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Engineering Literacy: A Component of Liberal Education

Abstract

In "*The Idea of a University*" Newman proposed a theory of liberal of education that had as one of its primary aims "*the enlargement of mind*" which is coincident today with what many educators call "*the development of the whole person*." It is becoming clear that as knowledge has become increasingly fractionalised that there is a need for an education beyond school that re-asserts the primacy of *"enlargement of mind*" as a goal of education. Such an education is necessary in the sense that it should help the student to "*connect views of the old with the new*;" indeed with the current explosion of knowledge one might add the new with the new. Its purpose is to give "*insight into the bearing and influence of each part upon every other, without which there could be no whole […] It is knowledge not only of things but of their mutual relations*." This insight is achieved through a comprehensive or universal knowledge. It is a theory that is as much about the development of skills in the cognitive and affective domains as it is about the acquisition of knowledge.

It is argued that a person who has no perception of the contribution that engineering can make to our understandings of behaviour and society is not liberally educated. At some stage (high school/university) they should experience the study of engineering literacy.

It is argued that the goal of engineering literacy will not be achieved without some missionary activity and curriculum innovation. The process of curriculum innovation is discussed briefly. Engineering literacy is defined and a model used in the training of teachers for engineering studies in schools described. The aim of the course for which they were prepared is defined and the implications for the curriculum and instruction summarised.

There is no single course design and much depends on the educational culture, the aims to be achieved, and the motives of those who want to achieve them. The paper begins with a brief general introduction to the subject that has focused historically on the introduction of technological literacy in schools.

Introduction

In 1959 the scientist and novelist C. P. Snow gave a controversial lecture on "The Two Cultures and the Scientific Revolution".[1] It generated a great deal of heat and not much light. He argued that in England there was a great divide between what might be described as a culture informed by the humanities and a culture that was informed by the sciences, this to the detriment of national development. Supporters of the two cultures thesis would argue that schools were to blame for shortages in the supply of students to science and technology studies in universities, because they did not emphasise these subjects in the curriculum. Shortages, they say, that have persisted to the present.

Some authorities argue that a broadly based school curriculum through to university entry would solve the problem. They have in mind curricula of the type offered in Scotland and Ireland[2]. Attempts to resolve this issue seem to have been half-hearted and the 'A' level remains at the core of the university selection process. In the twenty years following this debate it could be asserted with considerable confidence that an 'A' level in engineering science was the equivalent of 1st and sometimes 2nd year courses in four-year university programmes in other countries. This was achieved at the expense of breadth of study. From the age of sixteen a student, in that period, pursued three perhaps four subjects for two years either in the sciences or the arts (humanities).

For the most part, however, attention was focused on the schools and to argue that teachers should do much more to encourage students pursue careers in science and technology. Some schools experimented with engineering subjects. One outcome of their efforts was the creation of an 'A' level in engineering science. As an examination it was highly successful, as a source of supply of future engineers it was a failure. But several of its supporters argued that it should be seen as a component of liberal education. Many engineering professors objected to this examination and argued that all students should be able to pursue projects through which they would learn the pleasure of technology, and so government through its agencies sponsored "project technology". It apparently had no effect on the supply of students to technology programmes even though it was very successful at providing effective learning experiences[3].

In the last twenty or more years the term 'literacy' has developed to imply "an acquaintance with the basic principles of a subject". For example, in England primary (elementary) schools have been required to ensure that all pupils are numerate, and for this purpose a specified amount of time must be devoted to "numeracy" in each week. Another requirement is that all pupils should be IT literate. This has unfortunate consequences for the image of technology, for technology is more often than not equated with information technology. It is partly for that reason that the title of this employs the term engineering literacy.

