Analysis of critical thinking skills in an international, cross-institutional group of engineering Master's students

Michael D. Bramhall, Linda Gray, Chris Corker, Kenisha Garnett and Richard Hill

Abstract: *UK educators often express concerns that students from some cultural backgrounds frequently seem unwilling or are unable to apply critical thinking skills within their academic programmes. This may be due not to a lack of ability or confidence but rather to the way they have been previously taught and assessed. Often, the design of UK courses implicitly requires critical thinking skills, but the design of the use of these skills in courses may not have taken into account the conceptualization of critical thinking across a diverse global group of students. This paper reports on the results of a study of Master's engineering students from two universities in the UK to assess their conceptualization of critical thinking. The findings provide evidence that international engineering students' understanding of critical thinking is not well developed, although they may, without being aware of it, have a critical thinking mindset, and often display these skills.*

Keywords: *critical thinking; international students; Master's students; curriculum design*

Michael D. Bramhall (corresponding author) is with the Faculty of Arts, Computing, Engineering and Sciences, Sheffield Hallam University, Sheffield S1 1WB, UK. E-mail: m.d.bramhall@shu.ac.uk. Linda Gray is with the Department of Automatic Control and Systems Engineering, University of Sheffield, Sheffield S10 2TN, UK. Chris Corker is with the Faculty of Development and Society at Sheffield Hallam University. Kenisha Garnett is with Sheffield International College, Sheffield S3 7HQ, UK. Richard Hill is with the Department of Computing and Mathematics, University of Derby, Derby DE22 1 GB, UK.

Engineering programmes in UK higher education are often shaped by the (UK) Engineering Council's accreditation requirements. The UK Standard for Professional Engineering Competence (Engineering Council, 2003) is the guide used by professional bodies in engineering in the UK to align their accreditation requirements for professional membership and registration with the Engineering Council as an Engineering Technician (EngTech), Incorporated Engineer (IEng) or Chartered Engineer (CEng). The educational requirements to be a Chartered Engineer are an MEng degree; or an accredited undergraduate degree

plus an appropriate Master's degree or further learning at Master's level. One of the required competences is to 'conduct appropriate research, and undertake design and development of engineering solutions' (Engineering Council, 2003). This includes an ability to:

- identify and agree appropriate research methodologies;
- assemble the necessary resources;
- carry out the necessary tests;
- collect, analyse and evaluate the relevant data;
- draft, present and agree design recommendations, taking account of cost, quality, safety, reliability, appearance, fitness for purpose and environmental impact; and
- undertake engineering design.

Additionally, they need to be able to implement and evaluate the effectiveness of design solutions. This could include the ability to:

- ensure that the application of the design results in the appropriate practical outcome;
- implement design solutions, taking account of critical constraints;
- determine the criteria for evaluating the design solutions;
- evaluate the outcome against the original specification; and
- actively learn from feedback on results to improve future design solutions and build best practice.

Clearly an engineering graduate studying at Master's level will therefore need to develop and exhibit critical thinking skills. One definition of critical thinking is 'reasonable reflective thinking that is focused on deciding what to believe and do' (Ennis, 1987). Mason (2008) describes critical thinking as including deep and evaluative reasoning skills, critical or questioning attitudes and subject knowledge in depth such that critical thinking is therefore linked to the context of the discipline. Our view is that the engineer is often required to gather information, look for solutions, analyse the information, design solutions, then evaluate and reflect on the outcomes. However, questions arise: do our engineering programmes make clear to our students at the outset what we expect of them in terms of their critical thinking attributes? Do we prepare them well and help them to develop the necessary skills, or is it just implicit in how we teach engineering? What is their conception of critical thinking? Feng (2008) contrasts styles of learning in the UK with those in China and suggests that the Chinese learner tends towards the Confucian style, in which the learner is respectful of knowledge and works hard to memorize and understand, whilst the Western learner tends toward the Socratic style in which the learner is encouraged to question accepted knowledge and to develop their own ideas based on accepted knowledge. We believe it is not as clearly defined or demarcated as this and that students adopt a range of learning styles according to how they are taught and assessed. Critical thinking takes place, but it is not always evident.

Methodology

In order to establish our students' conceptualizations of critical thinking we needed to decide which attributes or components of critical thinking we would analyse with our students. In that context, Bloom's taxonomy (Bloom, 1956) can be used to help classify the levels of learning and development that students are expected to achieve in their courses and programmes. In engineering the higher levels of analysis and creativity are important components of critical thinking. Scheffer and Rubenfeld (2000) proposed 17 consensus components of critical thinking in nursing. Castle (2006) modified these and produced the 13 components as shown in Table 1.

