# Integrating Thinking Skills into Subject Content to Improve Engineering Learners' Problem Solving Abilities

**K. Loji,**[†] **Author**[†]

† Dept. Electrical Power Engineering, Durban University of Technology, P.O Box 1334 Durban 4004, South Africa, email: kabulol@dut.ac.za

## 1. Introduction/Context

The field of engineering is characterized by problem solving skills and abilities both during the time of study and the time practice. Statistics show that these skills are particularly lacking in learners accessing universities with the aim of studying engineering. To date many causes have been mentioned and are being investigated. As a remedial solution, number of universities have started implementing the foundation or extended curriculum programmes (ECP) in order to address among others, the issue of under-preparedness of learners accessing tertiary education and to ensure mitigating of the high failure rate that the education system in South Africa is going through.

In this paper I discuss and suggest how I have used cognitive education combined with other strategies, approaches and practices to improve problem solving skills and consequently reduce failure rate. I will provide a successful sample case in which I will give an account of the action research strategy that I have used. I will also provide a comparative analysis of students' performance between ECP students who benefited from the intervention in 2009 and main stream students who did not for the same subject. Lastly I will show how the intervention benefited to main stream in 2010 semester 1 and I will further reflect critically on my interventions and add students' comments.

## 2. Scholarly

The Engineering field of study is mainly concerned with problem solving and design and both require synthesis, analysis and evaluation, rated on the bloom's taxonomy scale as the three higher levels of thinking as shown in figure 1 (Miller, Imrie and Cox: 1998). This is supported by Lumsdaine *et al* among others who note that creative problem solving process involves all three types of thinking: analytical, creative and critical (Lumsdaine, E., Lumsdaine, M. & Shelnutt, 1999:11). This is very challenging for engineering learners in general and particularly for the kind of underprepared school leavers accessing the engineering faculties in South Africa.

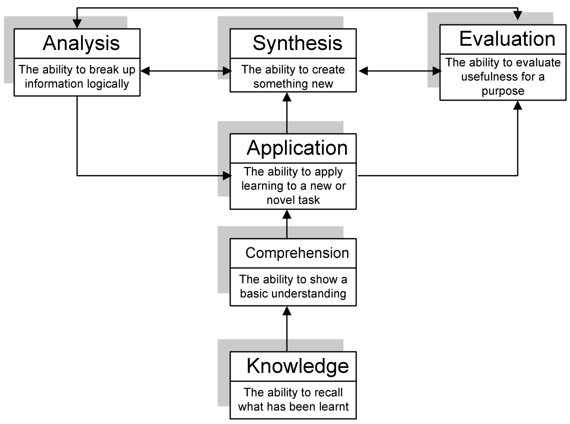


Figure 1: Interrelationship between Bloom's cognitive levels

As also noted by Naudé and Westhuizen (1996:164) and Miller (1998), observations carried out on learners inform us that in any kind of assessment learners are very good at remembering and repeating material from lecture notes and textbooks, but unable to solve problems which they have not previously seen or discussed.

This may be the result of the fact that the teaching arena is still dominated by the pedagogy based on old teaching methodologies mostly characterized by deductive teaching approach as mentioned by Sheppard *et al* (2009:39) in which "the professor stands at the front of the room, copying a derivation from his notes onto the board and repeating aloud what he writes" (Felder et al: 2000) while learners are attentively taking notes.

The teaching model, strategies and style will influence the learning model, strategies and styles of the learner. From another perspective, Reif (2008:32) identifies two types of knowledge: *declarative* knowledge -that specifies factual knowledge about a situation by describing the relevant entities in the situation and the relations among them- and procedural knowledge –that specifies methods or procedures meaning sequences of actions describing how to perform particular tasks. Both types are useful for the learner, however, more use of *procedural* knowledge over declarative knowledge may lead to learner's problem solving abilities reduction:

> Students often try to prepare themselves for a course examination by attempting to remember the particular method that they used on all preceding home-work problems in the course. But all this *procedural knowledge* (even if remembered) can make students quite inflexible and in great danger of knowing what to do if a problem on the examination differs somewhat from previously encountered problems. Hence the students would be much better prepared if they learned *declarative* knowledge about a few general principles applicable to all such problems. (Reif: 2008:35)

On the other hand it is a fact that at the age engineering learners access university they are still in formative stage of cognitive development (Sheppard *et al* 2009:24) and need adequate guidance in developing *reflective thinking*: the highest stage of cognitive development (Patricia King and Karen Kitchener as cited in Sheppard *et al* 2009:25) without which no ill-defined problem can be attempted.

Cognitive goals in engineering students need then to be developed as earlier as possible as this addresses the development of learners intellect (Eggen and Kauchak 1996:12) and, enhances their problem solving skills and discovery of new knowledge (Lau 2004) which better prepare and equip them for professional challenges.

To achieve the transformation described above and reach the ultimate goal of teaching for learning, teachers shall themselves change their way of facilitating learner. It is to that extend that my teaching style and strategies are under review for active teaching-active learning as it will be seen in the description of the innovation and in discussions were I self evaluate my progress as well as the impact of the change in my environment.

