one female participant from the US and two male participants from Australia. The second focus group (No. 2) was conducted with three male engineers from Germany, who recently graduated and now work in engineering management or consultant positions.

According to the methodology of Critical Incident Techniques, as described by McClelland[21, 29] Boyatzis[22] and Spencer[23], participants were either asked to recount critical learning experiences or critical events in specific job situations. The competencies which were perceived as crucial in this context were then related back to the participant's learning experiences in the wider sense of Accidental Competency acquisition. The transcripts were then coded for competencies and their mode of acquisition. In this way a total number of 17 incidents of Accidental Competency acquisition could be identified. However, it should be noted that this describes the number of specific incidents in which the respondents described forms of Accidental Competency acquisition. Due to the small sample size and the fact that the setup and the fundamental concepts are still being developed, this does not allow concluding a set of clearly defined fundamental competencies. Despite this limitation the early results are promising in establishing the phenomenon of Accidental Competencies and point out the path of further research in this area.

From the set of critical incidents three characteristic examples are presented in the following section in form of indicative quotes. Each of the quotes will be analyzed with respect to the competencies the respondents mention and their mode of acquisition. This will be used to identify Accidental Competencies which are then related to the existing literature.

Quote 1 (from the transcript of the discussion of focus group No. 2)

> *"The chaotic system of my degree structure with parallel courses and conflicting constraints was in retrospective a blessing. Today I am able to organize myself in similar conditions, manage my time and access information through networking with others"*

The following Accidental Competencies were identified:

- Ability to make sense of and work within complex systems (Compare Craig et al.[32])
- Ability to interact socially and build relations in order to gain information or advice (Gundling[33] describes "network, gets things done through others" as an innovation trait sought by 3M, compare also "use peer support" in Scott[34])
- Time management (Parkinson[35] classifies this as an enabling skill for life-long learning, compare also Graduate Attribute x in AMEA[4])

The mechanism of accidental competency acquisition identified in this example can be characterized as a meta-effect of curricular elements. The individual parts are the individual courses the student has to combine to achieve a valid degree schedule. On a higher or meta-level this poses a new learning task of dealing with a complex system with a number of formal constraints. This is embedded in the social context of the particular university system

and gives the student the chance to succeed by building personal relations and gather information through others. However, it should be noted that other effects, such as traditional learning, might have contributed to the acquisition of the stated competencies. Due to the limitations of the data the proportions of the respective contributions can not be evaluated at this stage.

Quote 2 (from the transcript of the discussion of focus group No. 2)

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

This illustrates what we term Accidental Incompetency on the attitudinal level (Refer to Figure 2b):

- The inability to use appropriate ways to access information in a complex socio-technical working environment (Compare AMEA "Ability to function effectively in multi-disciplinary teams"[4] or the ability to network[33, 34])

In this case the local interaction of elements in the educational process, which was presumably designed to aid learning, leads to the emergence of a negative effect on a global level. This operates on the competency level "below the waterline of the iceberg"[23]. Other authors see this as being fostered by the prevailing "lack of focused attitude teaching and learning efforts in universities"[28] which may lead to "teaching and learning of undesirable attitudes to the detriment of all"[28]. The mechanism of competency acquisition in this case can be partly attributed to the overall cultural imprint of the educational context. Based on other parts of the transcript of the focus group with this respondent, the person and personality of the teacher were identified as another contributing factor. Beyond that there are clearly other contributing factors. This shows that especially on the attitudinal level the influencing factors are difficult to isolate. The student's personal disposition or previous educational background might also play an important role but could not be extracted conclusively from the transcripts due to the limitations of the data.

Quote 3 (from the transcript of the discussion of focus group No. 1)

> *"During exam times we had enormous workload peaks. But somehow you got by. Today [in my job] I find that I can handle tight deadlines and do a lot of work in a short time. […] But somehow I initially had trouble structuring my workload. At university you always just do the work you need to do in order to survive at that point in time"*

This example demonstrates the complexity and ambivalence of the emerging properties of education as a complex system. On the one hand the pressures caused by the coaction of individual exams referred to in this quote which were originally intended to fulfill Tyler's fourth step of assessment in the instructional process (See Figure 1a), seemed to foster the following Accidental Competency

- Resilience[33] and coping with workload peaks[34]

On the other hand the effect created by the coaction of the individual assessment items also caused an "undesired attitude"[28]:

- Lacking incentive/motivation to strategically structure own work (compare "the ability to structure one's own work" in Pahl[36])

Since the high workloads did not allow the student to strategically structure his learning according to his personal preferences the ability and desire to structure own work was not sufficiently fostered or it was even hampered. Again, this might be influenced by other factors such as extracurricular activities. Additionally the student's recollection might be biased towards not taking those factors into account. This shows that the range of influences contributing to accidental competency acquisition is potentially larger and goes beyond the scope of this initial investigation.

