A journey of learning: from educational modules in materials science and engineering, to women in engineering, to experiential learning, to a liberal education for engineers

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ABSTRACT: Through an examination of the author's own activities in engineering and technology education, this paper explores a number of issues that have, and/or still, face engineering educators. It is a journey of learning both for the educator and the student. The learning experience is different for the two parties. Learning styles are different within the student body, for example, male versus female, and there is often a mismatch with the teaching styles of the educators. Through an examination of educational modules, women in engineering, experiential learning, and a *liberal* engineering education, we are led back to John Dewey's (1938) philosophy of *experience and education* in which the students are active members of the community and a sound educational experience involves both continuity and interaction between the learner and what is learned. Experience arises from the interaction of two principles: *continuity* and *interaction*.

INTRODUCTION

Engineering education has gone through many changes in the past 30 years. These changes have taken place not only as a result of changes in technology, but also in response to the changing requirements of accreditation bodies and the demands of society-at-large. Being technically competent is no longer sufficient. Accreditation bodies have moved, e.g. ABET in the USA [1], or are moving, e.g. CEAB in Canada [2], to an *outcomes-based* assessment process rather than one that was *input-based*, essentially a bean-counting process. Increasing importance is being placed on the so-called *soft skills* and the development of the holistic engineer [3]. This has lead to the development of a *liberal* engineering education with the incorporation of a mandatory *complementary studies* component. Increasingly, we are putting the emphasis on learning, rather than teaching and are becoming *learner-centred* or *learning-centred* institutions [4]: the term *learner-centred* is preferred to *student-centred* because *only the learner can learn* and it is not only the student who learns during the engineering education experience.

In this paper, these changes are viewed through the *eyes* of the author and are presented in four sections. In the first section, the development of *Educational Modules* is examined using the disciplines of materials science and engineering as examples. These modules were classified as *pedagogical, peer reviewed, interdisciplinary* and had specified *learning outcomes* (at the time referred to as *skills and knowledge taught* and *objectives*). The second section looks at *Women in Engineering* including recruitment and retention and learning styles (male versus female). The third section examines the many facets of experiential learning. the fourth section is a short, rather *broad brush* overview of what can, or should, be part of the liberal education of an engineer. In the *Concluding Remarks*, we return to the writings of John Dewey on *How We Think* [5] and *Experience and Education* [6], as well as what Gerald L. Gutek [7] has described as a *quest to create a philosophy that integrated human experience and the scientific method in a socially intelligent way to solve problems.* Is this not what we should be doing as engineers?

EDUCATIONAL MODULES

The author is, by education and practice, a materials engineer. As has recently been noted by Lyle Schwartz [8], although the pedagogical aspects of engineering education can be found in publications of the American Society of Engineering Education (ASEE) [9], which serves all of the engineering disciplines, there are relatively few examples of *independent activity in materials education*. One example cited by Schwartz [8] is the Journal of Materials Education (JME), which publishes a wide range of papers *from those of very specific technical nature and detail to broad discussion of accreditation and education principles* [10]. The Journal of Materials Education began publication in 1979 as the Journal of Educational Modules for Materials Science and Engineering (JEMMSE).

Early in the publication history of JEMMSE, the author and two colleagues in the UK were invited to prepare a series of four modules on x-ray line shape analysis, a valuable materials characterisation technique [11-14]. The first module examined the theory [11] and the second module looked at the practical applications [12]. The third module examined the particular application to polymers and amorphous materials [13]. The fourth module compared the various analytical methods used for line-shape analysis and included examples of experimental results [14].

The writing of these modules was certainly a learning experience for all three authors and the modules were much improved by feedback from reviewers. Each module had a number of learning outcomes (described as objectives) and a set of activities to support those learning outcomes. Nearest neighbour links were given together with information on: intended audience; learner study time; recommended support media; skills and knowledge taught; prerequisites. Thirty years have passed since the publication of those modules but many of the lessons learned have proved valuable in our recent work on learning outcomes for co-operative engineering education [15].

WOMEN IN ENGINEERING

Although, over the years, there have been worldwide shortages of skilled engineers, there has been a recognition that a major part of this problem has been the lack of women working in engineering and/or studying engineering. Despite efforts to attract women to engineering, the situation has not changed substantially in many years. Recent data for the UK, quoted by Dame Julia Stretton Higgins show that *only 8.75% of employees in engineering are women, that degree courses in engineering struggle to attract more than 10-15% girls* [16]. These percentages demonstrate both the recruitment and retention challenges. With regard to retention, Dame Julia Strethan Higgins has also noted that with respect to science, technology, engineering and mathematics (STEM):

> *More women than men drop out of careers in STEM subjects in academia and STEM careers in industry, especially in the 15-20 year range. This corresponds, one might observe, to the child-rearing age for many women* [16].