I realize and fully agree with Reif (2008:5) that learning can occur spontaneously *without* the aid of any deliberate assistance and conversely, [lots of] teaching can occur *without* any learning (a situation unfortunately all too familiar in many classrooms)

This paper is then also my own inquiry about how I can improve my practice as a teacher.
I found my inquiry in the fact that another way of raising an intrinsic motivation for personal professional development is to ask myself if whilst I am working as a teacher am I really "doing work" in the engineering sense, where "work" is the result of force applied times displacement, i.e.

$$W = F.d \qquad \text{... (Eq.1)}$$

As shown in equation (1) above, if either force (F) or distance (d) is zero, work (W) will be zero. To apply the analogy of equation (1) on my condition as a teacher, I assume that force (F) is my interventions of any kind in facilitating learning and distance (d) is the learners' achievement of preset goals and outcomes meaning, learning taking place.)

## 3. Trends

The issue regarding improving engineering learners thinking skills is an ongoing one in various fields of engineering education in the world. Redish and Smith (2008) of physics engineering education, Felder, Rugacia Stice and Woods (2000) of chemical engineering education , Sheppard, et al. (2009) among others stress the importance of *thinking* about *thinking*: that "metacognitive" approach to instruction which help learners to take control of their own learning by defining learning goals and monitoring their progress in achieving them. David Perkins who claims that: "*learning is a consequence of thinking*" (D. Parkins cited by Eggen and Kauchak 1996:44) suggest that *thinking* and *knowledge of content* be taught at the same time.

Adams, Kaczmarczyk, Picton and Demian (2007) among others consider that one of the most, if not *the* most important skill an engineer must possess is that of problem solving beside the one of being able to think creatively. Houghton (as cited by Adams *et al*, 2007) postulates that since *problem solving* is "what engineers do" then *problem solving skills* shall be the most important thing we can teach our students.

### 3.1 Problem Solving and cognitive education

I profoundly agree with the Sheppard that engineering education differs from most other professional education in a way that at the age engineering learners access university they are still in formative stage of cognitive development (Sheppard *et al* 2009:24). Beside this fact, South African learners accessing engineering faculties are more even underprepared with regard to possessing basic science knowledge.

Problem solving is a "*problem*" both for the learner and the teacher as it involves *reflective thinking*: the highest stage of cognitive development (Patricia King and Karen Kitchener as cited in Sheppard *et al* 2009:25) without which no ill-defined problem can be attempted. There is a need to develop as earlier as possible cognitive goals in engineering students as this addresses the development of learners intellect (Eggen and Kauchak 1996:12) and, enhances their problem solving skills and discovery of new knowledge (Lau 2004:...) which better prepare and equip them for professional challenges.

At the beginning of the engineering studies "problems" are engineering concepts based or subject matter based and as the learner progresses his abilities to solve broad based ill-defined problems or multidisciplinary design kind of problems are much more challenged due to complexity of the design process. My interventions with first year learners will mostly be addressing the concept based problems and at the mean time integrate thinking skill components throughout various activities to motivate the learners to engage in their own learning and to discourage passive learning.

The pressure on lecturers to improve the "pass rate" by means of any 'possible interventions" in engineering faculties is very higher. Improve the pass rate in engineering is the result of improving problem solving abilities, but "Possible interventions" could mean any of the following:

- Lower the standard level during assessments: this is achieved by asking during tests and exams similar questions (change numerical data only) as the ones that were solved in the tutorial, in the prescribed book or in previous tests or exams
- Use any available opportunity to provide "tips" before assessments and/or give the scope of the paper
- Ask all well-defined and straightforward problems explicitly not requiring any higher-level thinking. Make things simple for the learners and let them pass.
- Assess the potential causes of failure and apply possible and progressive corrective measures but keep a high standard that will prepare future engineers to solve familiar and unfamiliar problems during their professional career.

What counts for many learners and teachers nowadays is to pass and the much simpler the "pass process" will be the best for both. Consequently, the three first "possible interventions" which are not very demanding for both the learner and the teacher, are popularly used as "remedial solutions" and are spread over a large number of institutions (primary, high schools, as well as departments in faculties).

The last "possible solution" was chosen to address the deficiency of problem solving skill abilities,

### 3.2 Assessment of potential causes of failure

Investigations conducted on number of learners from mid 2007 revealed many potential causes of failure or difficulties. The three major causes were: Poor reasoning abilities, Low self commitment or independence in the learning and Low self confidence.

#### 3.2.1. **Poor reasoning abilities**

Poor performance in the engineering field as I mentioned it above is closely dependent on the possession of higher level thinking abilities. Observations carried out on engineering learners that I had interacted with for the last past four and half years indicates that they encounter difficulties to start the reasoning process wherever there is no straight application of formulae and worst where numerical data are not provided.