It is not clear when the term technological literacy came to be used in the non-IT sense. It seems to be related to the development of school technology programmes that were introduced world-wide in the nineteen-eighties[4]. These spawned a new area for discussion and research. A number of substantial papers on the meaning and role of technology in society were produced. It also led to discussions about the content of the curriculum, and some experimental courses were trialed and evaluated. Standards for technology education were developed in the US[5]. The odd paper referred to higher education and one or two books dealt with the issue of engineering in the context of technology[6]. By and large, however, engineering featured little in these discussions until a few years ago engineers began to take an interest in the contribution that philosophy could make to engineering. This has raised such issues as the identity of engineering and engineering practice; its relationship with science; the role of philosophy in teaching engineering students, and its role in the development of the curriculum[7]. This paper is a contribution to that debate in that its purpose is to argue that engineering literacy is a proper component of liberal education as understood by the nineteenth century Oxford academics such as Matthew Arnold, John Henry Newman and Mark Pattison[8].

For convenience the paper is presented in two parts. The first part presents the case for liberal education as presented by Newman in his "The Idea of a University".[9] The second part presents a model curriculum for engineering literacy. A brief introduction gives the background to the development of the model.

I. Newman's theory of liberal education and engineering

Enlargement of the mind versus knowledge

Of those who have been given the opportunity to found a University, how many have set down a theory of university education on which to base its practice? I do not know the answer to this question except in respect of the one person whose writings are extant and the cause of continuing controversy one-hundred and seventy years after their presentation. I refer to John Henry, Cardinal Newman whose writings on education are commonly gathered together, as he did in 1873, under the title of "*The Idea of a University*." Within them are what today we would call an epistemology or theory of knowledge together with a theory of curriculum that can be generalised from the specific context of the founding of a Catholic university. It must be unique that the framework of this theory of knowledge was first enunciated some years earlier in some sermons he preached as an Anglican priest to the University of Oxford between 1826 and 1843.[10] Apparently this was how higher education was often discussed in those days.

The concept that begins Newman's approach to liberal education is that of "*enlargement or expansion of the mind*" with which he associates the terms- "*philosophy*" and "*wisdom*." Newman considers this to be a process and one aim of university education is to help students develop the skills necessary for that enlargement. Although he does not use such terminology it is clear that he is concerned with both the cognitive and affective dimensions of student development as they are understood today.[11] He argues that while, at the time, it was a much-used phrase, it nevertheless required elucidation for its proper understanding. A similar argument applies at the present time, as for example when the phrase "*educate the whole person*" is used. Without further clarification this phrase can mean what an individual wants it to mean. Be that as it may, the question for engineering education is whether or not it contributes to that enlargement of mind that society would associate with a liberally educated person irrespective of what that person brings with them to their study? It is not the purpose of this paper to discuss this issue, but to argue that a person who has no understanding of how engineering relates to our other understandings of behaviour and society is not liberally educated. It is necessary, therefore, to come to an understanding of what Newman meant by enlargement of the mind and its relation to knowledge.

Newman argues "*that knowledge itself, though a condition of the mind's enlargement, yet, whatever be its range, is not the very thing that enlarges it*."[12] Our ability, for example, to remember numerous and wide ranging facts for the purposes of competing in general knowledge tests is not a guarantee of enlargement of mind. From the many illustrations that Newman gives of the enlargement process he argues that "*enlargement consists in the comparisons of the subjects of knowledge one with another. We feel ourselves to be ranging freely, when we not only learn something, but when we also refer it to what we know before*."[13] This would seem to be consistent with that present-day view of learning that it is the process by which experience develops new and reorganizes old responses.[14] This is clearly what happens or should happen within courses. Without it there could be no development or movement within a course but demonstrating that knowledge has been acquired is no guarantee that there has been enlargement.

Implications for the curriculum

Newman considered that all "[…] *the branches knowledge are, at least implicitly the subject matter"* of the university curriculum. Imparting this knowledge in a philosophical way gives a university its culture. This " *culture is a good in itself; that the knowledge which is both its instrument and result is called Liberal Knowledge;* […]"[15]It is a universal knowledge and the university is conceived of as a *Studium Generale* or a school of universal learning.