A Contextual Model of Competence Formation

Based on the literature and the findings of the explorative study a Contextual Model of Competence Formation is proposed (see Figure 3). This is a preliminary model and is not intended as a comprehensive description of the variety of mechanisms and contributing factors of competence acquisition.
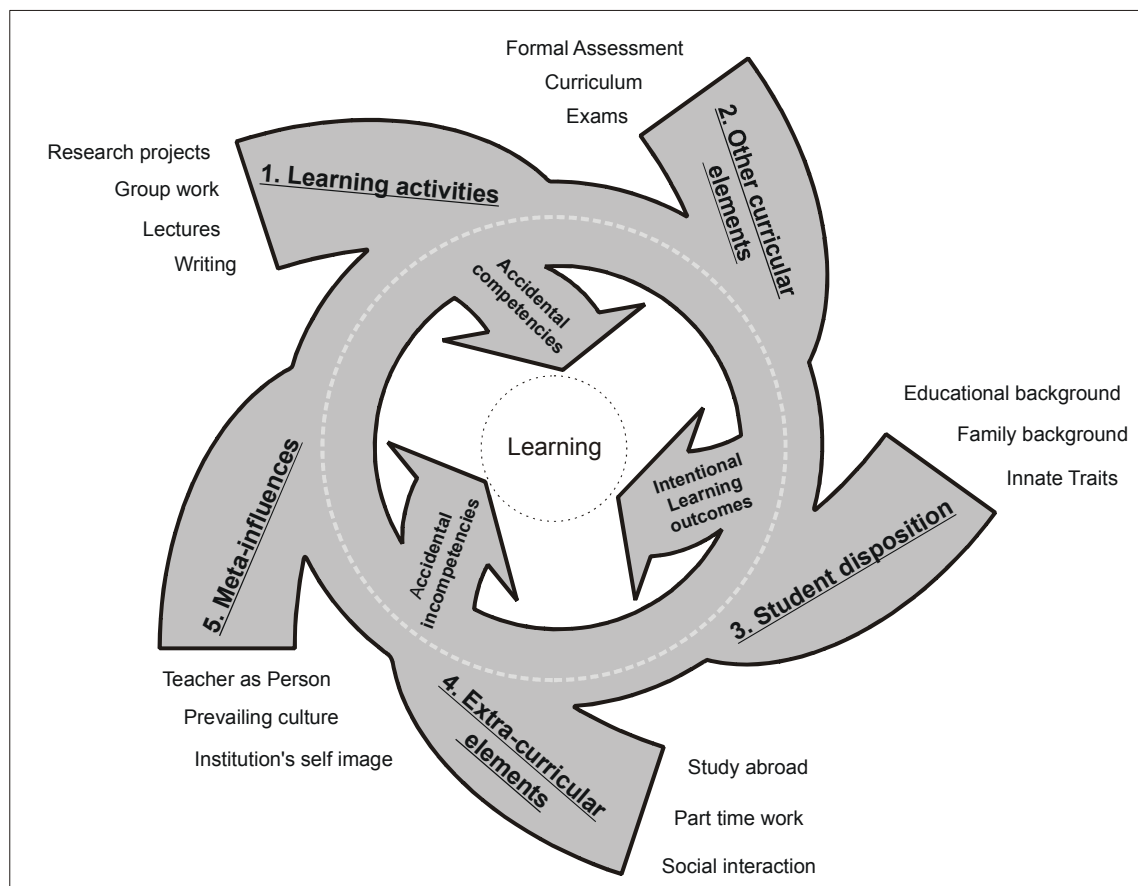

Figure 3: The Spiral Model of Competency Formation: Learning emerges from the coaction of elements surrounding the educational process.

The outer circle contains different clusters of the elements that constitute the complex system of education and thus contribute to the formation of 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 mechanisms of

formal assessment (see step 4 in Figure 2) are located in the cluster of general curricular elements (category 2). This includes the curriculum as a whole. This was illustrated in the analyses of the first quote where the degree structure and organization posed a learning task and a source of competency formation in itself.

The next category (category 3) identified, 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 extra-curricular activities (category 4) but can also strongly influence how the learning activities themselves (category 1) are received and lead to competency formation. The second quote of the student mentioning the influence of the general modus operandi of the institution opens up a category of meta-influences (category 5). This can be the culture or self-image of the institution but on a more specific level also the teacher as a role-model.

