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Interpreting Critical Thinking for Engineering Education – the Views of Academics

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Abstract

Third level educators are increasingly being called on to clarify the nature of the education they provide and the contribution of their graduates to society. There is therefore considerable interest in the generic attributes of graduates (Jones 2009), and how educational institutions can describe the quality of their graduates in ways that are meaningful to a wide range of stakeholders, including employers, professional groups and policy makers (Barrie 2006).

Critical thinking is considered by some to be the primary graduate attribute yet difficulties remain in arriving at precise definitions of the concept and how it is theorised for educational practice. This paper addresses this issue and offers a theoretical framework for critical thinking as it applies to engineering education.

The paper will describe: a series of interviews and documentary analysis of course work and course descriptors in the university that examine the perspective of academics from various disciplines and students of critical thinking. Together these data have been used with Karl Maton's Legitimation Code Theory to develop a model of critical thinking. Also described are plans for a series of interviews which draws upon the views of employers in engineering regarding the employability of university graduates and the importance of critical thinking as an attribute for newly qualified engineers.

A key finding is that critical thinking, rather than being a static attribute which is at the pinnacle of student attainment, is a dynamic concept which requires educators to guide their students through cycles of engagement with grounded descriptive knowledge and knowledge which is abstract and obtuse.

1. Introduction

In recent years, there has been considerable interest in the nature of graduate attributes. There is now greater demand placed on universities to demonstrate the added value of a university education and to be more explicit about what skills and attributes graduates possess over and above those who are not graduates. The concept of graduate attributes has been highly contested with diverse and competing ideas of what graduate attributes are (Barrie, 2006). Graduate attributes include some of the broader more transformative dimensions of higher education that should prepare graduates as agents of social good (Walker, 2010; Fallows & Steven, 2000).

One of those attributes that is seen as particularly important is critical thinking. It is a graduate attribute that many courses claim to produce in students. As a graduate attribute it is said by some researchers to be a defining characteristic of university education (Phillips and Bond, 2004). However, how critical thinking is understood and defined varies quite significantly between disciplines. The literature shows that there exists considerable debate about whether critical thinking can be seen as a generic or discipline-specific skill (Jones, 2007a; Barrie 2006). Many researchers point out that critical thinking is best taught as part of a discipline and should not be taught separately to the discipline curriculum (Bowden et al, 2004). Barrie (2006) points out that at the same time this might be contrary to the opinion that critical thinking is a generic attribute that should be common across all disciplines. Barrie (2006) also states that in disciplines where external bodies are engaged with accrediting courses, like in the field of engineering, we must also take account of accrediting bodies' definitions of graduate attributes like critical thinking.

There has been relatively little investigation into the relationship between disciplines or subject areas and the concept of critical thinking (Jones 2007b, 2007a) and how it is realised and recognised through curriculum and pedagogy (Jones 2007a, Maton 2007a). This paper describes a study that was carried out to examine how academics view critical thinking across a range of disciplines, including engineering and to examine if differences exist between professional and non professional disciplines and between science and humanities in terms of how they define, value, teach and measure critical thinking. The aim of this study is to explore the understanding and realisations of critical thinking in the university curriculum and in the world outside university.

Section 2 describes the methodology engaged in the study, Section 3 describes the analysis of the interviews and Section 4 describes the developed model and the analysis of the student work. Section 5 summarises our conclusions from the work completed so far, and the planned interviews.

2. Methodology

A major objective of this study was to engage with academics staff from a number of disciplines in order to determine their views on critical thinking. Therefore, a series of semi-structured interviews was conducted with 13 academic staff in 13 disciplines. Disciplines were selected to represent both the humanities and the sciences (including engineering) and to represent professional and non-professional areas. Table 1 lists the selected disciplines.

Table 1: Disciplines involved in the study

Discipline	Arts/Science	Professional – Y/N
Chemistry	Science	N
Agricultural Science	Science	N
Maths	Science	N
Architecture and Civil Engineering	Science	Y
Physics	Science	N
Mechanical Engineering	Science	Y
Economics	Arts	N
Sociology	Arts	N
Social Justice	Arts	N
Business	Arts	N
History	Arts	N
English	Arts	N
Law	Arts	Y

In order to select the appropriate person for interview in each discipline, initial contact was made with Heads of Department in each of the disciplines as listed in Table 1. The purpose of the

study was explained to the Heads of Department who were asked to nominate a member of academic staff who has an awareness of teaching and pedagogical approaches in the school and who would be able to talk to us about the place of graduate attributes, particularly critical thinking, in that discipline. The nominees of the Heads of Department were then contacted and asked to become involved in the study. These nominees were told what the study was about and also what would be required of them if they agreed to being involved. Once agreement had been obtained, appointments were made for the interviews.