As an illustration, typical sample examples of questions that learners struggle to attempt are given below:

Question 1

Consider two bulbs of the same power P connected in parallel across a source V and giving certain brightness. You connect a third bulb of the same power P in series with the first two (still connected in parallel) and you double the source voltage. What will happen to the brightness of the first bulbs, will it increase, decease or remain the same? Substantiate your answer.

Question 2
What angles the minute's and hour's needles of a watch make when the time is 26 past 2?

Question 3
In the circuit diagram given in figure 2 below, if all the resistors are equal to $R_1$, Show that the equivalent resistance measured between terminals A and B ($R_{AB}$) is equal to $\frac{5}{6} R_1$

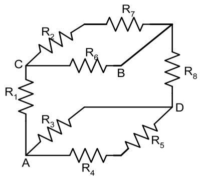


Figure 2: circuit diagram for sample question 3

When asked where their problem is, or where are their difficulties, learners often respond by the question: "how do we know what we should start with to solve the problem or what should be the trigger on the starting point?

Learners are clearly affected by the lack the basic reasoning principles (a part from the formulas) which support their reasoning, reinforce their confidence and validate the process toward the solution. The validation of the process occurs after confrontation between what the learners is doing and some tangible axioms, principles, laws, theorems...that are proven to be true and that will ring the bell if the learner deviates from what does make sense. As a result when assessed, they are "mechanically writing" to fill in the paper or they don't start at all.

### 3.2.2. Very low commitment in self-studying (Lack of independence in their learning)

As a legacy from the twelve years of schooling and probably the perpetuation of the same teaching approaches at tertiary learners show very low commitment to self-study. Some of the indicators are:

i) Learners do not afford to miss lectures, if they do they encounter enormous difficulties to recover as they cannot sustain self study on matters that had not yet been discussed in class;

ii) Extra recommended resources are rarely consulted if learners are not explicitly forced to consult them for assessment purposes

iii) Most of their work done without supervision is of low standard: there is no responsibility of self-learning;

### 3.2.3. Low self confidence and low motivation in learning

This is the obvious consequence of the two other potential causes of failure mentioned above. Unfortunately, low self confidence and low motivation may lead to drop off with all other possible consequences. Space does not allow to elaborate more on the

## 4. Description of innovation

### 4.1. Teaching inductively

The most current dominant pedagogy in teaching engineering principles is a deductive in which as mentioned by Sheppard et al (2009:40) lectures are illustrated by "interrogations and blackboard demonstrations because of among others the challenge of large classes and increasing pressure to cover material". However, deductive teaching method is not learner centred and does not encourage the learner to engage in self and deep learning. Figure 2 (a) borrowed from Sheppard et al summarize deductive teaching method and one can identify the "*professor*" role of the instructor and the quite passive role of the student. Inductive teaching approach shown in figure 2 (b) as suggested by Sheppard et al (2009:50) was the model chosen in many of our lessons and was supported by the following basic processes of thinking: Observing - Finding patterns and generalizing - Form conclusions based on patterns - Assess conclusions based on evidences (Eggen and Kauchak 1996:52).

### 4.2. Need of Conceptual Framework

Sheppard et al (2009:48) suggest that student learn with understanding when they have the opportunity to develop a *conceptual framework* for the facts so that they are not trying to store them as disconnected pieces of information. This is supported by Eggen & Kauchak (1996:14) who consider *cognitive structures* as *conceptual frameworks* by noting that "one way of viewing the information we have stored in our memories is to think to it as an organised and interconnected network of ideas often called a conceptual framework". They differentiate a simple to a complex framework with the later said to have "many points to which new information can be connected, resulting in more information being stored in memory" compared to a simple framework allowing less information to be stored.

