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Facilitating intellectual and personal skills development in engineering programmes

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Abstract: *Accreditation of engineering programmes now requires evidence of substantial development of personal skills in addition to discipline knowledge. Criteria developed by professional bodies refer to a broad range of personal skills such as teamwork, leadership, communication, self-direction for life long learning and ethical awareness. It is argued here that the development of personal skills is synonymous with a growth in intellectual development (Perry, 1999) and reflective judgement (King & Kitchener, 1994). Engineering programmes are in general very good at developing technical knowledge and skills but many students fail to achieve acceptable levels of intellectual development by final year. Student-centred learning, provided through a group-based, project-driven spine throughout the programme, can facilitate a high level of intellectual development and lay a foundation in thinking for personal skills to be developed to the level required by professional bodies. Programme teams should consider measuring and reporting levels of intellectual development as part of quality assurance and accreditation processes.*

Introduction

Engineering graduates are under increasing pressure to demonstrate high levels of personal skills. The accreditation criteria of professional bodies such as the Accreditation Board for Engineering and Technology (ABET) in the US, Engineers Ireland and Engineers Australia, to name but a few, now include the development of a broad range of personal skills (ABET, 2008; Engineers Australia, 2011; Engineers Ireland, 2007). Evidence of a 'strong contribution', a term used by Engineers Ireland, to the development of teamwork, lifelong learning, ethics, communication and self-direction is required in the programme to satisfy the accreditation criteria. Numerous anecdotes of intensive probing for personal skills are relayed by graduates applying for their first job. Many employers devote significant time to assessing the level of personal skills during the recruitment process. Government reports on skills needs often call for greater attention to be paid to the development of critical thinking, creativity and innovation in engineering programmes (Forfás, 2009). Today's engineering students are experiencing the effects of curricula changing in response to this new outlook of graduate attributes.

Achievement of high levels of many personal skills is greatly facilitated by a concurrent growth in intellectual development – autonomy in learning, commitment to ethics, willingness to lead and display initiative are hallmarks of the relativistic thinker. The engineer whose intellectual development has not yet passed the dualistic and multiplistic stages and is still reliant on authority for direction and decision making will not score highly on personal skills, will be unattractive to employers, and has yet to realise his/her potential. Personal skills development will be facilitated by an engineering curriculum that promotes growth in intellectual development. Attention should be paid to the intellectual development of the students throughout the programme to optimise their progression from dualistic to relativistic thinking. Process facilitated student-centred learning can support this growth. Evidence of strong contribution to programme outcomes related to design and personal skills should also come from measurements of levels of intellectual development among students.

Intellectual Development Models

Intellectual or student development models attempt to categorise the stages of development evident in young adult and later years, from adolescence to adulthood. Each stage is associated with a different way of viewing the nature, origin and value of knowledge and the use of evidence in justifying decisions. Progression from one stage to the next reflects an increasing sophistication in one's view of knowledge and use of evidence to support argument. How one reasons through open-ended problems to provide and defend answers is noticeably different in each of the stages. These stages can be broadly grouped under dualism, multiplicity and relativism. When presented with three alternative models the dualistic thinker will wonder which is the right one (and why the lecturer is presenting the other two); the multiplistic thinker, believing that anything goes, will attempt to add his/her own model to the list; while the relativistic thinker will consider each model based on the evidence used to develop it, judge which is appropriate for a particular circumstance and examine the pros and cons of each (adapted from Rapaport, 1984). A number of intellectual development models exist, the dominant ones being Perry's model of Ethical and Intellectual Development (Perry, 1999), King & Kitchener's model of Reflective Judgment (King & Kitchener, 1994), Belenky, Clinchy, Goldberger & Tarule's Women's Ways of Knowing (Belenky, Tarule, Goldberger, & Clinchy, 1997) and Baxter Magolda's model of Epistemological Development (Baxter Magolda, 1992). These models are only briefly described below as the emphasis in this paper is on their relationship to engineering education. Summary reviews of these models can be found in Love & Guthrie (1999) and Felder & Brent (2004).

We know from studies reported by Perry (1999) and King & Kitchener (1994) that the typical outlook of a student entering college is that of the dualistic thinker. This student is young, has just finished school and expects certainty in life. He/she believes there is a right answer to every question and that academics, being figures of authority, know these answers and will provide them. Unquestioning assimilation of knowledge is the goal of this student; questions are only asked to make sure the information has been transcribed correctly. A movement to the next stage, multiplicity, is marked by an acceptance by the student that there is uncertainty in some areas, i.e. a number of right answers may exist but the way an answer is defended is not considered – the student does not yet apply a rigorous approach to choosing a solution. The acceptance of uncertainty is significant, however, as it allows progression to the next stage, relativism, in which uncertainty is now accepted as a permanent feature of life, problems are seen in context and judgements are evaluated based on their adequacy.