At issue is the meaning of "universal." Today we take it to mean "all inclusive" but as Culler points out this was not the case in Newman's time especially as it was used in the context of university education. At that time its usage derived from "*uni-versum*" and meant "*turned into one*." There was, Culler writes - "*a desire to see things whole that forced men to look at the whole body of things, and therefore the true character of a university is not that it teaches all the sciences but that whatever sciences it does teach, it teaches in a spirit of universality*." [16]But this does not mean that it can be done within a single specialism for each subject has something of its own that is specific to itself to offer. Newman wrote; "*If we might venture to imitate* […] *Lord Bacon, in some of his concise illustrations of the comparative utility of the different studies, we should say that history would give fullness, moral philosophy strength, and poetry elevation to the understanding*. […] *the elements of good reason are not to be found fully and truly expressed in any one kind of study*" […] moreover, " *if different studies are useful for aiding, they are still more useful for correcting each other*" […].[17]Each study has its own characteristic way of thinking, and each subject makes its own contribution to our understanding, hence the importance of the skill of thinking. It is the argument for including engineering as a subject in the curriculum of general education.

Necessarily "man," who is at the centre of this aim has to be viewed in all his relationships. […] "*What is true of man in general would also be true of any portion of reality however minute. If we wished to know a single material object-for example, Westminster Abbey-to know it thoroughly, we should have to make it the focus of universal science. For the science of architecture would speak only of its artistic form, engineering of its stresses and strains, geology of its stones, chemistry and physics of the ultimate constitution of its matter, history of its past and literature of the meaning which it had for the culture of a people. What each one of these sciences would say would be perfectly true to its own idea, but it would not give us a true picture of Westminster Abbey.*" [18] So wrote Culler to further illustrate Newman's idea. To get a true picture the sciences would have to be recombined and this recombination is the object of university education. We might go further and add that it is through such recombinations that advances in thought and practicalities are made. But Newman did not think recombination was the same as all the subjects taken together. It "*is a science distinct from them all and yet in some sense embodying the materials of them all.*" [19]This activity is what Newman called liberal knowledge and at other times, as Culler notes, philosophy, *philosophia prima*, Architectonic science or Science of the Sciences. He did not pursue this concept in any great detail, but in the today's jargon it would seem to be a reflective activity of synthesis. An ability to bring all the parts together in order to make a judgement for which reason the subjects of the curriculum cannot be taught as entities isolated from each other. The consequences of this capability for the educated person so produced were set down by Newman in the oft quoted statement about the ends of a university education given in exhibit 1. This statement clearly shows the importance of development in the "affective" as well as the "cognitive domain." To gain such a comprehensive view, study of as wide a range of knowledge as is possible, this to include engineering, is necessary; but how is that to be achieved without some missionary activity and curriculum innovation, and at what level?

"University training is a great ordinary means to a great ordinary end: it aims at raising the intellectual tone of society, at cultivating the public mind at purifying national taste, at supplying true principles to popular enthusiasm and fixed aims to popular aspiration at giving enlargement and sobriety to the ideas of the age, at facilitating the exercise of popular power, and refining the intercourse of private life. It is the education which gives [persons] a clear conscious view of [their] own opinions and judgements, a truth in developing them, an eloquence in expressing them; and a force in urging them. It teaches [them] to see things as they are, to go right to the point, to disentangle a skein of thought, to detect what is sophistical; and to discard what is irrelevant. It prepares [them] to fill any post with credit, and to master any subject with facility. It shows [them] how to accommodate himself to others, how to throw himself into their frame of mind, how to bring before them his own, how to influence them, how to come to an understanding with them, how to bear with them. [They] are at home in any society, [they] know when to speak and when to be silent, [they are] able to converse, [they are] able to listen, [they] can ask a question pertinently, and gain a lesson seasonably, when [they] have nothing important [themselves], [they are] ever ready, yet never in the way, [they are] a pleasant companion, and a comrade you can depend upon; [they know] when to be serious and when to trifle, and they have sure tract which enables [them] to trifle with gracefulness and to be serious with effect. [They] have the repose of mind which lives in itself, and which has resources for its happiness at home when it cannot go abroad. [They have] a gift which serves them in public and supports [them] in retirement, without which failure and disappointment have a charm. The art which tends to make a [person] all this, is the object which it pursues as useful as the art of wealth or the art of health, though it is less susceptible of method, and less tangible, less certain and complete in the result."