Initially, focus groups were held with Master's engineering students from the two collaborating universities, to determine how they conceptualized critical thinking. Nine questions were devised for the initial focus group sessions with these engineering Master's students (see Table 2). These questions were produced with reference to the content of engineering degree programmes, which includes significant investigative project work. These focus groups were facilitated by independent researchers so that the students could speak freely about their thoughts and experiences.

A range of themes emerged from the analysis of the focus group data.

- There was a significant expectation of being closely guided by academic tutors that outweighed the expectation of self-directed learning.
- There was a lack of appreciation of any need to challenge, probe and evaluate established views.
- Participants predominantly demonstrated a lack of understanding of the need to provide a rationale to justify any particular approach, although they did identify the need to be systematic.

The resultant need to gather more information about students' conceptualization of critical thinking informed the content of a survey questionnaire, for exploring four key topic areas:

- information management;
- inquisitiveness, organization, systematic approach;
- problem solving and analysis; and
- open-mindedness, reflexivity and evaluative skills.

Table 1. Components of critical thinking.

Component	Skills required
Information seeking	Inquisitive seeker of knowledge, truth and understanding, identify and search relevant sources for evidence and gather data/
Analysis	Break down the whole into parts to discover function, relationships, with a systematic approach.
Evaluation	Make judgements and draw issues based on reliable evidence.
Reflection	Contemplate own thinking, knowledge and assumptions to allow for a deeper understanding.
Creativity	Generate, discover or re-structure ideas and imagine alternatives.
Prediction	Predict potential outcomes and consequences.
Discrimination	Identify inconsistencies, distinguishing relevant from irrelevant, recognising differences and similarities.
Context	Consider background and influences relevant to an issue.
Perseverance	Pursue a course of action with determination to overcome barriers.
Flexibility	Ability to adapt, modify or change ideas, processes and behaviours.
Open-mindedness	Tolerant of divergent views, identifying own beliefs and prejudices.
Knowledge transfer	Change nature of form or function from one concept to another.
Confidence	Develop effective communication style, trust own reasoning skills, with intuitive and insightful understanding.

Source: Modified versions of Castle (2006) and Scheffer and Rubenfeld (2000).

Table 2. Focus group questions based on critical thinking compontents.

Questions	Critical thinking component	Themes for analysis
Q1. Where do you think students should find information during their academic courses?	Information seeking; discrimination; context.	Information management skills.
Q2. What do you think is the best way for students to decide what to read as part of their academic work?	Information seeking; discrimination; context.	Information management skills.
Q3. What do you think is the best way for a student to decide what tasks to do in their MSc project, and in what order to do these tasks?	Analysis.	Inquisitiveness, organization, systematicity skills.
Q4. What do you think is the best approach to problem solving?	Analysis; perseverance.	Problem solving and analytical skills.
Q5. Thinking about carrying out experiments, what do you think is the best approach to interpreting results?	Evaluation; prediction.	Problem solving and analytical skills.
Q6. What does the term 'reflective practice' mean to you?	Reflection; knowledge transfer.	Open-mindedness, reflexivity and evaluative skills.
Q7. Suppose you were a project supervisor for an MSc student designing a robot. How would you expect the student to come up with the design in terms of the process?	Creativity; context; knowledge transfer.	Inquisitiveness, organization, systematicity skills.
Q8. If you were asked to write an essay that compares and contrasts two journal articles, how would you approach this?	Discrimination; evaluation; context; flexibility; open-mindedness.	Open-mindedness, reflexivity and evaluative skills.
Q9. If the project supervisor for your MSc project asked you to justify your use of a particular method for evaluating a set of data, how would you do this?	Confidence.	Inquisitiveness, organization, systematicity skills.

The questionnaire was distributed to a taught postgraduate engineering cohort of 109 students (approximately 50% from each institution): the representation of nationalities in this cohort is shown in Table 3. Questions from the focus groups were included in the questionnaire to assess the relative importance of and links between the themes which emerged. Some questions were merged because they covered similar critical thinking components (Table 2). The factors for each question reflected the points raised by participants

Table 3. Representation of nationalities in the student cohort studied

Nationality	Representation
Bosnian	1%
Bulgarian	1%
Spanish	1%
Syrian	1%
Brunei	2%
Pakistani	2%
Greek	3%
Iranian	3%
Libyan	3%
Thai	3%
Nigerian	12%
Malaysian	13%
British	14%
Chinese	17%

during the focus groups, ensuring each response option was mutually exclusive. This enabled the challenge of evaluating and choosing among different perceptions of critical thinking, and producing sufficient justification for proposed action, to be dealt with effectively.