During this progression the student's view of the role of the teacher changes from the only source of knowledge to one source of expertise among others. The student's view of his/her own role changes from a passive recipient to an active constructor of knowledge – an epistemological change. The view of peers in the learning process changes from irrelevant to legitimate. A student's position on this scale has a fundamental influence on how the student engages with a learning activity.

Perry's model (1999) has nine positions, the first six relate to epistemological change and the remainder defined by degree of commitment to decisions. King & Kitchener (1994) focused on epistemological development which influences the way one reasons through ill-structured, open-ended problems. This is labelled reflective judgement and is synonymous with post formal critical thinking. The seven stages in their model are grouped into three categories: (i) pre-reflective thinking, which is similar to dualism and early multiplicity (positions 1 to 3 on Perry's scale), (ii) quasi-reflective thinking similar to late multiplicity/relativism subordinate(position 4) and (iii) reflective thinking, which is similar to relativism (positions 5 & 6). Students can operate at more than one level. Interviews measure functional level, that evident in independent spontaneous thinking. With support, one can reach a higher optimal level, typically one stage above functional (King & Kitchener, 1994).

Relationship between gains in intellectual development and personal skills

A comprehensive set of personal skills can be found in the accreditation guidelines produced by professional bodies in the field of engineering. For example, Engineers Ireland require that a programme facilitate the development of an "*understanding of the need for high ethical standards in the practice of engineering…the ability to work effectively as an individual, in teams and in multi-disciplinary settings, together with the capacity to undertake lifelong learning [and] the ability to communicate effectively with the engineering community and with society at large*" (Engineers Ireland, 2007). These requirements are shared by many accrediting bodies; ABET in the US have similarly phrased outcomes and Engineers Ireland are signatories to the Washington Accord and a member of the European Network for Accreditation of Engineering Education. A student's current level of intellectual development has important implications for the level to which these skills can be developed.

Consider the dualistic thinker: he/she does not view him/herself as a valid source of knowledge, does not yet appreciate that knowledge is a process of construction controlled by the learner and believes there is a right answer to everything which the lecturer will provide. This belief relates to both process and product, i.e. what is to be learned and how. This outlook is not consistent with the attainment of the accrediting body's programme outcomes outlined above. The ability to work independently on an open-ended problem requires an attitude that one can learn independently of the teacher. To work meaningfully in a group one must view the members as legitimate sources of knowledge. To commit to a set of ethics one must view oneself as owning those values, beliefs and knowledge, not handed down without thinking but the result of considering opinions based on the evidence presented, the way it was gathered, and the context in which this happened. These are hallmarks of relativistic thinking.

Life long learning, managed independently by the learner, is consistent with a constructivist epistemology where one accepts that knowledge is created through an active process of inquiry with input from various sources and where nothing is final but open to re-evaluation and modification. King & Kitchener (1994) describe the reflective thinker as an active player, not a spectator, in the process of learning who accepts that solutions to ill-structured problems must be constructed. Lifelong learning will be a challenge for the dualistic thinker who is reliant on authority for direction. Likewise, the multiplistic thinker will approach this in an ad hoc manner and will not address knowledge gaps in a rigorous manner.

The view of peers in the learning process changes dramatically across the intellectual development spectrum: dualistic thinkers rely on authority only and do not see peers as valid sources of knowledge; multiplistic thinkers accept peers but do not analyse or evaluate their arguments; while relativistic thinkers accept their peers may have valid arguments worthy of debate. For a group to have a meaningful conversation, i.e. one that leads to the development of understanding, members must view each other as legitimate sources of knowledge. Members must also view themselves in the same way. The ability to work with others in a meaningful way, a key requirement in the programme outcomes, follows the acceptance of the legitimacy of peers which emerges on the path towards relativism.

The first six stages in Perry's model (1999) relate to intellectual development while the last three differ in the way one commits to a judgement in a relativistic world. Perry labelled this 'ethical development' as the change relates to the firmness of beliefs and depth of responsibility associated with one's decisions. Engineers are expected to have 'ethical responsibility' as their actions and decisions address a societal need in most cases. Development of ethical responsibility to a high level requires a corresponding high level of commitment within relativism. Dualistic and multiplistic thinkers are far below this position. They simply accept a set of values handed down (dualism) or believe that everyone is entitled to his/her own opinion without a need to question (multiplicity).