Exhibit 1. From the *Idea of a University* (1852) as in the 1947 edition edited by C. F. Harrold, Longmans, Green, London. The seventh discourse on Knowledge and professional skill p 157. The items in […] are changes from the third person masculine in the original

Curriculum innovation

The process of curriculum innovation takes place in a historical and cultural context on which is largely dependent. It generally ignores models of curriculum design, its outcomes resulting from the opinions of the promoters and their experience. Yet systems analyses of the curriculum process show it to be very complex.[20] The one exception is the generally accepted premise that any statement of content has to be preceded by a declaration of aims and objectives (outcomes). Few innovators seem to be aware that even establishing aims and objectives is a complex process that requires "screening."[21] Ignorance in this case would seem to be justified since examples of "screening" are rare although two have been completed in engineering.[22] In brief, "screening" tests the validity of aims and objectives in the light of what philosophy, the psychology of learning, sociology and history have to say about them. For example, the model described below must in the first instance, derive from an understanding of technological literacy that is not only the view of the proponents but acceptable to the public- expert and lay. The proponents will have therefore to be schooled in the development of the idea and of any debate surrounding it.

The success of any curriculum innovation depends on some missionary activity. The idea has to be sold and the model shown in exhibit 2 was the result of selling the idea of technological literacy to the management of The Christian Brothers in Ireland. It involved learning to deal with a different culture with its own language that was in opposition to the language of business and industry. Fortunately their education officers wanted to introduce engineering (technological)studies into their schools and for this they wanted nearly a million dollars (in today's money) to set up a laboratory and manufacturing facility for the training of teachers.[23] One of the grounds that was used in objection was the attention given to the role of engineering wealth creation and what was perceived to be a lack of attention to values. The proponents argued that this was a mistaken view of engineering since all engineering was grounded in values, so they used the illustration in exhibit 2 to make their point. It shows that engineering is grounded in values- personal (e.g. religious), professional and societal. The whole activity is dependent on the individuals and the organization that both shapes them and is shaped by them.

That model was derived from the experience of other curriculum philosophies of engineering,[24] task analyses of engineers at work,[25] and extensive information derived from a study of developments in technological studies in high schools in Europe.[26] It does illustrate the need for knowledge in other areas and the need for the relations between them to be clear. Implicit in the problems that engineering has to solve are complex relationships, and the need to be able to synthesise in bringing about their solution

An important contributory factor was the experience of participation in a programme in a British University designed to develop scientific literacy through physics.[27] It posed several important questions for this project. First, should the course be taught from a historical perspective? Second, how much should its success depend on mathematics? Third, should there be an experimental component? And, fourth, what should the duration of the courses be? Discussion of these and other questions is for another occasion, the purpose this paper being to argue that engineering is a component of liberal knowledge.

Engineering literacy

Engineering is defined here as the art and science of making things that meet the needs of self and society. It is an activity and central to that activity is "design." It is an activity that is a service to both individuals and society that continually creates new problems for both. It is used to create change and at the same time creates the need for change. It requires individuals to develop the skill of adaptability that includes the ability to judge the merits or otherwise of a particular innovation. Engineering literacy requires that we understand how individual's, organizations and society interact with technology, and this requires an appreciation of the values we bring to that understanding. The components of engineering literacy are: (1) the engineering of artefacts or the art and science of designing and making things; the term artefact is to be interpreted broadly to include such things as a computer programme; (2) the engineering (technology) of organizations or the art and science of making organizations work for people; (3) information technology or the art and science of acquiring data in an appropriate form for problem solving and, (4) the art and