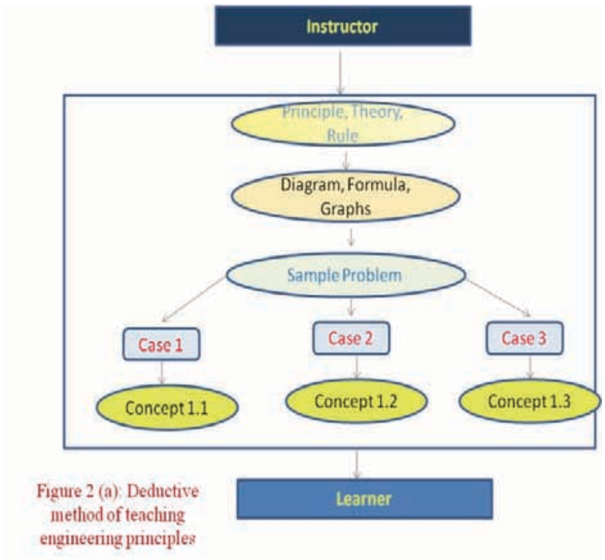


Figure 2 (a): Deductive method of teaching engineering principles

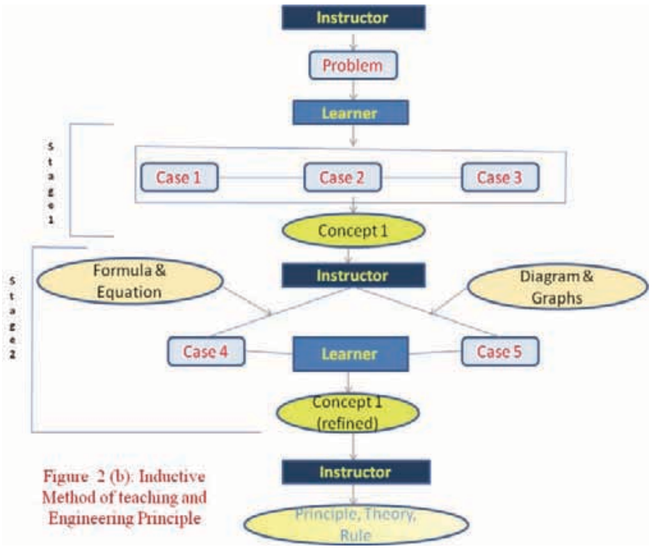


Figure 2 (b): Inductive Method of teaching and Engineering Principle

In addition to the conceptual framework, Eggen & Kauchak (1996:15) suggest the use of cognitive structures as "*schemas*", which describe knowledge as dynamic and useful sets of interconnected ideas, relationships, and procedures. They consider that "Schemas not only organize information and tell us what to expect from the world; they also tell us how to operate within it". Beside "Conceptual framework" and "Schemas", Lumsdaine *et al* suggest the use of mindset metaphors and we have made extensive use of that during class activities.

These strategies enable us to reach the ultimate goal of analytic problem solving by encouraging learners to [always] internalize and construct a framework for conceptual understanding (Sheppard *et al*: 2009:48) as it is indicated in the 2 sample lessons below.

### 4.3. Integrating thinking in subject content

Because of the necessity of learning and understanding concepts that will be used in the course of the program, problem-solving with first year learners was mostly addressing concept based problems (well-defined problems), over open-ended or design problem types which are of higher level of thinking.

The following sample lessons illustrate the way "thinking skill" was integrated in the subject content to get the learners overcome the threshold difficulties of learning all new - in a sense that they were not properly taught- very abstract and "confusing concepts".

#### 4.3.1. Sample lesson 1: Concept of Voltage, Resistance and Current and the relationship between them

Voltage, Current and Resistance are fundamental concepts in engineering field and understanding of these concepts qualitatively and the relationship between them is a milestone in putting in place the first building blocks toward engineering studies. Traditional way of introducing learners to these concepts is usually by presenting a lecture on *atomic structure of the matter, electrical charges,* and later on introduces *voltage, resistance and current* which are all "abstract" and meaningless for underprepared first year's learners. The result is that these concepts are learned each separately, in a disconnected manner and learners' performance when assessed is minimal and limited to answering the question "what?", they can define the concepts but not clearly establish the interdependence between them.

Learning is measured with performance. Reif (2008:4) defines "learning" as the process whereby a learner's initial performance $P_i$ changes to a final performance $P_f$ where the learner do things that he/she could not do initially. In other words, to realise that learning happened one must assess and compare the initial performance and final performance to note the positive difference which is "learning".

1. Observation, finding patterns and generalizing

Initial performance in our case was deeply assessed to understand the level of performing of the learners with regard to the concepts. Learners were required to produce evidences in various forms to demonstrate their understanding of voltage, resistance, current and more importantly to explain how these concepts are connected and interdependent. As noticed by Halloun and Hestenes (cited in Reif, 2008: xiii) learners emerge with significant misconceptions, with fragmented knowledge that they cannot reliably use, and without the problem solving abilities needed to apply the acquired knowledge. Almost 80 % of our learners showed rote learning, confusion and no clear linkage with the concepts.

The big question is how can the learner visualize these "abstract" concepts in manner that when they refer to them they give them their physical meaning and not just explaining them by mean of a formula?

Learners were then taken to the lab to observe electrical phenomenon without explicitly indicating to them which equipment was going to perform what function. The objective was that from experiments they will understand deeply the role of each component and from the results of the observation they will be able to extract the fundamental concepts and their meaning. Equipment are given alphabet names to facilitate the process, but also to minimize the importance of the "name" over the "function" of the equipment as a car driver will necessary not need to know the name of the car parts (gear lever, steering wheel, accelerator,....) to control the car.

Equipment used;

Voltage supply (A), leads (B), 3 resistors of different values (C, D and E), a bulb (F), a voltmeter (G), an ammeter (H), a switch (I).

The following was performed.

- First stage:

  - Observation:

i) Set the supply at *zero* volt and use a voltmeter to take the output measurement and note that the reading is *zero*;

ii) Increase the voltage to at a *certain value* and using the voltmeter measure that voltage and note that it *is not zero;*

*iii)* Reduce the voltage to *zero* and connect the bulb to the supply voltage, *observe that nothing happens,*

iv) remove the bulb, *increase the voltage,* re-connect the bulb and *observe that the bulb is on this time*,

v) *Decrease* progressively the *voltage* and note that the *brightness of the bulb is decreasing*.