Although not mentioned explicitly by Engineers Ireland and ABET in their accreditation criteria (ABET, 2008; Engineers Ireland, 2007), critical thinking, creativity and innovation are often called for by professional bodies and government skills needs reports (e.g. Forfás, 2009). As explained by King & Kitchener (1994), critical thinking is synonymous with reflective judgement. They distinguish between formal and post formal critical thinking – the former relates to the use of critical thinking techniques while the latter relates to the way one reasons through an ill-structured, highly open-ended problem. This depends on one's epistemic assumptions and level of intellectual development. For the dualistic thinker, creativity will be a task to keep the teacher happy by getting the right answer while the multiplistic thinker may be creative but won't critically reflect on the creation. Again, high levels of attainment in critical thinking and creativity accompany high levels of intellectual development.

Specification and design of systems to meet defined needs is a key skill across engineering disciplines specified in accreditation criteria (ABET, 2008; Engineers Ireland, 2007). Grappling to determine solutions for open-ended problems is particularly important in a world that is experiencing unprecedented consumption of its resources. In design, a student develops his/her solution to a problem based on a sound level of understanding of the discipline, often having specified the requirements as well. It must be accepted that many solutions will work; it is not that one is right and others wrong but that each is evaluated based on its properties, suitability for context and tested against the specifications which in turn must be evaluated in a similar way. One must intelligently argue one's case as well as doing the maths. This is relativistic thinking; high levels of skill in design are possible for relativistic thinkers. A student that is highly dependent on authority for affirmation of opinions will see design as a guessing game at best or a task to be avoided at worst. For a programme to have a strong contribution to "*the ability to design components, systems or processes to meet specific needs*" (Engineers Ireland, 2007) it must facilitate the progression of students to relativistic thinking as much as possible.

Amount of intellectual development during college

In a number of studies summarised by King & Kitchener (1994), the typical gains in development during four years in college have been measured to be half a stage on their Reflective Judgment model, from a mean of 3.5 (late pre-reflective) in the first year samples to a mean of 4.0 (early quasi-reflective) in the fourth year samples. Significant differences between scores for adult and traditional age students were not observed. Progression from 3.5 to 4.0 is small but positive. This gain reflects a move from temporary to widespread uncertainty in knowledge, a realisation that some problems are ill-structured and that evidence is required as part of justification. However, widespread uncertainty is also seen in the area of evidence, hence judgement about evidence is also uncertain. A stage 4 thinker assumes others think this way too, including authority figures, which leads to the idea that everyone is equally entitled to an opinion without the need to justify it in a rigorous, considered manner.

A single study in the context of engineering education which measured development of engineering undergraduates over four years scored first year students at 3.3 and fourth-year students at 4.2 on the Perry scale (Wise, Lee, Litzinger, Marra, & Palmer, 2004). This represents a move from early (position 3) to late (position 4) multiplicity but not as far as relativism (position 5). Wise et al. (2004) did not find any relationship between grade point average (GPA) and Perry position in the students they interviewed. This suggests that despite a limitation in intellectual development and associated post-formal critical thinking the engineering student can be very successful in the programme and achieve high grades. In addition, progression along the scale during the college years has been shown to be more modest for engineering students compared to those in humanities and social sciences (Jehng, Johnson, & Anderson, 1993).

Role of student-centred learning

Principles associated with student-centred learning, which come from the constructivist view, are well aligned with the promotion of relativistic thinking. Intellectual development should be seen as a journey from dualism to relativism that is individual for each student, has different start and end points for each and should occur in a steady, progressive way from first to final year. An engineering programme should facilitate as much development as is possible for each student to justify the high levels of skills claimed in the accreditation criteria. It is easy to make claims for the development of ethics, for example, but deliver in a didactic way. In interviews with accreditation panels students can report being forced to think for themselves when the change was only from dualism to multiplicity.

Achieving relativistic thinking after four years in college is indeed a serious challenge given the data reported on final year students. In fact, student-centred learning requires a level of autonomy in learning that lies in relativism for it be as effective as it promises. Dualistic thinkers may not get the point of student-centred learning but must in some way experience the disjunction that exposure to it creates so they are motivated to progress. Their desire is for certainty in everything, both what and how. Modules that satisfy this desire by providing the 'right' answer in a didactic approach to learning avoid provoking the students into the difficult intellectual dilemma of moving to the next stage. Although some may appear to be bored in lectures, they are happy to postpone this transition.

