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Teaching, Education, Engineering and Technological Literacy

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Abstract

In 2010 James Trevelyan [1] argued on the basis of studies of the work that engineers do that the engineering curriculum required to pay more attention to the development of what have come to be known as "soft skills", as for example communication and the ability to perform effectively in teams. He noted that engineering courses that taught communication treated communication "only as information transfer" when what was required was a comprehensive development of social interaction skills. He thought that this could be achieved if students were given the opportunity to teach in their courses because "*education, like engineering practice, relies on special kinds of social interactions reflecting the specialized knowledge that defines the context"*. He argued that students should be trained to teach because they also learn when they have to explain to "*others using such methods as cooperative learning and peer instruction"*. Support for Trevelyan's thesis is to be found in a review of research on learning-by-teaching and its implications for engineering education reported by Carberry and Ohland [2]. Although it is known that some students are trained and paid to act as tutors for small groups in some programmes no information is given in either of these papers about the content of that training. It is argued here that substantial prior training may lead to more effective learning exchanges and subsequently better teaching in higher education.

It is argued that students may benefit more if they have to teach an unfamiliar subject. The training may be linked to the preparation, implementation and evaluation of classes in that subject. Possibly the most effective way of achieving an understanding of the skills involved transfer to engineering is by cooperative education in which one of the experiences is in a school. However, while there are other pathways to achieving the same goal it is not the purpose of this paper to advocate any one way but to illustrate potential that the cognitively adjacent subject of Technological and Engineering Literacy has to offer.

A minimalist approach to training that would meet Trevelyan's requirements based on the concept of "teaching as research is presented". The paper is presented in two parts. The first sets out the case student teaching in Engineering and technological Literacy. The second outlines a minimalist curriculum that is supported by classroom action research undertaken by student teachers. It is preceded by its own introduction.

Part I

Introduction

In 2010 James Trevelyan argued on the basis of studies of the work that engineers do that the engineering curriculum required to pay more attention to the development of what were recently called "soft skills" in the US and are now known as "professional skills", as for example communication and the ability to perform effectively in teams. He noted that engineering courses that taught communication treated communication "*only as information transfer*" when what was required was a comprehensive development of social interaction skills. He thought that this could be achieved if students were given the opportunity to teach in their courses because "*education, like engineering practice, relies on special kinds of social interactions reflecting the specialized knowledge that defines the context"*. He argued that students should be trained to teach because they also learn when they have to explain to "*others using such methods as cooperative learning and peer instruction"*.

Trevelyan's position is supported by a review of research on learning-by-teaching by Carberry and Ohland [2]. They argued on the basis of the available research that there were circumstances in which "learning by teaching" could be a substitute for teacher-centred instruction, aid student learning and help them understand learning-how-to-learn. They provide a useful review of cooperative learning in engineering, as it relates to this topic that supports Trevelyan's position. Pollock of the University of Glasgow [3] described how students learning basic mechanics learnt given topics in small groups and then taught these topics to other small groups. Pollock reported that there was some evidence that teaching others does improve the retention of the learning: there was also evidence that the method used helped understanding and retention of the concept(s) taught.

Neither Trevelyan or Carberry and Ohland discuss what preparation in pedagogy might be useful in preparing students to teach although for some peer tutoring the students are give training and paid. It is argued here that substantial prior training may lead to more effective learning exchanges irrespective of whether it is undertaken as a tutor with one or two students, perhaps in a cooperative learning group, or as an instructor with a class of twenty students.

However, this brings into question the role that educational studies may have more generally in engineering programmes.

It is argued that students may benefit more if they have to teach an unfamiliar subject and the training may be linked to the preparation, implementation and evaluation of classes in that subject. However, while there are other pathways to achieving the same goal it is not the purpose of this paper to advocate any one way but to illustrate potential that the cognitively adjacent subject of Technological and Engineering Literacy has to offer.