*vi)* Connect an ammeter in the circuit with the bulb still in and vary the voltage to notice that at voltage *zero* there is *no lighting* and *no current reading*. And if *voltage increases* or *decreases, the brightness of the bulb* together with *the current also increase or decrease*

It shall be noted that at this stage

(1) The learner is not yet familiar with the equipment. The teacher's role is then to guide the learners in their attempt to follow instructions carefully and precisely to arrive at the predicted outcome (Sheppard et al, 2009:75). The first demonstrations are controlled or assisted experiments (see figure 3(a)) and once learners make progress in operating equipment the lessons tend to be open-ended experiments (figure 3 (b)) where the instructor's role is minimal in manipulating equipment and limited to set goals, organize and generate problems.

(2) Before the starting of the lesson, learners are told that from the experiment or any other examples or study case (for lessons that are not necessary practical or logistic does not allow practical experimentation), their task is to look for patterns and differences (Eggen & Kauchak, 1996:79) and they would be able to use them establish some relationship between physical quantities or solve problems (Eggen & Kauchak, 1996:80) whatever the case may be.

(3) Learners are encouraged to refer to quantities using conceptual framework. The teacher should also bear in mind that confusions between the equipment (actual physical component; e.g. bulb) and the physical quantity (e.g. resistance) and the observed phenomenon (light) will be manifest in the process of finding the patterns.

- Finding patterns and generalizing:

To make the process of finding patterns easier, learners were asked to use a table and fill it as displayed in table 1:

Table 1: Worksheet for finding patterns

| Equipment | Phenomenon observed | Role and function of the equipment | What other equipment you know in life which can be compared to and/or associated with | Physical quantity (electrical) associated with | Name and anything else you can say |
|---|---|---|---|---|---|
| A | | | | | |
| B | | | | | |
| C | | | | | |

Expected patterns to be found and focused on are: (1) voltage source (power supply) is the cause of the effects, (2) resistance (resistor) is the object (passive) and electric current is the consequence of the “link” between the two to (3) produce certain effects (light, heat in a resistor...later on magnetic effect in a coil); (4) voltage and resistance can exist as standalone physical quantities but current cannot exist if voltage and resistance are not connected.

2. Form conclusions based on patterns and Assess conclusions based on evidences

➢ Second stage

(1) Discussions on findings

Learners are now taken into a discussion from the findings in order to form conclusions based on the patterns. Emphasis was put on clarifying the concepts, distinguishing between physical component and physical quantity (its value and the equipment which is used to measure it) and establishing the relationship between the electrical physical components. Reif refer to as specific discrimination tasks whereby learners are helped to detect, diagnose, and correct likely confusions between somewhat similar concepts (Reif, 2008:82)

Learners were able to discover Ohm’s law by themselves and could state it in their own words.

(2) Linking theories and practical

At this stage it was crucial to link to findings to real life application for relevance and introduce the threshold concept of electrical engineering. The main business of electrical engineering is to take power from one point to another point. This is done through medium (matter) and everything surrounding us is matter. By observing the surrounding area, learners could come up with an obvious understanding of that fact. From observation, learners could also categorize the matter and start referring to it as one category serving as the vehicle (conductors) of power and the other serving as the safety material (insulators).

Theories about atomic structure of the matter, electric charges can now be revisited and concepts of voltage, resistance and current re-defined and refined. Ohm’s law is mathematically modelled and graphs can be plotted for some numerical examples.

(3) Assessing conclusions based on evidence

Using different values of resistors with one voltage source value, or one resistance value and a variable supply, verify ohm’s law first in a virtual lab using software package (in our case Edison 4.0 was used) to mimic actual equipment and their operation (Burtler, 1983 as cited in Sheppard et al, 1996: 92) and thereafter practically in the actual lab.

#### 4.3.2. Sample lesson 2: Charging and discharging process of a capacitor

Capacitor is one of the 3 main components that are used in the engineering field beside the resistor and the inductor. The goal of this lesson was to help the learner to understand the electrical behaviour of a capacitor which is completely different from the one of the resistor (resistance) which learners has been familiar of for some few weeks already. Basic laws as applied to a resistance have been understood and applied in various applications. Introducing capacitor and capacitance to learners at this stage will have the advantage of using what has already been learnt and state differences and/or similarities between the two (capacitor/capacitance and resistor/resistance). However, learners are often confused and struggle when they have to apply similar reasoning to two components that are different in essence.

The ordinary way of teaching is to present *a definition of a capacitor*, generally considered as a passive electrical component that stores electrical charge and has the property of capacitance (Floyd, 2010:485), describe the capacitor, and explain the charging process before producing formulas linking physical quantities related to the capacitor (capacitance, charge,...)

The metaphor used in our lesson was the one of a classroom as shown in figure 5 (a). Unlike the sample lesson 1 which started by lab demonstrations, this lesson started with an open-ended problem.