A series of semi-structured interviews was carried out with 13 academics from these disciplines. The objectives of the interviews were:

- (1) To discover how the academics themselves defined critical thinking
- (2) To find out how the relevant discipline defined critical thinking
- (3) To establish the value and importance of critical thinking in the particular discipline (for students and for graduates)
- (4) To discover if there was discussion and debate within the discipline about graduate attributes and critical thinking
- (5) To establish how critical thinking was taught in the discipline and how it might be recognised, assessed and measured in students and their work.
- (6) To examine if critical thinking is addressed explicitly or implicitly in each discipline
- (7) To discover the barriers to inducing critical thinking in students.

Each interview lasted for at least an hour and was recorded and transcribed afterwards, to simplify analysis. Section 3 will describe this analysis of the interviews.

At the end of the interview, interviewees were asked to nominate one or two modules which demonstrated critical thinking being developed in students. They were then asked to provide all literature associated with this module – module descriptors, learning outcomes, assessment tasks and any handbooks or other literature that might be available to students taking the module. The purpose of obtaining this literature was to carry out a documentary analysis of the pedagogical approaches used in the modules and to find out what assessment tasks were being used to assess critical thinking. This resulted in documentation from 20 modules being made available to the research team. Section 3 will describe the analysis of the documentation.

In addition, interviewees were asked to nominate students from the top, middle and bottom of the achievement range whose work we could examine. Students were contacted by the lecturer and were asked to give consent for anonymised pieces of assessment work to be made available to the research team. The reason for obtaining this work was to see if it was possible to see critical thinking in student work. The research team also wished to examine if differences in the level of critical thinking were apparent in pieces of work with high, low and average grades. The types of student work made available ranged from single essays to large final year projects and theses.

3. Analysis and Results

3.1 Introduction

The study is a multi-method qualitative study, involving in-depth, semi-structured interviewing (Fontana & Frey 2003) together with documentary analysis. All interviews were recorded and transcribed. These interviews were then imported into NVivo 9 for analysis. The interviews were coded to find:

- Definitions of Critical Thinking – the interviews were coded for examples of where there were subject specific definitions of critical and for examples of where academics felt that critical thinking might be a transferable or generic skill.

- Barriers to Critical Thinking
- Facilitating Factors for Critical Thinking
- Critical Thinking in the Curriculum – the interviews were coded to identify teaching strategies that promoted critical thinking, how critical thinking was taught for undergraduates and postgraduates and how critical thinking could be assessed or measured.
- Critical Thinking as an outcome of university education – interviews were coded to identify how critical thinking was valued by the discipline and to identify how important academics felt critical thinking was for students.

3.2 Definitions of Critical Thinking

It is hoped that this work will inform research into critical thinking in the university curriculum. While critical thinking is often stated to be very important to graduates, the definitions of what critical thinking really is are confused and diverse. Do all disciplines see critical thinking as the same? Our analysis of interviews would suggest that definitions are broadly similar, with some differences between disciplines in a number of areas. The greatest differences, in terms of definitions of critical thinking, however, lies in how the disciplines have reached those definitions and in how firmly those definitions are rooted in literatures and knowledge of educational and pedagogical approaches.

It became apparent very early on that some disciplines, such as social justice and law, have very clear ideas of what critical thinking is, its transferability and its importance:

“In terms of my own understanding of critical thinking that it is just absolutely the centre of everything that either myself or my colleagues would have done over the years in terms of trying to get people to not just take things at face value. Always thinking, is that true, what is the evidence, whether the counter possibilities if you were looking for a way of substantiating it how would you do it? If you were looking for a way of disproving it, how would you go about it? Examining if somebody says something, find somebody who criticizes and evaluate the counter positions and so on. I mean that seems to me to be what I have been doing since I became an academic 35 years ago.”