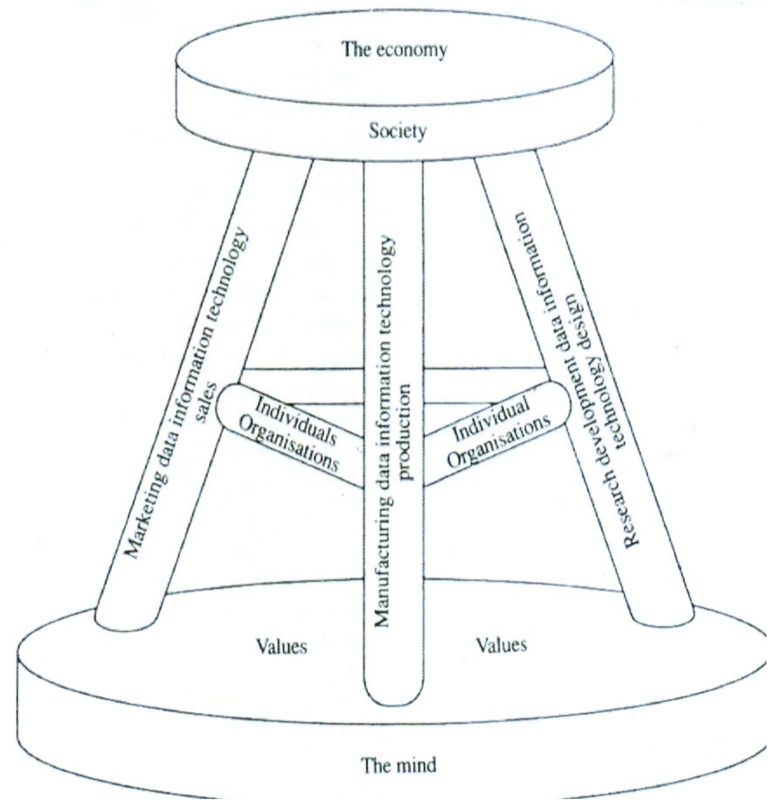

Exhibit 2

science of understanding self and others and the factors that contribute to our aspirations and behaviour.[28]

Engineering as conceived here embraces the study of the political economy, and the study of man *qua* man. It utilises several different "languages" that between them are a multitude of relations. The case for its inclusion in any programme of liberal (general) education, is that the subjects of the curriculum, excepting religious education (theology), when taught disparately, have very little to do with the needs of students as they enter the world; or the needs of society. This is in the sense that there is no real understanding of the implications of technological development for life and social structure; or that economic survival depends on the ability of industry to utilise the technology of organizations and artefacts for its efficiency in generating wealth. Engineering brings all these things together as the simplification of the activity in exhibit 2 illustrates. The base of the stool represents the power of human beings that resides in their minds. It is the mind that is the source of ideas and decisions. Information is passed from and to the mind along the legs that contain the technologies of action that support the economy and embrace society. The horizontal support represents the binding forces brought about by the interactions between individuals and their organizations.

Engineering literacy has as its objective, the appreciation of engineering through an understanding of the relationships as represented by the model. Its contribution to liberal education would be to give an insight into the way of thinking of engineers in order to enable judgements to be made about the value of projects and the risks associated with them. A by-product of this approach is the development of generic skills related to problem finding and problem solving especially as they relate to the design cycle. It receives from liberal knowledge that ability that helps a person to understand themselves in relation to others and society more generally.

The prime aim of a course in engineering literacy would be to show the relevance of engineering to the solution societal problems and to develop capabilities in the judgement of the merits of solutions that are proposed. It would involve showing the students what engineers do when they are doing engineering, an aim that implies giving them an experience which might be through case studies or some kind of investigation or project. An American course that wanted to teach what biologists do when they are doing biology to non-scientists used research papers in the case study mode among small groups of students[29].