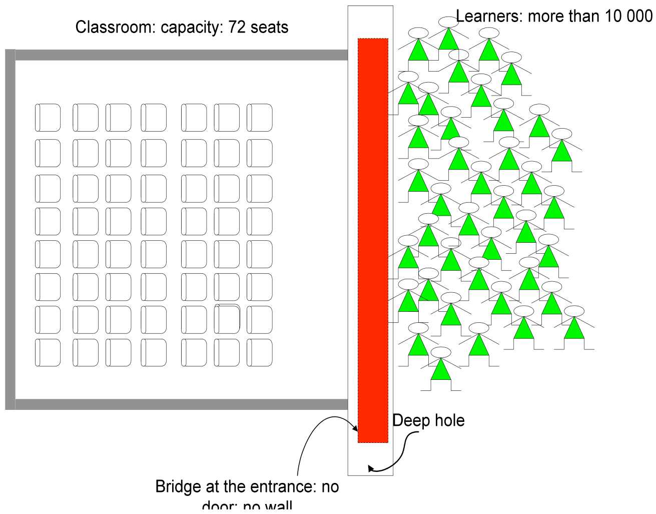


Figure 5(a): classroom metaphor used to explain the charging process of a capacitor

**The problem**

A classroom has a limited capacity of 72 seats (this is just a number) and has a large entrance say of the size of a wall. A huge number of learners awaiting to get access to the classroom and are separated from the entrance by a huge hole that they can cross only if a bridge is put over the hole and not a single learner wants to miss the class.

**Activity 1: Brainstorming and finding patterns**

*(i)* *The bridge which was initially removed is placed on the hole to allow access: explain in your own words what is likely to happen and what can you consequently advise;*

*(ii)* *If anyway the room is full at its capacity, meaning 72 seats, what will happen if we remove the bridge (a) for the 72 learners in the room and for the rest of the learners;*

*(iii)* *If thereafter the bridge is re-placed can the learners in the room be able to move out? If yes how? If not what can be done to help them to move out?*

From these questions, discussion will follow and the following facts extracted:

(i) Once the bridge is placed, everyone will want access resulting into a disastrous collision. To avoid that a wall with a door should be built on the entrance (previously empty space, to control the flux of the learners getting access when the bridge is closed; The first flow of learners will be huge and progressively, since seats are occupied, learners coming in will slow down as they have to check for any seat still available.

(ii) I the bridge is removed the learners in the room will be trapped in and the large number outside will stay there waiting for an opportunity to get access once the bridge is re-placed;

(iii) Although the bridge can be put back, the learners outside will not be able to move in and the ones trapped in to move out. To allow the ones in to move out the unique alternative is to make provision of a back door meanwhile the bridge should be removed or the door locked otherwise other learners from the ones outside, will come in and replace the ones that are moving out.

**Activity 2: From metaphor to real application: drawing analogies**

Through intensive questioning and comparison, similarities are established between the classroom metaphor and the electric circuit in figure 5(b) which describes the principle of operation of a capacitor:

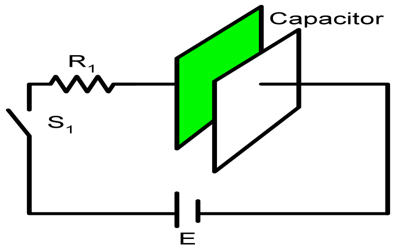


Figure 5 (b): capacitor in a charging circuit

(i) Room is the plate of the capacitor and the capacity or size of the room is analogue to the capacitance of the capacitor.

(ii) The learners are the charges and their number and movement is analogue to the charging current,

(iii) The bridge represents the switch and plays no active role apart from allowing the learners to get in the room meaning, allowing for current flow.

(iv) The first flow of learners will be huge and progressively, since seats are now occupied, learners coming in will slow down as they have to check for any seat still available. This explains the logarithmic shapes of respectively the charging voltage and current.

$$i_c = I_{initial(\max)} e^{\frac{-t}{RC}} \qquad \text{... (eq.2)}$$

$$v_c = E(1 - e^{\frac{-t}{RC}}) \qquad \text{... (eq. 3)}$$

(v) The door is the resistance in series with the capacitor, the smaller the door the resistance and if the door is closed the resistance is infinite, meaning the resistance in the circuit is now an open space; also the smaller the door, the longer it will take for the room to get full and vice versa which explain the concept of time constant $\tau$ and the total charging time (approximately $5\tau$ )

$$\tau = R.C \qquad \text{... (eq.4)}$$

Since the door is the resistance one will understand that if there is no door, mean no resistance, the disastrous collision is nothing else than a short circuit in the circuit of the capacitor.

(vi) $R_2$ (and $S_2$) in figure 5 (c) are representing the alternative door for the learners to move out since the other learners are still waiting at the door and cannot be pushed away: positive charges trapped on the plate during the charging time, cannot go back to the positive side of the source. They an empty space to fall in and disappear of the plate in the charging part cannot go back to the source.