Findings

Information management skills

The most frequently used sources of information were the library and university sites (86% and 82% respectively). Whilst Internet search engines are a popular source of information, there was greater use of general search engines (79%) compared to academic search engines (56%). This is also apparent in the number of students (68%) who felt the best information for coursework is found by searching the internet for quick solutions to questions. In summary the students recognise the importance of exploring background and context, but need to trust their own reasoning skills; there was evidence of too much reliance on tutor guidance and the use of Google®.

Inquisitiveness, organization, systematic approach

This is the ability to analyse a large task, break it down into smaller parts, design solutions, produce prototypes and give justification for the processes chosen. Students were asked how they used these skills in developing their Master's research project: 67% showed evidence of independent thinking in saying they would propose project tasks to their supervisor, although 81% said they preferred to be guided by their supervisor. Most understood the need to understand context (98%), background (98%), limitations (93%) and scope/aims of defining the project (92%). Most also understood the need to justify their project methods by comparing a range of methods, but stated they would use methods used in previous similar projects or use the easiest route. There appeared to be a lack of self-confidence, independence and analysis in depth with regard to this theme.

Problem solving and analytical skills

This theme is about applying theory to practice for dealing with complex problems. Engineers typically are required first to understand the background to a problem, then analyse and propose a solution, develop it and finally test and evaluate the success – or otherwise – of their solution. In this theme the results showed evidence of a systematic approach to problem solving, with 91% of students using expert solutions, 83% reviewing the literature, and 86% exploring similar problems. When asked about presenting data, most stated that they used visual presentation – graphs, charts, etc – but some 50% said they would let the reader draw their own conclusions from these. The results show that the students exercise good lateral thinking skills to adapt solutions to deal with particular problems. They understood the need to link theory to experimental results and exhibited proficiency with laboratory-based work using exemplar engineering methods. However, the results did suggest that they needed to be confident about their analytical skills.

Open mindedness, reflexivity and evaluative skills

This theme was about reflective practice, making sense of similar or contrasting viewpoints, and the ability to formulate their own views and opinions: to analyse and learn from experience. The results suggested that there was no general consensus amongst the students about the meaning of 'reflective practice'. It has to be admitted that this was perhaps due to an ambiguity in the questions used in the questionnaire: more work needs to be done to explore this theme further.

Conclusions

Using focus groups and questionnaires, this research into the conceptualization of critical thinking by international engineering students has provided evidence that the understanding of critical thinking of such students is not well developed. However, these students may, without being aware of it, posses a critical thinking mindset and critical thinking skills. We would argue that staff observations that students from some cultural backgrounds lack an understanding of critical thinking are possibly more the result of the different expectations and backgrounds of the staff with regard to thinking processes and learning styles.

Future work

Further work is required, using the data gathered, in particular to investigate the effect of different cultural backgrounds in the analysis of student responses and the impact, if any, this has on students' conceptualizations of critical thinking.

Acknowledgements

The authors would like to thank the UK Higher Education Academy's Engineering Subject Centre for a small scale teaching development grant to fund this research.

References

Bloom, B.S. (1956), *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain*, David McKay, New York.

Castle, A. (2006), 'Assessment of the critical thinking skills of student radiographers', *Radiography*, Vol 12, pp 88–95.

Engineering Council (2003), UK *Standards for Professional Engineering Competence (UK-SPEC),* http://www.engc.org.uk/ecukdocuments/internet/document%20 library/UK-SPEC.pdf, last accessed 10 May 2012.

Ennis, R.H. (1987), 'A taxonomy of critical thinking dispositions and abilities', in Baron, J.B., and Sternberg, R.J., eds, *Teaching Thinking Skills: Theory and Practice*, Freeman and Co, New York, pp 9–26.

Feng, A. (2008), Presentation from Workshop: *'Culture of Learning: What? Why? and How? — Enhancing the Academic Experience of Chinese Students'*, Sheffield, available online at: http://shef.ac.uk/content/1/c6/08/39/87/Sheffield%20Talk%2026–06–08.ppt, last accessed 10 May 2012.

Mason, M., ed (2008), *Critical Thinking and Learning*, Blackwell, Oxford.

Scheffer, B.K., and Rubenfeld, M.G. (2000), 'A consensus statement on critical thinking in nursing', *Journal of Nursing Education*, Vol 39, pp 352–359.