Engineering and Technological Literacy

Recent discussions about the nature of technological and engineering literacy reveal that the topic covers a wide range thought and practice ranging from the sociology of the impact of technology on society to the engineering of artefacts. In consequence there are several audiences that may be addressed, as for example children who are technologically but not philosophically literate or, those adults that need a form of vocational education to enhance their life skills. A student in this area has therefore to ask philosophical questions about the aims of education and the purpose of technological and engineering literacy, the purpose of which is to encourage a philosophical disposition and reflective capacity without which a curriculum cannot be planned. Given such a curriculum the student is then able to bring understandings derived from educational theory practice to the design and implementation of lessons. It is shown that much of what happens in managing the classroom situation is relevant to the practice of management. Training for such teaching may be accomplished concurrently after a basic induction.

The advantage of having students design lessons for the early stages of engineering and technological literacy is that while the concepts may be difficult they have the advantage of some knowledge of engineering that will be helpful at the engineering end of the spectrum of engineering and technological literacy studies whereas at the other end of the spectrum that embraces the humanities and the social sciences they are likely to be stretched. But it is at this end training should begin.

Developing a defensible theory of learning

Every teacher should be able to defend the tasks they set students to learn [4]. That is, their teaching should be based on a theory of learning that they have tested and can stand over. In this sense every teacher has to be researcher in order to find out which theories work for them in the classroom and which do not [5]. Such research may range from establishing the merits of some of the 51 Classroom Assessment Techniques suggested by Angelo and Cross [6], as for example the Minute Test or to more substantive pseudo scientific exercises of the kind undertaken by Heywood [7] the curriculum process of which is outlined in exhibit 1. But for these to be successful the learner (student teacher) has to have some idea of what learning is.

1.	Academic Course: Introduction to activity (2 – 4 hours)
2.	Student Preparation (a) *Read the literature on the designated topic* (provided) (b) *Select a small topic from the literature for investigation* (this may be to replicate on of the studies reported in the literature). (c) *Design a lesson to test the hypothesis shown in (b)*; (this to include the entering characteristics of the pupils, a statement of aims and objectives, the instructional procedures showing how they will test the hypothesis etc) (d) *Design a pupil test of knowledge and skill which is directly related to the objectives of the lesson*.
3.	Academic Course: (only if students require a seminar) to iron out difficulties (2 hours).
4.	Student Implementation (a) Implement Class as designed. (b) Immediate Evaluation. (i) What happened in the class? (ii) What happened to me? (iii) What have I learnt about myself? (iv) What have I learnt about my pupils?
5.	One Week (or so) Later. (a) Test Students (b) Substantive evaluation (i) How does what I have done relate to the theory which I set to evaluate? (ii) How, if at all will this influence my teaching in the future? (c) Submit report at the required time.
6.	Academic Activity. Reports assessed using a semi criterion referenced scheme.
7.	Academic Course. (a) Return reports (b) Give general feedback. (c) Ask students to complete an evaluation form

Exhibit 1. The process that was followed for each of five activities with the exception of the activity that compared expository with discovery teaching when a second test (repeat) was required to be given after about six weeks (Heywood, 2008).

A hard lesson that every student teacher has to learn is that students do not necessarily learn what the teacher wants them to learn because the student does not comprehend what the teacher means and takes away something else from what is presented. For example, teachers and students can take away quite different meanings from statements of outcomes required for an engineering course [8]. This suggests that if they can do that with items that are supposed to be "objective" and not open to interpretation some will get into difficulty when they have to learn abstract concepts. But there is another point, and it is part of the reason we give tests of prior knowledge, it is that students bring something with them to each class that may not be misconceptions, and may be valuable. Teaching and learning are two sides of the same coin-conversation.

Any form of teacher training of this kind necessarily has to begin with an introduction to learning and one of the ways of achieving this is through reflective practice by the students on how they learn (sometimes called meta-cognition). Students will be engaged in distinguishing between reasoned argument and opinion which most beginning students find difficult to do. Questioning assumptions is very difficult [9]: it is difficult to do not only for students but for experienced people because their experience can be inhibiting in that it prevents them looking outside of the box [10]. Some students coming to the social sciences for the first time find their values challenged and are unable to cope with this situation (cognitive dissonance). Engineering and Technological Literacy requires students to handle concepts in engineering, philosophy, social sciences and technology.