King & Kitchener (1994) outline a number of principles to encourage development. One is to match instruction to level. For example, a student at position n on Perry's scale may not be able to understand an activity aimed at position n + 2 (Rapaport, 1984); this can occur when a student is asked to do a self-directed final year project after years of predominantly didactic teaching. On the other hand, pitching the activity at too low a level will fail to engage. Learning, teaching and assessment strategies should require students to operate at their optimal level.

A student-centred approach to learning, in particular a group-based project-driven approach such as problem or project-based learning (PBL) in which the learning process is facilitated by the tutor, will allow many of King & Kitchener's (1994) other suggestions to be implemented. This process includes the use of ill-structured, open-ended problems based on discipline content. The use of small groups allows students to be treated as individuals so each can operate at their own level. Frequent, formative feedback from the tutor on a student's performance can focus on development issues and require students to move on from their current stage. PBL creates a disjunctive experience in early years, thereby encouraging movement, but can be prevented from becoming excessive by the tutor. Problems can become progressively more complex over time to maintain activity at the optimal level. Assessment can also shift focus: a heavy emphasis on self-directed learning and group collaboration skills can be maintained for the first one to two years; as development occurs this can be relaxed, contact hours can be reduced and feedback can move to other areas such as design, creativity, ethics and formal critical thinking techniques. By the final year students should have progressed to as high a level of development as possible with a corresponding level of attainment in personal skills. In their work, Wise et al. (2004) found that group-based project-driven modules enhanced development and argue for the importance of sustaining student-centred learning to maintain development.

The framework for self-assessment used in Alverno College (Loacker, 2000) is an example of using reflection on performance to facilitate development. Students are required to analyse and evaluate performance before suggesting ways to improve based on criteria provided for them in the early stages but developed by themselves in later years. The Alverno College Ability-Based Learning Program (Mentkowski, 2000) is very much aligned with the integrated development of discipline and personal skills throughout the curriculum. This is in keeping with the development of a reflective practitioner, a label Schön (1991) gave to those he found to be effective in their professional roles. It also falls under the 'engagement' and 'participatory' categories of conception of personal skills development described by Barrie (2007), these categories being the most complex identified in his study.

Ways of measuring intellectual development

In research studies, position on the Perry scale is commonly determined by interview, essay or questionnaire, listed in decreasing order of both time and richness of data (Moore, 2000). The essay test is known as the Measure of Intellectual Development (MID) and relates to the intellectual positions on the scale, i.e. 1 to 5. Students are asked to write three short essays about learning in class, making a decision and choosing a career. Both the MID and the interview must be assessed by trained raters which is time consuming and expensive, hence a demand for easier methods (Wise, et al., 2004). Moore (2000) developed a questionnaire as an alternative which is called the Learning Environment Preferences test. The Reflective Judgment Interview (RJI) is used to determine position on the Reflective Judgment Model (King & Kitchener, 1994) again requiring the use of trained raters.

PBL tutors that have an in-depth understanding of intellectual development can estimate position through observation in the group meetings and by reading students' reflective reports. Demands for certainty and direction from authority (e.g. tutor or a web search engine) are easily identified during group discussions. Likewise for inappropriate use of evidence to justify decisions and lack of in-depth consideration of alternatives in design and problem solving tasks. This can be labelled as a lack of critical thinking but, as King & Kitchener (1994) point out, this is post-formal critical thinking, influenced by epistemic assumptions. Formal critical thinking tools play an important role but are best chosen and implemented by relativistic thinkers.

Conclusions

The high levels of personal skills demanded by accrediting bodies should be accompanied by a growth towards relativistic thinking throughout an engineering programme. Intellectual development and personal skills development are so intertwined that some terms such as critical thinking and ethical development are used in describing both. Personal skills such as teamwork, self-directed learning, life-long learning and design are heavily influenced by one's view of knowledge. Neither a dualistic nor multiplistic outlook is consistent with the degree of independence in thinking that is required for these graduate attributes. Proficiency in these skills is contingent on a mature method of reasoning and a high degree of autonomy.

Engineering programmes do encourage growth but many students only reach multiplicity by the time they graduate despite achieving high grades. This is positive and is a personal challenge for the students resulting in feedback of high demands placed on them by lecturers but is not far enough to satisfy the outcomes specified in accreditation criteria. Student-centred learning, provided through a group-based, project-driven spine in the programme, can facilitate progression to a high level.

It is worth considering the idea of measuring and reporting intellectual development positions of final year engineering students as part of the accreditation process. Such data will allow staff and accreditation panels to determine the levels achieved during all years of the programme so the potential for independence in lifelong learning, design, critical thinking and ethics can be estimated. Programme teams who foster high gains in intellectual development can defend high levels of achievement in programme outcomes prescribed by accrediting bodies that relate to design and personal skills.

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