For engineering this aim may be expressed in terms of the ability to comprehend papers of the type that appear in *IEEE Technology and Society* and *IEEE Spectrum* but especially articles and comments in quality newspapers.

To achieve this aim it would be necessary that the materials and activities used should
1. illustrate the structure of thought and methods of inquiry in engineering and how it differs from science especially physics;
2. illustrate the centrality of design in engineering;
3. provide an insight into the processes of engineering to such a point that students would be able to increase their understanding unaided, when circumstances required it;
4. enable them to compare the structure of thought and methods of inquiry in engineering to those of their own subjects and interests;
5. consider the implications of the view that engineering design is a social process;
6. help them gain an insight into their own moral purpose.[30]

From inspection of these objectives it would appear that a course in engineering literacy would contain consideration of the following:
The sources of engineering ideas and problems (creativity, invention and innovation).
The design and manufacturing cycle. Modelling
The potential and limitations of materials and processes.
The potential and limitations of machines for the manufacturing process.
The determinants of cost, quality and morality in engineering and manufacturing processes (optimization).
The determination of risk and safety in engineering taking into account moral purpose.[31]
The significance of product design in engineering, and design in styling.
The potential of electronic devices in information technology, and control technology.
The assistance which the application of scientific principles can give to each stage of the engineering activity.
The significance of industry in wealth creation and the roles of the entrepreneur and innovator.
The significance of the market in product design and manufacture.
The voting contribution of the individual in a democratic society as a determinant of prevailing and future socio-economic models.
The understanding of human behaviour and factors that contribute to personal and interpersonal competence.[32]

Again, at first sight, the achievement of these objectives would appear to be a tall order for what is likely to be a relatively short course, so the question of approach looms large. Newman's idea of re-combination suggests there are two methods that are most likely to achieve the integration that is required. These are case studies and mini-projects coupled with advanced reading following the learning technique of the advanced organizer. Atman and Bursic found in a controlled study of engineering students that those who read a textbook about engineering design subsequently exhibited more complex design processes than those who had not.[33] But such books have to be carefully chosen and it might be better to prepare specifically designed materials as was done by Heywood and Montagu Pollock in the radio astronomy section of a course in physics for arts (humanities) students.[34] Case studies are often used in the teaching of engineering ethics and carefully chosen ones can be used to illustrate the role of science in design. In respect of the former the well-documented failure of the Challenger Space Shuttle disaster that exploded and killed its crew is still in use even though the event occurred more than twenty years ago. It shows quite clearly the need to understand how other people think through illustrations of the thinking of managers and engineers as they tried to determine if the shuttle should be launched. It also deals with the problems in the relationships between professionals (engineers) and managers, and it is a reminder of need for managers in these circumstances to be engineering literate.[35] There are, of course, more recent cases as a paper *Learning from disasters'* shows.[36] The same paper also illustrates an article that achieves the primary aim of a course in engineering literacy. There are other articles that can be used to both develop and assess basic engineering science.[37]

Other case studies may be provided to show how engineering science is used in engineering design. For example, the matrix in exhibit 3 is from a series of matrices that were designed to show the parameters that have to be taken into account when designing an aircraft ventilating system.[38] But there is nothing like practice and this can be achieved through projects of three types. These are design and make projects undertaken by an individual, the design and make projects undertaken in teams, and projects (investigations) undertaken for the purpose of undertaking a technical investigation. An example of the latter is the construction of bridges with balsa-wood for the purpose of investigating the parameters of different types of structures. But none of these methods will contribute to liberal knowledge unless there is reflection on the process and outcomes achieved.