Part 2

Introduction

Four areas of knowledge and understanding that are likely to help engineering students in the everyday activity of engineering are discussed. In each of these areas student teachers were asked to carry out a classroom research to discover for themselves some or all of the knowledge discussed. Details of each exercise are given at the end of each section. The full details of the investigations carried out by the student teachers have been given elsewhere [9]. The data was derived from the reports submitted for each exercise at the time of assessment, each assessment schedule being annotated. This data was supplemented by questionnaires given regularly throughout the 12 years that the class for which these reports were required was run. The reports and therefore, the activities, were required to follow the schema shown in exhibit 1.

Teaching concepts

There is no better place to begin to understand how we handle concepts than at that end of the spectrum of engineering and technological literacy that asks questions such as- “What is engineering?” (What does an engineer do?), “What is science?” (What does a scientist do?) “What is technology?” (What does a technologist do?).

These are important philosophical issues and in recent years have been much debated [11]. They are conceptually difficult, but discussion of these topics will necessarily draw students into the problems of “teaching” these issues, or enabling students to come to understanding of them, and therefore, how to understand abstract concepts. At the other end of the spectrum where they have some understanding they will need to be brought face to face with the literature on the misperceptions that students have about concepts in engineering science where they will find that even advanced students have difficulties with abstract concepts in engineering science. There is a vast literature on this topic, much of it in the cognitive sciences, but fortunately there are some review papers about misperceptions and concept inventories in engineering that stand the test of time [12]. Notwithstanding the development and validation of many concept inventories there still remains the problem of teaching concepts and ensuring they are not misperceived. One of the best introductions to the topic will be found in a paper by Clement in a 1981 issue of *Engineering Education* [13].

The advantage of teaching engineering and technological literacy students is that there aptitudes and attitudes will not necessarily be focused on engineering and while they will be seeking an understanding of engineering they will not be seeking it an advanced level. One way they will seek understanding is through the use of examples. Most of us find that examples help us learn and teachers often give examples for that reason.

Cowan writes that he had been convinced that conceptual understanding began with examples by the mathematics educator Richard Skemp. Skemp, wrote Cowan, "*that it is essential that a concept is first encountered in the form of examples which establish the beginning of understanding. And he maintained that it is only when an initial understanding has been acquired, through the use and consideration of examples, that any abstract generalisation or refinement of definitions is possible or meaningful. For only at that point, he asserted has the learner developed sufficient understanding of the underlying concept on which to build theories and understanding which use and consolidate the concept.*" [14]

Cowan went on to describe how he had seen an elegant demonstration of the technique at an international conference in a keynote address on the acquisition of concepts. The lecturer "*taught her audience as she had taught her research subjects, the grammatical concept of the morpheme. First, she provided an assortment of examples, all of which were undoubtedly morphemes – and so the concept was established in the minds of the listeners- including me, who had not hitherto encountered it. Then she quickly tabled a set of examples, all of which were not morphemes, although a little earlier I might have classified, while I was still uncertain about what a morpheme is. Thus the concept was yet concreted in the minds of the learners like me in the audience, as it had been in the research study. As her next step, and in refinement of our understanding, she gave us some borderline examples of morphemes and no more, and finally, other borderline examples which were marginally not morphemes. By this time we had well and truly mastered the concept of the morpheme from examples*" [14, p 2].

There is ample research to show the value of teaching by examples and using non-examples in a supporting role. De Cecco and Crawford [15] described a scheme for teaching concepts that uses examples and non-examples (exhibit 2). Stage 1 requires that the teachers are not only clear about what their terminal objectives are but that the students are equally clear. While this may be regarded as a general there will be times when it is desired that the students explore and it is not possible or desirable to indicate the outcomes. Concepts may be indentified by their 'attributes' and 'values'. Their attributes are dimensions of colour, form and size. Each attribute has a value. For example the colour of an object is usually inadequately described by the primary colour – red can vary from scarlet to crimson. Some attributes are more dominant than others and concept learning is at its most difficult when the attributes are not obvious. For this reason at stage 2 the teacher has to reduce the number of attributes to be learned and the most important attributes dominant. At any age when learning a concept the learner is likely to try and simplify the concept.