This challenge in recruitment of women in engineering was recognised and addressed, at an early stage at Ryerson University in Toronto, Canada. A Women in Engineering (WIE) Committee was formed in 1989 and an annual Discover Engineering Summer Camp was launched in 1991 by the WIE Committee and its industry partners [17]. The primary objective of the programme was *to introduce young women in high school to the challenges and rewards of engineering through a variety of fun, hands-on activities and discussions led by women engineers, scientists and students* [18]. In the first 9 years of operation of Discover Engineering, over 1,000 young women attended the programme [17]. The hands-on a activities were found to be the most effective component of the camp [17].

Discover Engineering has since been expanded to include visits to high schools and one-day conferences for Girl Guides and young women in high school [18-20]. Despite such initiatives as Discover Engineering, the enrolment of women in engineering programmes in Canada peaked at around 21% in 2001, then dropped, and has remained in the 17-18% range from 2004 to 2011 [21]. These percentages are slightly higher than the numbers for the UK quoted by Higgins [16]. This has lead to an examination (re-examination?) of why so few women choose to become engineers and the image of engineering among secondary school students [16][22]. Many factors have been cited including: *...streaming out of math and science courses, perception of difficulty, lack of exposure to role models, lack of knowledge about engineering and the social status of the profession* [22].

As well as a recruitment issue, there is also a retention issue. One factor in retention is the gender differences in learning styles specific to science, mathematics, engineering and technology [23][24]. A number of useful papers on this topic can be accessed through the Web site of the National Institute for Women in Trades, Technology and Science (IWITTS) [25]. In a multi-year study of over 5,400 students at more than 20 universities, the Centre for the Advancement of Engineering Education (CAEE) showed that female engineering students tend to approach design differently from male students and report less confidence and course preparation to do design [26]. The key observation of IWITTS is that *When instructors and technology courses account for different male and female learning styles the retention rates of women improve* [25].

EXPERIENTIAL LEARNING

The title for Chapter 8 of John Dewey's book, *Experience and Education* is: *Experience - The Means and Goal of Education* [6].

In this chapter, Dewey repeats the principle that education must be based upon experience if it is to accomplish its ends for both learners and for society. This *experience* must always consist of the actual life experience of the individual (student).

Barry Posner made a similar point in discussing leadership education, namely: that leaders learn through practice they *do*. To use Posner's own words:

> *Too often schools teach students about leadership; about leadership theories and concepts as applied to leading. Learning about leadership is not the same as learning to be a leader. Students often learn about what it takes to be a great leader, but they do not learn to be leaders nearly often enough. Just as medical students cannot become surgeons unless they operate on live patients, just as priests cannot find their faith unless they work with suffering members of their congregations, just as elected officials cannot make budget allocations without trade-offs between competing goods, so students cannot become leaders if their learning is restricted to the classroom* [27].

In a similar vein, it could be argued that: learning about engineering is not the same as learning to be an engineer.

Along with collaborators at the University of Windsor and Glasgow Caledonian University, the present author has examined experiential learning in engineering [28], analysed the experiential learning modes relating to the effective education of engineers [29] and examined work-based learning (WBL) in terms of the theories of experiential learning [30]. The paper by Johrendt et al [28] begins with a quote from Seymour Papert: *Learning is not separate from reality* [31].

This paper [28] then summarises what is considered to constitute experiential learning and relates this to the work of Seymour Epstein, who identified two independent, yet interactive, modes of human information processing (learning), namely: *experientia*l and *rational* [32] and to Sternberg's model of the *Triarchic Mind* where he first defines intelligence as the *capacity for mental self-management* and, then, goes on to define three domains of intelligence, namely: componential (academic); experiential (creative); and, contextual (street-smart) [33]. These ideas are explored further by Blair et al [29] and Chisholm et al [30].

Johrendt et al describe five work-based approaches to experiential learning that have been used in engineering programmes [28]. All approaches develop the student's capacity for mental self-management. They are all learner-centred, practice-based and involve a journey of self-discovery and learning that results from direct involvement in real world environments. All approaches are underpinned by a reflective analysis in the real work environment. The other key point made by Johrendt et al is that these approaches (models) *also develop experiential learning that directly relates to the needs and requirements of the learner, while delivering outcomes suitable to the organization that provides the work-based environment* [28].

Blair et al describe three examples from the University of Windsor, which provide opportunities for students to engage in various forms of experiential learning [29]. These examples included a 3rd Year *Automotive Engineering Fundamentals* Course, a 4th Year *Capstone Go-Kart Design* course and the engineering cooperative education programme. The value of the instructional laboratory has been further explored as described by in Johrendt et al [34][35]. Furthermore, it has been demonstrated that key skills, such as teamwork, effective communication, ethics, safety, creativity and the ability to learn from failure, can be imparted to students through an instructional laboratory.