In our work in Ireland we successfully experimented with one-week intensive courses in manufacturing, and technical investigations with high school students aged between 15 and 17. These focused on the development of practical skills and the acquisition of key concepts upon which a course of this kind could be built.[39]

Discussion

The purpose of this paper has been to argue the case for engineering education as a component of liberal knowledge as defined by Newman. It is argued that the mere attendance at lectures in a number of different subjects does not provide liberal knowledge unless the relationships between the subjects are understood and the focus is on the "person" and the "personal.". This will necessitate an integrated approach to curriculum design.

Resources Operations	Energy	Space	Force	Material	Men
Form and properties	Heat, CO2, Effective Temperature				
Location and acquisition	In wings off main power **X**				
Measurement			Compressor characteristic. Pressure/flow Temperature. **X**		
Control		Pilots, passengers, Stewards, compartments			
Transformation and conversion	Cooling: heat removal from fluid			Filters in order to remove dust etc	Number of passengers and crew
Transmission		Recirculated air for heat balance	Method of regulation	What has to be recirculated? What has to be lost?	

Exhibit 3. B. T. Turner's application of a matrix developed by G. G. S. Bosworth to the problem of aircraft ventilation.[27] Detail is obtained by further expansion of the boxes (see exhibit 4). For example it can show a family tree of compressors. In this way the curriculum can be built up on the basis of problems that may or may not be projects. The insertions in the matrix are given as examples. One field of study will appear in several places. Students could be encouraged to build their own matrix at the beginning of a course and pursue the branches of knowledge into where it leads them. A model curriculum that made use of this approach is described in Heywood, Turner et al (1966)

	Energy	Space	Force	Materials	Men
Location and acquisition	**X**	Wings	Torque Shaft	Normal steels except for blading	Design organization of sub-contract
Measurement	Kerosene fuel and ram air	Determined by available space left in wing and flow and pressure of ram air.	**X**		

Exhibit 4**.** Shows the first expansion of columns two and three in Exhibit 2.

It is argued that engineering curricula illustrate an internal need for recombination within themselves, as students often do not perceive the interconnectedness between the individual subjects.[40] Achieving this would be a step toward learning the skill of synthesis (recombination) necessary for the acquisition of liberal knowledge. Case studies and design projects lend themselves to the study of engineering literacy. Ideally, for more effective group work, especially in design, a course would be made up of students from different disciplines including engineering. There is no single course design and much depends on the educational culture, the aims to be achieved and the motives of those who want to achieve them.

1. Snow, C. P. (1959) *The Two Cultures and the Scientific Revolution*. The Rede Lecture, Cambridge. The reply (0pposition to the thesis) came from F. R. Leavis in the Richmond Lecture at Cambridge on *The Significance of the Two Cultures*.

2 In the k-12 programme in England at the time students chose to do either science or arts(humanities) between the ages of 15 and 16. They then specialised solely in these areas. They usually took three or four subjects e.g pure maths; applied maths; physics; chemistry. In Ireland and Scotland the final school leaving examination students would take examinations in the humanities, languages, the sciences and maths but to a lower level than those in England. The examinations in England are called 'A' levels.

3 There is a short account of the development of this examination in Carter, G., Heywood, J and D. T. Kelly (1986). *A Case Study in Curriculum Assessment. GCE Engineering Science (Advanced).* Roundthorn Press, Manchester. For a review of the debate that led Engineering Science and "Project Technology" see Page, G. T. (1965). *Engineering among the Schools*. Institution of mechanical Engineers, London.

4. See for example Blandow, D and M. Dyrenfurth (eds) (1992) *Technological Literacy, Competence and Innovation in Human Resource* Development Proceedings First International Conference on Technology Education. Technical foundation of America ISSN 08633401.

5. *Standards for Technological Literacy: Content for the Study of Technology* (2000) International Technology Education Association, Reston, VA

6 See for example Mitcham, C (1994) *Thinking through Technology. The Path between Engineering and Philosophy*. University of Chicago press, Chicago.