1. Describe the performances expected of the student after the concept has been learned.
2. Reduce the number of attributes to be learned in complex concepts, and make important attributes dominant.
3. Provide the student with useful verbal mediators.
4. Provide positive and negative examples of the concept in terms appropriate; number and realism.
5. Present the examples in close succession or simultaneously.
6. Provide occasions for student-response and reinforcement of their responses.
7. Assess the learning of the concept.

Exhibit 2.. de Cecco and Crawford's seven instructional steps for concept learning.

It is evident that concepts in science can be very difficult to understand. One reason for this that often they cannot be seen (e.g. force, gravity, momentum). For example, when teaching "clouds" to twelve to thirteen year olds emphasise attributes such as colour, height and shape and avoid difficult attributes such as structure, moisture content, and electrical charge. Those can be dealt with at a later time when the students are better able to cope with abstractions. A spiral curriculum describes an approach to the design of the curriculum that is built on this idea. Thus, in this example the students meet the concept on several occasions during the schooling and on each occasion more material is added to the understanding of the concept.

Graduate student teachers including scientists and engineers find it difficult to define attributes and values but the evidence is that when they are forced to think about the dominant features of a concept they find it to be an aid in the planning and implementation of a lesson. It is also evident that part of the confusion young students have in learning concepts is that many teachers do not take a step by step approach which ensures that the students understand the dominant attributes first. But this takes time and often teachers are unwilling to give that time because of beliefs about the need to cover the syllabus. This is particularly true of instructors in higher education.

There is some evidence to support the view that student learning is enhanced if teachers help them to distinguish between conjunctive, disjunctive and relational concepts. A conjunctive concept is one in which the values are added together. For example automobile as compared with motor cycle and bicycle. A disjunctive concept is probably the most difficult to learn. In a disjunctive concept the attributes and values are substituted one for another. Sometimes they are 'culture bound'. For example, individuals often have difficulty in understanding the games that are particular to a culture – Cricket and Baseball, or Gaelic and American Football. A typical disjunctive concept is that of neighbour.

Relational concepts often relate to science such as distance and direction. It has two attributes that have to be substituted for each other or be related. The "and/or" construction needs to be carefully explained by the teacher as it may be difficult to understand.

It is contended here that failure to grasp the importance in learning by teachers in school and higher education can create difficulties for students. It is well understood that students can acquire misperceptions of science that persist early in their schooling. In higher education teachers pay little attention to the need to determine that students understand concepts although there is a growing use of concept inventories. But these are of little use if teachers do not review their own teaching. Perhaps the most important lesson that has to be learned is that many students need much more time than is often allowed to learn concepts. This has implications for the structure of the curriculum and the importance of concentrating on the essential key concepts.

If students are to teach then they need to be trained in the importance of concepts and methods of ensuring they are learnt. The earlier it is done in a course the more likely it is to contribute to their own understanding of the factors that influence their learning.

Exercise 1. Student teacher research activity for concept learning and its outcomes

The student teachers were required to read the summarised researches in de Cecco and Crawford [15] and McDonald [16] and replicate one of the researches in order to come to conclusions about the best way to teach examples. At the end of the report they were required to read an additional text on teaching concepts and say if they would change their final evaluation as a result.

After the exercise they were asked if, on reflection, they would have done something differently about one- fifth said they would have changed their method. The preferred alternative was concept mapping. Taken together the students confirmed McDonald's finding that pupils differ in their ability to profit from examples but more students prefer a mix of positive and negative instances with positive examples beginning the sequence.

Knowing about students

All the evidence suggests that we do not know as much about our students as we think we do. If you think that is contentious then ask yourselves how much you know about the learning preferences of your students. Or, to put it in another way- "is your teaching influenced by the learning preferences that your students have?" I suggest that many teachers when faced with this question will have to answer "no". Yet we all have preferred ways of organizing what we think about and see, or different styles of conceptualisation and patterning activities. Styles are dispositions to their learning that students bring with them; strategies are approaches they learn as a result of their attempts to learn and to adapt to the learning environment. These styles may the most important characteristic that an individual has in respect of learning so we ought to know what the range of styles in our classes are and this can be done by the use of or another of the available inventories.