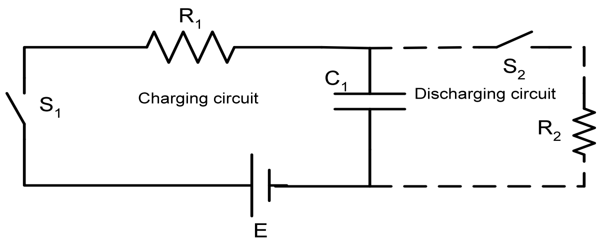


Figure 5 (b): Charging and discharging circuits of a capacitor

**Activity 3: Refining concepts**

Learners are given tasks to theorise on all other aspects of the capacitor such as the construction, the types, the applications.... Depending on the dynamic and the challenges, sample numerical examples can be provided at this stage to help learner re-enforce the understanding of the concepts.

### 4.4. Other interventions:

Building up from previous experiments, these interventions were progressively introduced as from 2007 but consistent use of them was more effective in the last 2 years.

- The use of EDISON 4, software for simulation of basic circuits enhanced the learner's understanding of several concepts since they could visualize and predict the result before comparing them with the theories learnt (since 2007)
- Additional tutorials with some answers purposely wrong were provided and wrong answers were subject of good class discussion (2008)
- Problem solving method (for right answer problems) and techniques were provided and learners were required justify every step taken in solving the problem meaning to tell why this option and not the other one; Learners were often reminded of the importance of the reasoning process in problem solving over the answer deduced from a formula in calculations; As advised by Reif (2009:82), examples of right answers resulting from wrong procedures were often provided and discussed to increase awareness (2009)
- Peer mentoring: performing learners explaining to poor performing learners: this was helping both the learners since by explaining to the weaker learner the stronger learner was re-enforcing their own understanding (2010);
- Improvised daily or weekly class tests (2010):

## 5. Discussion of the results

### 5.1. Intervention and performance on Extended Curriculum Programme (ECP): 2009

Interventions on ECP benefited to 86 students during 2009 and all were new students since in principle; all ECP repeaters were joining the main stream (semester course). Year-end results were used as the "overall performance indicator" and the analysis based on candidates that were admitted to write the exam. These represent 72,09 % of the registered students during 2009.

(a) The overall pass rate was 66, 12% which was relatively higher than in 2007 and 2008 (18% and 32% respectively) of the implementation of the ECP programme which I was still the coordinator and the lecturer in charge for EE1/ETEC1. Heavy current, Light Current and Computer Systems learners were attending as one group and Mechanical and Industrial were forming another class. Table 2 shows results comparison between them.

(b) A comparison between the exam and final class average percentages (last 2 columns of table 1) show a very small deviation between the 2. This is an indication that the overall performance of the class in terms of their individual records is the reflection of their performance throughout the year.

Table 2: ECP summary of 2009 results

| | Registered | % Wrote | % Pass | % Fail(*) | Class HM(**) | | Class LM(***) | | Class Ave | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Course/Diploma** | | | | | Exam | Final | Exam | Final | Exam | Final |
| **Heavy Current** | 10 | 90 | 77.77 | 22.23 | 85 | 77 | 33 | 36 | 61.11 | 59 |
| **Light Current** | 20 | 60 | 50 | 50 | 70 | 69 | 20 | 33 | 49.25 | 50 |
| **Computer Systems** | 11 | 63.63 | 71.42 | 28.58 | 62 | 61 | 48 | 46 | 53.71 | 54 |
| | | | | | | | | | | |
| **Mechanical** | 20 | 80 | 75 | 25 | 93 | 85 | 28 | 33 | 60.6 | 59 |
| **Industrial** | 25 | 72 | 61.11 | 38.89 | 88 | 81 | 35 | 38 | 50 | 52 |

(*) % fail include candidates to supplementary exam. (**): Class Highest Mark; (***): Class Lowest Mark

**Comparison between ECP vs. Main Stream during the same year (2009)**

Note that the students were subjected to the some tests, assignments and exam throughout semester 2. However, more than 60 % of the main stream classes were repeating the subject. Note also that ECP repeaters 2008-2009 were attending in the main stream classes except 4 learners amongst which only 2 passed. The comparison is given in table 3 where all highest values are highlighted.

(a) The main stream classes (HC/ LC and CS in particular) have excelled in the percentage of candidates that wrote the exam as well as in the lass highest marks. This may have been caused by the leniency of treatment during the compilation of year marks where as lecturers we sometimes "give the chance to write" to relatively poor performing students. The highest marks per class would be the result of repeating student's performance.

(b) All the other parameters which are essential in the learners progress (% pass and class averages) are in favour of the ECP learners.