Definitions of critical thinking in disciplines like social justice and law were informed by reference to educational literature and theories. In those disciplines, discussions had been conducted between colleagues about the importance and meaning of critical thinking and there had been attempts to explain critical thinking to students.

For other disciplines, such as agricultural science and engineering disciplines (architecture and civil engineering, mechanical engineering), critical thinking was felt to be important and featured in module descriptors and learning objectives but when asked what critical thinking was and to give some definition of critical thinking, the definitions held by those disciplines of critical thinking were not very clear and there was no real single definition agreed in any of those disciplines of critical thinking. It was apparent that little discussion had taken place in these disciplines about what critical thinking really was and the term was being used in learning objectives without a concrete understanding of its meaning. In those disciplines, while interviewees agreed critical thinking was something that should be encouraged in students, there was little real knowledge of research into critical thinking or of how critical thinking has been defined in education and pedagogical literature. The definitions used for critical thinking tended to be a little vague and were focussed on improving students’ ability to think independently or on encouraging more creative thinking.

However, while differences exist, there are some striking similarities in how disciplines defined critical thinking. In the interviews it became apparent that many of the ideas that different disciplines hold about critical thinking are similar, whether they are informed by literature and research or not. Most agree that critical is about being able to look at evidence, whether that is

scientific evidence or historical evidence, and to be able to reflect upon, analyse and question that evidence. Critical thinkers, in most disciplines, were people who were questioners, who could problem solve (particularly in the technical disciplines) and who could use experience and evidence to inform their decisions - critical thinkers were people who could use known knowledge and skills to solve unknown problems and situations.

3.3 Barriers to Critical Thinking

Significant barriers to encouraging critical thinking in students were deemed to exist in the third level system. The most important and most frequently mentioned in the interviews were:

- The secondary education system: There was considerable criticism across all disciplines of the secondary education system which all academics blamed for producing students who could *“learn off mathematical formulae or mathematical tricks and regurgitate them in exams”*. Across all disciplines it was felt that the second level system rewarded students who were strategic, who could learn off facts and required little or no independent thought. In fact, it was felt that the secondary system discouraged critical thinking and so universities first year groups were populated by students who had received high marks to gain a place in university courses, with few if any critical thinking skills. This meant that those students were uncomfortable with independent learning and needed to learn this skill of critical thinking, analysis and questioning from scratch in first year.

Reference was also made to the fact that in Ireland, students enter university at a very young age, which may mean that they are not as cognitively mature as their European counterparts:

“Remember that we get our students very young by international standards, they really are quite immature in 1st year and even in 2nd year. They have been, I think, not very well served by the nature of their secondary education and we talked about that earlier on. By 3rd year they are beginning, perhaps, to become a bit more mature themselves as people and therefore be able to think a bit more critically as in master’s year. A lot of them are doing their masters at the age of 21 or whatever, when a lot of continental European undergraduates wouldn’t be half way through their undergraduate degree. So we do have that rather unusual age profile in this country.”

- Large class sizes: It was felt by many of those that we interviewed that larger class sizes were detrimental to producing critical thinkers. Teaching approaches in these situations were more traditional and there was less time for debate, discussion and deeper thinking:

“So in terms of encouraging something like qualitative like critical thinking, it is a very big challenge if you have got a class of 300 three times a year, three groups of 300 or 400, trying to engage with them at that level, it is a long way removed from it.”

- Lack of basic skills in students: In some courses, like economics and engineering, students arrived into the undergraduate courses from a variety of backgrounds with different subjects taken at second level. Therefore, the first year in university was very much taken up with trying to ensure that all students had the same basic mathematical skills and statistical skills:

“...the big hurdle that we have to get over is a more basic one and that is the numeracy skills, mathematical skills and statistical skills for our students are things we have to

invest a huge amount of time and effort in. And therefore to that extent the critical side gets shoved to one side by the shear technical demands of the subject.”

The same problem was found in many of the scientific and mathematical disciplines, like engineering and chemistry, where students are taking a wide variety of new science and mathematical subjects in the first year and must be brought to a certain technical level before they can embark on any more challenging work, requiring critical thinking. It was felt that subjects like engineering, economics and chemistry are so content driven in the early years that the space for introducing critical thinking was minimal. This was less of a problem in courses in the humanities. Does this indicate that students are badly prepared in these technical subjects at second level? Does this mean that universities are doing the jobs that should be done at second level and therefore cannot engage in what should be done at 3rd level – that is encouraging critical thinking, independent learning and questioning? This should be something that those of us in engineering should be concerned about.