Grasha [17] grouped the factors that contributed to learning styles into five categories. They are-

Cognitive *relating to the acquisition, retention, and retrieval of information.*

Sensory *relating to the acquisition of information via the senses.*

Interpersonal *relating to the acquisition of information within social groupings and groups, influenced therefore by the roles and role expectations, group norms, leadership and discourse (occasions of formal and informal learning).*

Intrapersonal *relating to the influence of the individual on him/herself. Needs and motives and especially the thinking needed for self-control.*

Environmental*- relating to the physical environment in which we learn and the resources provided.*

Among engineers the best known inventory for assessing a person's learning style is the Felder-Solomon Index [18]. The parameters of this index are:

Visual/Verbal. Contrasts those who receive information visually with those who prefer verbal explanation.

Sequential/Global. Contrasts those who like a step by step presentation of knowledge with those who like knowledge to be "presented in a broad potentially complex manner that allows them to fill in blanks through "ah-ha" moments".

Active/Reflective. Contrasts those who receive knowledge through hands on activities while internal reflection drives the reflective learner. In the Kolb model the hands-on learner is one who learns through concrete experiences.

Sensing/Intuitive. Contrasts those who like factual knowledge and experimentation with those who like theories and principles. This comes from the Jungian model developed by Myers-Briggs. Within the MBTI are the dimensions of extraversion and introversion popularised by the Eysenck tests, and used by Furneaux [19] in his study of engineering students.

Another learning style dimension that if frequently mentioned in teaching is that of convergent and divergent thinking. Teachers, it is said, respond best to students who are convergent thinkers. They are students who like the confines of traditional teaching and assessment. Very often teaching styles are convergent. Divergent thinkers are associated with people who are creative. There is contradiction between the demands for achievement in conventional assessments and the demands for creativity.

Exercise 2. Student teacher activity related to learning styles and its outcomes

The more important issue was raised by Grasha. That is- "*Should teaching styles be matched to learning styles?*" I put this to the student teachers for whom I was responsible and asked them to obtain their students learning styles, to design a lesson that would take the students through each learning style, to design a test to test the material related to each quadrant and then to see if there was a correlation between the measured learning style and performance. All this is fraught with difficulty not only because of the assumptions that have to be made but because the test design was complex and difficult. So why persist, as I did, over a ten year period. Simply because it achieved the goal I wanted it to achieve.

Irrespective of the two inventories that were used and the difficulty that some pupils had in understanding them they divided the class into groups with which the student teachers were comfortable. Moreover, the student teachers were happy with their preferences as revealed by the inventories. In the first place this led them to ask questions of their teaching style and whether or not it was disenfranchising some students. In the second place it led them to appreciate that a *sine qua non* of effective teaching is variety. I have no means of telling if their findings led to permanent changes in teaching behaviour. The answer to Grasha's question is a little more complex than might be expected because even if the answer "yes" it is very unlikely that a teacher will have a class of students that all have the same style and that style is that of the teachers. Apart from the teaching/learning dimension thinking about a student in terms of his/her learning style can be a valuable aid to understanding that student. It is important to remember that on-line learning has to be designed to respond to a variety of teaching styles.

In relation to engineering practice

One of the lessons that can be transferred to practice is that we all have preferred ways of learning. That understanding will help us to understand that people differ in all sorts of ways and not least in the way they perceive problems. Understanding that may remove communication blocks.

Design/problem solving heuristics

Billy Koen [20] has demonstrated the significance of heuristics in everyday thinking and more especially in engineering. Nevertheless some students find the concept of heuristic difficult particularly when it is generalized. In particular it can be argued the heuristic of engineering design belongs to a more general category as Perkins [21] has argued. He distinguished between knowledge as information and knowledge as design. Since design is a structure adapted to a purpose and Perkins argues that if we view the knowledge we have as structures that will enable us to go beyond the frames of reference of our experience. We can see this worked out in Kallenberg's [22] approach to the teaching of ethics to engineering students, and we can also see that by substation of the engineering examples it is a more general application of design as knowledge. As both Kallenburg and Koen point out in any area of thought and practice that is 'messy' heuristics are valuable.