Table 3: Comparison results 2009: ECP vs. Main Stream

| | Registered | % Wrote | % Pass | % Fail(*) | Class HM | | Class LM | | Class Ave | | Lecturer |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Course/Diploma** | | | | | Exam | Final | Exam | Final | Exam | Final | |
| **Heavy Current/ECP** | 10 | 90 | 77.77 | 22.23 | 85 | 77 | 33 | 36 | 61.11 | 59 | K LOJI |
| **Heavy Current/Main** | 91 | 91.2 | 65.05 | 34.9 | 91 | 85 | 16 | 26 | 53.13 | 54.3 | Lecturer 1 |
| | | | | | | | | | | | |
| **Light Current/ECP** | 20 | 60 | 50 | 50 | 70 | 69 | 20 | 33 | 49.25 | 50 | K LOJI |
| **Light Current/Main** | 141 | 71.63 | 36.63 | 63.4 | 77 | 78 | 18 | 27 | 41.93 | 46.6 | Lecturer 2 & 3 |
| | | | | | | | | | | | |
| **Computer Syst/ECP** | 11 | 63.63 | 71.42 | 28.58 | 62 | 61 | 48 | 46 | 53.71 | 54 | K LOJI |
| **Computer Syst/Main** | 56 | 75 | 38.09 | 61.9 | 75 | 69 | 18 | 27 | 41.26 | 45.5 | Lecturer 2 & 3 |
| | | | | | | | | | | | |
| **Mechanical/ECP** | 20 | 80 | 75 | 25 | 93 | 85 | 28 | 33 | 60.6 | 59 | K LOJI |
| **Mechanical/Main** | 59 | 89.83 | 64.15 | 35.8 | 87 | 83 | 19 | 27 | 55.18 | 58 | Lecturer 1 |
| | | | | | | | | | | | |
| **Industrial/ECP** | 25 | 72 | 61.11 | 38.89 | 88 | 81 | 35 | 38 | 50 | 52 | K LOJI |
| **Industrial/Main** | 0 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | |

(*) % fail include candidates to supplementary exam. (**): Class Highest Mark; (***): Class Lowest Mark

A new book "Principles of Electric Circuits: Conventional current version" different from the prescribed book used by the main stream classes was introduced;

## 5.2. Intervention on mean stream: 2010 semester 1

The ECP was phase out at the end of 2009. It gave me the opportunity to apply the interventions on main stream. 101 learners from Industrial Department benefited from the interventions. Although because of the reduced time and the limited numbers that could be accommodated at once in the lab all interventions were not efficiently applied, results (see table 4) show a good performance of those learners compared to the other main stream learners (Heavy current, light current, computer systems) except mechanical learners. I should mention here that mechanical department has decided to offer Electrotechnology 1 to learners from S3 meaning after they have passed their maths 1 and 2, and this could be the reason (subject to further investigation) why their performance was relatively good compared to Industrial.

Table 4: 2010 results all main stream

| | Registered | No Wrote | % Pass | % Fail(*) | Lecturer |
|---|---|---|---|---|---|
| **Course/Diploma** | | | | | |
| **Heavy Current** | 123 | 63 | 51 | 49 | Lecturer 1& 2 |
| **Light Current** | 176 | 92 | 52 | 48 | Lecturer 2 & 3 |
| **Computer Systems** | 82 | 60 | 43 | 47 | Lecturer 4 |
| | | | | | |
| **Mechanical** | 66 | 51 | 77 | 23 | Lecturer 1 |
| **Industrial** | 100 | 58 | 70 | 30 | K LOJI |

## 5.3. Students comments

A survey was given to learners (2010) to provide their feedback on interventions that they received. The survey was based on the following topics but I will only show comments for topics directly impacting on students' performance in relation with problem solving:

- Most challenging thing in the subject; 67,8 % mentioned the difficulty of understanding key concepts of the subject above all. It is obvious that this affected negatively their problem solving approach.

- Teaching and learning methods: 71,3 % revealed that attending classes contributed the most to their success. This may be interpreted as a success in facilitation of learning. At the meantime this shows a huge lack of self commitment in their studies.

- Mode of delivery during class lectures: positive comments (65,9%) were made on the inductive method of delivering which the learners refer to as presenting questions and discussing answers. Another strong positive view came to support the explanation of topics by the lecturer while writing on the board.

- Impact of the newly introduced study manual: general comments were positive for this intervention. Negative comments on this intervention were mostly made by learners who failed and this could be also related to lack of commitment in self study.

### 5.4. Impact on the lecturer

Very transformative and since improving teaching is a process the inquiry about how can I improve my practice as a teacher has just started. More still to learn and to experiment.

### 5.5. Areas of improvement and the way forward

(i) Logistic does not allow for efficient applications of new methods of teaching for improvement: Consider limiting the number of amphitheatre lectures with a large (passive) number of learners over the active lab centred classes;

(ii) Review on a long run the assessment processes and methods from summative to formative

## 6. Conclusion

In engineering field, where problem-solving is the main task. Thinking skills are of utmost important and it is imperative that this be included in the curriculum.

This paper showcased how thinking skills were integrated in the subject content of a subject with the goal of teaching for learning and improving under-prepared learners' performance in engineering field consequently reducing the gap between high schools and tertiary. Two sample examples were displayed to demonstrate that and results showed satisfactory performance. However, the effectiveness of the interventions is likely not to succeed if not applied holistically throughout the full program.

This ongoing study has also revealed some areas that still need to be improved and is calling for more debates and discussions on engineering education matters especially regarding thinking skills. The author will be grateful for any input that could be of positive contribution to the discussion.

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