7 (a) Christensen, S. H et al (eds) (2007). *Philosophy in Engineering*. Academica, Denmark.
(b) Workshop on Philosophy and Engineering (2008). Royal Academy of Engineering, London.
(c) Christensen, S. H et al (eds) (2009). Engineering in Context. Academica, Denmark.
(d) Poel, I and D. Goldberg (2009). *Philosophy and Engineering. An Emerging Agenda (Philosophy of Engineering and Technology*). Springer-Verlag, London.

8 See for example Sparrow, J (1967). *Mark Pattison and the Idea of a Un*iversity. Cambridge University Press.

9. Newman, J. H. (1873) *The Idea of a University. Defined and Illustrated. 1 In nine discourses delivered to the Catholics of Dublin. 2. In occasional lectures and essays addressed to the members of the Catholic University.* Longmans, Green, London. This edition was reprinted in 1947 with a preface and introduction by C. F. Harrold and also published by Longmans, Green. It is this issue that is referenced in the text

10. Newman, J. H (1890) *Fifteen Sermons Preached before the University of Oxford*. 3rd ed. Rivingtons, London.

11. See for example chapter 6 of Heywood, J (2005). *Engineering Education. Research and Development in Curriculum and Instruction*. IEEE/Wiley, New York.

12. *loc.cit* ref 10. 14th Sermon para 21 – p 287

13. *ibid*

14. Saupe, J. L (1961) in P. Dressel (ed).. *Evaluation in Higher Education*, Houghton Mifflin, Boston

15. *loc.cit* ref 9 p189

16. Culler, A. D (1955) *The Imperial Intellect. A Study of Cardinal Newman's Educational Ideal*. Yale U.P. New Haven. P 180.

17. *loc. cit* ref 9. p 155

18. Culler's illustration is chosen over Newman's because of the reference to engineering, p 182 ref 11.

19. *loc.cit* ref 11 p 182. In Newman ref 9 see pp 40 ff and the fifth discourse.

20. See Ch 1 ref 11.

21. Heywood, J (1981) The academic versus the practical. A case study in screening. *Institution of Electrical Engineers Proceedings* Part A. 128, (7), 511 – 519. See also ref 20.

22. See ref 21 and Heywood, J et al (1966) The education of professional engineers for design and manufacture. *Lancaster Studies in Higher Education* No 1 pp 1 – 104.

23. Murray, M and J. Donovan (1986) Resources and deficiencies in the voluntary sector of secondary education in Ireland in Heywood, J and P. Matthews (eds). *Technology, Society and the School Curriculum: Practice and Theory in Europe*. Roundthorn Press, Manchester.

24. See refs 3 and 22.

25. Youngman, M. B., Oxtoby, R., Monk, J. D and J. Heywood (1978). *Analysing Jobs*. Gower Press, Aldershot.

26 Heywood, J and P. Matthews (eds)Technology, *Society and the School Curriculum. Practice and Theory in Europe.* Roundthorn Publ. Manchester

27. Heywood, J and H. Montagu Pollock (1977) *Science for Arts Students. A Case Study in Curriculum Development.* Society for Research into Higher Education, London.

28. Heywood, J in Toward technological literacy in Ireland. An opportunity for an inclusive approach pp 221 – 256 in ref 26.

29. Epstein, H (1970) A Strategy for Education. Oxford University Press. It is summarised in ref 27 Ch 7.

30. *loc.cit* ref 28

31. ibid

32. *ibid*

33. Atman, C. J and K. M. Bursic (1996). Teaching engineering design. Can reading a textbook make a difference? *Research in Engineering Design*, 8, 240 – 250.

34. *loc.cit* ref 27

35. See discussion in Davis, M (1998) *Thinking Like an Engineer*. Oxford University Press

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37. See for example the papers used for the comprehension sub-test in Engineering Science A level of the Joint Matriculation Board. See Carter, G, Heywood, J and D. T. Kelly (1986) *A Case Study in Curriculum Assessment. GCE Engineering Science (Advanced)*. Roundthorn, Manchester

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