Exercise 3. Student activity in relation to teaching decision making and its outcomes

I had neither of these things in mind when I asked my students to design and implement a lesson to evaluate the merits of Wales and Stager's design/problem solving heuristic for teaching decision making. This heuristic was widely discussed by engineering educators in the nineteen seventies (Eck and Wilhelm, 1979 [23]; Heywood[24]).

The task was pretty well impossible given the constraints within which these graduate student teachers had to function because I asked them see if by using the heuristic their students learning improved. Of course the teacher might record an increase in achievement but they would not be able to be sure if that increase was due to the heuristic or not. Neither, did I discuss the nature of knowledge with them but, given the remit suggested here for engineering students, for them to approach epistemology from this perspective makes sense.

My students were given literature that introduced them generally to decision making and in which there were a number of heuristics. They were also given details of Polya's model for learning mathematics. Most students used the Wales and Stager heuristic (exhibit 3)[25] which was published in a series of articles in *Engineering Education*: some used Polya's. Many students put in the "look back" activity not in the original model which was also required by the assessment rubric.

The most interesting outcomes were (1) the value that most student teachers and many students attached to the effect that it had on the structure of their lessons and learning (meta-cognition), and (2) it caused many of the student teachers to examine their own decision making processes. It seemed that moderate to weak students valued the structure. Some bright students did not want to be placed in these constraints. A feature that should be given much more significance was that of questioning. Questioning is a high level skill and it is wanted as much in industry as it is in the classroom. Wales and Stager likened the activity to that of a detective and they published a series of exercises based on Sherlock Holmes to show how the model worked [26]. The decision maker as detective had to ask when defining the situation – Who is involved? (the actors), what things are involved? (the props), what happened? (actions) When did it happen? (scene), Where did it happen? (scene), Why did it happen? (cause), How serious is its effect? (effect) etc. they also claimed that model was generalisable and wrote separate books for nursing and mathematics.

1. Define the situation.
2. State the Goal.
3. Generate ideas.
4. Prepare a Plan.
5. Take action.
6. (Look back)

Exhibit 3. Wales and Stager's decision making model – Method of Guided Design.

Design as a general process

The generalisability of the design process is well illustrated by the process of lesson planning and implementation. In this study all the subjects of the high school were represented and the model was found to be of use which tends to support Perkins thesis- knowledge as design [27]. As Trevelyan argues, placing engineering students in a teaching situation exposes them to all the processes that they will experience in industry provided that the generalizability of the model is made known to them. The rubric (heuristic) of assessment that these student teachers had to follow is a design heuristic, as is illustrated by comparison of exhibit 1 with exhibit 3. An important lesson for these student teachers' was that just because there was a plan it did not have to be followed rigidly, something that managers have to learn. Sometimes listening to a student and changing tactics as a result is beneficial to all. Starting from the perspective of engineering students who will teach others, either their peers or high school students, it enables Koen's views about heuristics and their role in engineering practice to be considered. It also opens up the possibility of investigating the relevance of Perkins theory of knowledge as design. Similarly it can provide a valuable introduction to critical thinking. The student teachers in this project were introduced to dimensions of that debate.

All of these activities required planning, implementation and two kinds of evaluation. The first, from the tests they had designed and evaluated. The second, from reflections on the exercise undertaken at various stages in the process. These are key skills required in industry.

Comment

Trevelyan proposed that engineering students should be required to teach their peers and that this would help them acquire some of the skills they are said to lack in the industrial situation. I have tried to develop this notion in terms of teaching high school students as well as their peers. I have suggested that topics from the realm of technological and engineering literacy about which they should have some understanding provide a better basis for teaching than the occasional exercise of teaching their peers. A general conclusion of the more than 7000 case I had to review was that these exercises are all very well but you cannot treat them as isolated exercises. If a learning styles approach is to be used then it has to be integrated into the teacher's curriculum and not just a once-off.

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