- The modular system: For some academics, the existence of a modular system made it more difficult to create critical thinkers. Students were less likely to see links and coherence between their courses when each subject was an independent module and some academics felt that a programme approach was more conducive to creating critical thinkers in disciplines. Therefore, engineers should be taught in engineering programmes with an overall more cohesive approach to the design of that program which would allow critical thinking skills to be embedded across subjects and for subjects to be linked.

3.4 Facilitators to Critical Thinking

There were several things that academics felt helped and facilitated them in engendering critical thinking in their students. In particular, it was felt that less traditional teaching approaches, like problem based learning and group work, where students were engaged in independent learning, were more likely to lead to critical thinking.

Academics also felt that students who spent longer in university also became stronger critical thinkers than others. There was an element of cognitive maturing evident in students, that as they moved further and further away from their experiences in second level and more exposed to different type of teaching and different ideas at 3rd level, their ability to be critical thinkers and to engage in critical reflection was strengthened, particularly in post-graduate students:

“But clearly you expect a student's ability to engage critically arguments to become more sophisticated as they go on. But that is partly because they become more sophisticated in the particular forms of critical thinking that are inherent in that discipline.”

3.5 Critical Thinking in the Curriculum and Critical Thinking as an Outcome of a University Education:

Disciplines were very different about how they felt that critical thinking could be assessed and taught. The professional disciplines, like engineering, architecture and law, were keen to build critical thinking into their modules from an early stage, even if they did not call it critical thinking. But they asked students to develop analysis skills, research skills and skills of independent learning very early on and built these into the curriculum. They used diverse assessment techniques (work placement, theses, research projects, group projects) to try to assess if students had developed these skills. This may be because these disciplines are training students for particular careers (engineer, architect, solicitor/barrister) and in those careers it is

felt that people must be able to question themselves and others, must be creative and must be analytical.

Disciplines from the humanities (like social justice and sociology) also saw critical thinking as something that needed to be embedded into a curriculum from the first day the course began. This is not surprising given the particular subjects in question (social justice and sociology) where analysis, questioning and reflection of theories must be core to these studies.

In other non-professional, scientific/mathematical disciplines, like economics and chemistry, it was felt that critical thinking was not a skill that would be engendered in all students early on in their academic careers and in those disciplines that some students would not actually need to learn this skill until they were final year or postgraduate students. This may be because these students are not generally being trained for a particular career and the degrees undertaken are more general than a professional degree. Indeed, we were told by those in the scientific and mathematical disciplines that not all graduates needed to be critical thinkers as they may not be in careers where critical thinking was important or valued, although these careers are very much in the minority. For most graduates, in these disciplines, critical thinking was still seen as an important attribute that universities can engender in graduates and it was acknowledged that progress in these disciplines and successful careers in these disciplines would usually require some level of critical thinking.

4. Model for Critical Thinking and Future Work

Arising from the analysis of the interviews, and from the literature reviewed, a model for critical thinking was established to help with the analysis of the module descriptors and the student work. This model draws upon both the work of Maton (2007a; 2009) and how academics seemed to view critical thinking. While there were differences between academics in our interviews, it was apparent that there were also broad similarities in how they defined critical thinking. The differences lay mainly in how developed or informed that definition was, with disciplines like social justice and law having very firm definitions that were informed by the literature; while disciplines like engineering had definitions that had arisen from experience and empirical data rather than from research or literature. Both groups, however, saw critical thinking as something more abstract, less context dependent and requiring some form of judgement or analysis on the side of the student. This links closely, we feel, to some of the work of Maton (2009) where he defines concepts of semantic gravity and semantic density:

Semantic Gravity:

Strong semantic gravity – this implies that the work is context dependent and empirical.

Weak semantic gravity – less bound to context, more abstract.

Semantic Density:

Strong semantic density – this implies a lot of meaning is packed into symbols or individual words. Examples are not given.

Weak semantic density – this implies unpacking of the meaning with examples and evidence.