As mentioned for some of the above categories their element interact at several levels (indicated by the arrows in Figure 3) and lead to the formation of competencies. This includes learning outcomes through formal learning processes but also Accidental Competencies and Incompetencies.

Discussion

The results presented here are from an exploratory study and as such it is not possible to draw definitive conclusions. The findings were presented in the form of descriptions of incidents of Accidental Competency formation. At this early stage of the investigation this does not allow us to conclude a comprehensive inventory of Accidental Competencies. However, the results illustrate the potential of the concept of Accidental Competencies to explain a phenomenon that engineering educators have commented on anecdotally; that graduates are sometimes observed to have abilities important to professional performance in the workplace that are not explicitly linked to the stated learning objectives or the content of the curriculum[34].

The findings indicate that forms of learning occur which are not acknowledged in the current paradigm of outcomes-based education. The concept of outcomes-based education is founded on Tyler's[12] and Bloom's[13] fundamental theories of instructional design[11] (See Figure 2). This notion of the achievement of specified learning objectives through targeted instruction is recognized as useful tool in illustrating intentional aspects of learning[37]. However, it's usage in today's outcomes-based education contains the implicit assumption that all learning outcomes can be achieved through targeted instruction, thus taking an overly deterministic view on learning. Building on these fundamental educational theories the concept of Accidental Competency formation (Refer to the Spiral Model in Figure 3) takes a broader systems approach to education by incorporating forms of learning which have previously not been acknowledged.

Further exploration of the significance and mechanisms of competency formation through the interaction of all elements surrounding the curriculum could foster a deeper understanding of student learning. In this respect the concept of Accidental Competency formation offers a unique framework to enquire into the nature of engineering competence. One of the advantages it that it bridges the competency gap between education and practice (Refer to Table 1). This means on the one hand that the competencies identified are crucial for the individual respondent in specific real-world job situations. On the other hand their acquisition

through alternative forms of learning has occurred within the educational framework in the wider meaning, as presented in this paper.

The concrete benefits of this investigation are twofold: Firstly the concept allows exploring new forms of student learning and making them accessible for engineering educators. If education were to acknowledge these alternative forms of learning the positive effects could be fostered and negative effects potentially avoided. However, at this point a word of caution is necessary. Since the concept of Accidental Competency Formation is based on the assumption that education is in fact a complex system some of these benefits might be difficult to reap and equally some of the negative effects might elude the measures taken by engineering educators.

The second beneficial outcome can be obtained through the derivation of specific engineering competency requirements. The competencies drawn from the critical incident interviews can bridge the competency gap between education and practice. These specific competencies identified are relevant in real world engineering and at the same time potentially accessible in education. Additionally due to the alternative research framework the competency requirements obtained could go beyond the scope of traditionally stated learning outcomes.

Conclusion and Outlook

Much of the discourse on engineering competence is not firmly grounded in the fundamental literature within the field. Within the broader area of competency development, a consistent definition of the concept of competency is in dispute. Specifically in the field of engineering the definition of explicit engineering competency requirements across the competency gap between education and industry proves difficult. It can be concluded that if further enquiry can show that Accidental Competencies play a significant role in competency acquisition in engineering education, universities will have to take a wider view on education and take those potentially influential elements surrounding the formal process into account.

Future work will focus on identifying Accidental Competencies in order to better understand their mode of acquisition. The necessary data will be collected in focus groups and individual critical incident interviews. From this an inventory of accidental competencies and their behavioral indicators will be compiled. The subsequent analysis will derive specific recommendations on how to utilize the identified mechanisms for the benefit of engineering education.

References

1.   ASEE 1994, *Engineering Education For A Changing World*, American Society for Engineering Education, Engineering Deans Council, Corporate Roundtable.
2.   Engineers Australia 1996, *Changing the Culture: Engineering Education into the Future*, Institution of Engineers, Australia, Barton, A.C.T.
3.   ABET 2004, *Criteria for Accrediting Engineering Programs*, Accreditation Board for Engineering and Technology.
4.   Engineers Australia 2005, *Accreditation Management System Educational Programs at the Level of Professional Engineer*, The Institution of Engineers, Australia.

5. Mann, L.M.W. and Radcliffe, D. 2003, 'Using a Tailored Systems Engineering Process within Capstone Design Projects to Develop Program Outcomes in Students', paper presented to ASEE/IEEE Frontiers in Education Conference, Boulder, CO.

6. Noor, M.J.M.M., et al. 2002, 'A New Engineering Education Model for Malaysia', *International journal of engineering education.*, vol. 18, no. 1, pp. 8-16.

7. Noor, M.J.M.M., et al. 2005, 'Developing A Malaysian Outcome-Based Engineering Education Model', paper presented to The 4th Global Colloquium on Engineering Education GCEE 2005, Sydney, Australia, 26. - 29. Sept.