With respect to co-operative education programmes in engineering and computer science, an interdisciplinary research team was formed at the University of Windsor to develop and assess learning outcomes. The appropriateness of existing methods for outcomes assessment were assessed and new reflection and assessment tools were developed. Both qualitative measures, based on student perceptions of the achievement of learning outcomes, as well as quantitative measures, based on portfolio reviews, employer evaluations and faculty feedback on work term reports were used. Further details can be found in Johrendt et al [15][38], Watters et al [36] and Jaekel et al [37].

Our discussion on experiential learning would not be complete without a brief reference to Problem-Based Learning (PBL). PBL has two key components, namely: the starting point is a problem and it is a student-centred (learner centred) approach. The PBL curriculum is organised around a series of problems and the learning favours self-directed learning, group work, critical thinking and self reflection. The teacher has the role of facilitator and coach rather than *sage on the stage*. As noted by Northwood et al in their paper on PBL in the health sciences and engineering and the potential impact on the global workplace:

> *PBL emphasizes learning instead of teaching. Learning is not like pouring water into a glass; learning is an active process of investigation and creation based on learners' interest, curiosity and experiences, and should result in expanded insights, knowledge and skills* [39].

LIBERAL EDUCATION

As originally suggested by Bordogna [40] and elaborated upon by Northwood [3], there was a strong need for the education of a holistic breed of engineer - graduates with the skill to work across intellectual, social and cultural boundaries. This need was, at least in part, being driven by globalisation [41]. At the time of the publication of these papers in 2003-2004, there was considerable discussion of the potential vehicles for the delivery of holistic engineering education. It was already agreed that all the skills required of the holistic engineer could not be acquired by rote teaching and rote learning as practiced in a traditional classroom lecture-based approach [42]. Discussion and debate centred on how the non-technical, sometime called *soft skills*, could best be imparted to engineering students [43].

Also at that time, it was considered that many of these *soft skills* were related to one's emotional intelligence (dubbed EQ). A number of approaches were taken to integrate EQ skills into the engineering curriculum, including WBL (Work-Based Learning) and PBL (Problem- (or Project-) Based Learning) [44]. All of these approaches incorporated an experiential (learning) component. Thus, we see the later development of learning-centred (learner-centred) approaches that incorporate a substantial experiential component and many universities and engineering departments employ one or more *experiential learning specialists*.

The present author has described in some detail the transition of the University of Windsor to a learning-centred university [4][45][46]. Learning-centred simply places the desired results of teaching, i.e. learning, at the centre of conversations. However, becoming learning-centred is more than a semantic change. Rather, it is a major philosophical shift for higher education. Student learning is the most significant goal at the university: it is the end to which all educators' efforts are conducted. Two key questions must then be asked, namely: How will what we do improve and expand student learning? and How will we know it has? The implications are vast for the assessment of learning, design of instruction, formulation of policy and conduct of university business. Learning-centred involves actively engaging students in their learning. When choosing teaching methods, after the outcomes has been set, students are considered first, before the instructor or the material. At the University of Windsor, a range of activities in support of learning-centredness has been identified that includes activities in three areas, namely: the instructor, the administration/administrative support and the learning environment [45].

It is illustrative at this point to quote a previous Provost at the University of Windsor, Professor Neil Gold, on his answer to the question, *Why is the University of Windsor investing in the challenging task of changing the institutional culture to reflect more learning-centred values?* His answer stressed two points:

- The demand for learning-centred education will continue to grow throughout the 21st Century (the century of the student).
- A learning-centred culture works for the benefit of the entire community [47].

CONCLUDING REMARKS

The journey towards the education of the holistic engineer continues. A recent overview of what was new at Ontario, Canada's schools of engineering as they prepare for tomorrow's engineer mentioned a workshop titled, *Envisioning the Renaissance Engineer* [48]. This was a *vision of engineers who are well-rounded problem solvers - socially responsible, entrepreneurial, creative in their artistry and technically proficient* [48]. The concept of the *renaissance* engineer is similar to that originally put forward for a *holistic* engineer.

The path we are taking could be described as *learning centred holistic education* [49] with a major component of experiential learning. A note of caution is in order here. As emphasised by Haddara and Skanes [50] with respect to cooperative education, we should ensure that the experience always translates into true experiential learning and values.

We finally return to John Dewey, and the question posed at the end of the *Introduction* section [5][6]. This author believes that the answer is *yes*: we should integrate human experience and the scientific method in a socially intelligent way to solve problems. As emphasised by Dewey, this experience arises from the interaction of two principles: *continuity* and *interaction* [6]. As pointed out by Gutek, Dewey advises us to *question those who tell us what to think* and to *step back from the noisy clutter of the information age and to reflect on the true conditions of our lives and problems* [7].

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