We see semantic gravity (SG) and semantic density (SD) as inversely proportional – that is that they move in opposite directions along a continuum. While strong semantic density is more likely to be associated with critical thinking, it is not desirable to *always* have strong SG and weak SD or vice versa. Instead, it is important to have movement along the continuum and to recognize that critical thinking is dynamic. It is a movement backwards and forwards between the real and the abstract, the narrow context and the broader generalities.

When the interviews had been coded, module descriptors and all accompanying documentation relating to the nominated modules was also uploaded to NVivo. In addition, anonymised work from students (submitted with the permission of the students involved) was also scanned and uploaded to NVivo for coding. This documentation was then analyzed using the model of critical

thinking as outlined above. As mentioned above, critical thinking is dynamic. In our model we see weak SG/strong SD as being represented by “why do I do this?” and strong SG/weak SD as “how do I do this?”

For students to be critical thinkers, there must be movement back and forth between “why do I do this” and “how do I do this”. In our analysis of module documentation we sought to find guidance and pedagogical approaches that would engender the ability to conceptualise, to abstract and to develop strong semantic density in students. We looked for those approaches that would lead students to ask “why do I do this?” However, it is also important that the students can set their debates and reflections in context, to describe the context of their arguments and reflections, and that they can also exhibit strong SG and so module descriptors and handbooks related to modules were also analysed to find those guidelines and approaches that would bring this about and would show students how to do what they needed to do.

The analysis of the documentary analysis will be dealt with more deeply in a future paper. However, the main conclusions that were reached in relation to this documentary analysis are:

- Critical thinking is evident in the work of students but student require guidance on how critical thinking may be achieved. It is important that assessment tasks are clearly described and outlined to students with key words that will help students to transition from concrete to abstract and back to concrete.
- This guidance is actually more important than the assessment task itself. We examined long essays where little critical thinking was evident, while we saw short blogs and paragraphs where students clearly demonstrated the ability to move from concrete to abstraction and conceptualization. The differences were that in these tasks, modules had been accompanied with detailed handbooks and clear instructions for assessment tasks that showed students what was required from them and gave clear guidance on the students.
- Students are capable of critical thinking at all levels – from first year to postgraduate. However, expecting students to suddenly learn critical thinking in their final year will not bring results. Those pieces of work where critical thinking was most evident were in courses in modules where critical thinking had been introduced from year 1 and where students were constantly challenged to learn more than facts. This is particularly important in professional courses, like engineering, where so often we are told there is no opportunity to challenge students early on as there is so much content to be gotten through. However, we argue that for students it is vitally important that they learn not only facts and content but also how to think and how to be critical thinkers from a very early stage as this will help them to transition from the learning methods they are used to in the second level system to engaging in deeper more meaningful learning.

5. Future Work and Conclusions

From the analysis of the interviews with academics from different disciplines and the analysis of students work, a key finding of this work is that critical thinking is important to most discipline but that the clarity of understanding of the term “critical thinking” varies quite significantly, with disciplines like law and social justice having very clear and precise definitions of critical thinking while professional and scientific disciplines are less clear on what they mean when they ask students to be critical. However, even in those disciplines, like engineering, where definitions are less well-informed and less clearly expressed, investigation and close analysis of what academics were saying show that many of the ideas and perceptions academics from a range of disciplines have of critical thinking are similar: all seem to agree that it involves students being more questioning, less accepting of facts as given to them and that it generally is a skill that students attain as they move from lower years to higher years.

There are differences in approach to teaching critical thinking across disciplines. The greatest difference is that in disciplines like engineering where academics are less sure of their own definitions of critical thinking, there is less explanation of the term to students and students are not told quite so explicitly what is expected of them. While in disciplines like social justice and law, students are given guidance of how to become critical thinkers and of what is expected from them as they move through the university system. In our opinion, if universities claim to produce critical thinkers, we need to be more explicit about what it is and how it is realized and how it can be recognized. It is with this in mind that we have developed a model that outlines what we feel critical thinking is: a movement from the concrete, from the factual to the abstract and back again – an ability to use knowledge and facts to create ideas, concepts and solve problems but also to use these developed concepts and ideas in the real world. In our opinion, this model of

Leading on from this work, the next stage is to engage with the employers. Letters have been sent to employers in engineering, health, IT and education in order that we might find out what they think of critical thinking, how important it is to their employees and whether universities are answering their needs. It is intended that the interviews will take place in summer 2011.

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