8. Walther, J., Mann, L., and Radcliffe, D. 2005, 'Global Engineering Education: Australia and the Bologna Process', paper presented to The 4th Global Colloquium on Engineering Education GCEE 2005, Sydney, Australia, 26. - 29. Sept.

9. Engineers Australia 2004, *Australian Engineering Competency Standards - Stage 1*, The Institution of Engineers, Australia.

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

11. Heywood, J. 1997, 'Outcomes Based Engineering Education I: Theory and Practice in the Derivation of "Outcomes" A European Historical Perspective.' paper presented to FIE'97, Frontiers in Education 27th Annual Conference, Pittsburgh, PA, 5. - 8. Nov.

12. Tyler, R.W. 1949, *Basic Principles of Curriculum and Instructions*, The University of Chicago Press, Chicago.

13. Bloom, B.S. and Krathwohl, D.R. 1956, *Taxonomy of educational objectives: the classification of educational goals*, McKay, New York.

14. Mager, R.F. 1962, *Preparing instructional objectives*, Fearon Publishers, Palo Alto, Calif.

15. Skinner, B.F. 1938, *The behavior of organisms: an experimental analysis*, Appleton-Century-Crofts, New York.

16. Lewis, A. 1997, *An Overview and Analysis of the Introduction of Competency-Based Training and Vocational Recognition in Australia*, International Labour Office, Geneva.

17. Burns, R. 2002, *The adult learner at work: the challenges of lifelong education in the new millennium*, 2nd edn, Business + Publishing, Warriewood, N.S.W.

18. Chomsky, N. 1980, *Rules and representations*, B. Blackwell, Oxford.

19. Lachman, R., Lachman, J.L., and Butterfield, E. 1979, *Cognitive psychology and information processing : an introduction*, Hillsdale, N.J.: Lawrence Erlbaum Associates; distributed by Halsted Press, New York.

20. Anderson, J.R. 2000, *Cognitive psychology and its implications*, 5th edn, Worth Publishers, New York, NY.

21. McClelland, D.C. 1973, 'Testing for Competency rather than for intelligence', *American Psychologist*, vol. 28, pp. 1-14.

22. Boyatzis, R.E. 1982, *The competent manager: a model for effective performance*, Wiley, New York.

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

24. Plonka, F., et al. 1994, 'Competency requirements in the Greenfield paradigm: the manufacturing engineer of the 21st century', paper presented to Frontiers in Education Conference, 1994. Twenty-fourth Annual Conference.

25. 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.

26. Boam, R. and Sparrow, P. (eds) 1992, *Designing and Achieving Competency: A Competency-Based Approach to Developing People and Organizations*, Mcgraw Hill Training Series, McGraw Hill Book Company, London.

27. Weinert, F.E. 1999, *Concepts of Competence*, Definition and Selection of Competencies (DeSeCo), Organisation for Economic Co-operation and Development (OECD).

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

29. McClelland, D.C. 1998, 'Identifying Competencies with Behavioral-Event Interviews', *Psychological Science*, vol. 9, no. 5, pp. 331-339.

30. Robinson, M.A., et al. 2005, 'Design engineering competencies: future requirements and predicted changes in the forthcoming decade', *Design Studies*, vol. 26, no. 2, pp. 123-153.

31. Cilliers, P. 1998, *Complexity and postmodernism: understanding complex systems*, Routledge, London ; New York.

32. Craig, N., et al. 2005, 'Integrating Complex Systems Study into the Freshmen Mechanical Engineering Experience', paper presented to The 4th Global Colloquium on Engineering Education GCEE 2005, Sydney, Australia, 26. - 29. Sept.
33. Gundling, E. and Porras, J.I. 2000, *The 3M way to innovation: balancing people and profit*, Kodansha International, Tokyo ; New York.
34. Scott, G. and Yates, K.W. 2002, 'Using successful graduates to improve the quality of undergraduate engineering programmes', *European Journal of Engineering Education*, vol. 27, no. 4, p. 363.
35. Parkinson, A. 1999, 'Developing the Attribute of Lifelong Learning', paper presented to 29th ASEE/IEEE Frontiers in Education Conference, San Juan, Puerto Rico, November 10 - 13.
36. Pahl, G. 1994, 'Merkmale guter Problemloeser', in *Psychologische und paedagogische Fragen beim methodischen Konstruieren: Ergebnisse des Ladenburger Diskurses*, p. 58–67.
37. Jolly, L. and Humphries, J. 2003, 'Using an Electronic Tool to Encourage Pedagogical Change', paper presented to 14th Annual AAEE Conference, Melbourne, Australia.