Development and Implementation of Learning Assessment Template in Engineering Courses

A. Anil Kumar
Department of Electrical and Computer Engineering
Prairie View A&M University

Abstract

In this paper, we discuss the development and implementation of a template for assessing learning in engineering courses within the scope of ABET Student Learning Outcomes. The tenet is that learning can be assessed at different levels of competence or ability. While there are multiple approaches to such assessment, notably – Bloom's Taxonomy, the 5E Model, the Kirkpatrick Model, to name three – implementation at each level is somewhat unrealistic, owing to the non-/semi-quantitative nature of assessment. Specific implementations in three electrical engineering courses – Network Theory 1, Physical Principles of Solid State Devices and Communication Theory – will be presented. The approach is based on assessing students' progress via four levels of ability – unconscious incompetence, conscious incompetence, conscious competence and unconscious competence. Both formative and summative assessments will be discussed based on improved performance on tests as well as on an end-of-semester project that requires navigating through open-ended scenarios.

Introduction

Critical thinking, creativity and ability to solve as yet unsolved problems, have been touted as the most important elements of twenty-first century skills.[1-6] In particular, they have been a staple requirement for Student Outcomes from Criterion 3 of ABET.[7] However, based on comments and concerns from the industry, there is a marked gap in skills between graduation and workforce requirements. For instance, a student may be good in technology but does not know how to use it in a given context. Or, a student is well-versed in computing but does not know how to transfer that skill to a new application. The general belief is that learning can be assessed at different levels of competence or ability. While there are multiple approaches to such assessment, notably – Bloom's Taxonomy[8], the 5E Model[9], the Kirkpatrick Model[10], to name three – implementation at each level is somewhat unrealistic, owing to the non-/semi-quantitative nature of assessment. For instance, in Blooms' Taxonomy, there are six levels of competence: remember, understand, apply, analyze, evaluate and create. Experience shows that the more levels there are, the more difficult it becomes to assess learning at each stage. The approach chosen in this paper is based on assessing students' progress via four levels of competence – unconscious incompetence, conscious incompetence, conscious competence and unconscious competence.[11] Each level can be quantified more easily, as will be seen from the three examples to be presented. Specific implementations in three electrical engineering courses – Network Theory 1, Physical Principles of Solid State Devices and Communication Theory – will be presented.

In the following we will present a description of the four levels of competence, followed by actual implementation two courses in electrical engineering.

Assessment By Levels Of Competence

According to the Training Industry (2023):

> *"The four stages of competence, also known as the four stages of learning, is a model based on the premise that before a learning experience begins, learners are unaware of what or how much they know (unconscious incompetence), and as they learn, they move through four psychological states until they reach a stage of unconscious competence. By understanding the model, trainers can better identify learning needs and develop learning objectives based on where their target audience is in the four stages related to a given topic."*

Table 1 – The Four Levels of Competence

Level of Competence	Manifestation of Competence
Unconscious Incompetence	In unconscious incompetence, the learner isn't aware that a skill or knowledge gap exists.
Conscious Incompetence	In conscious incompetence, the learner is aware of a skill or knowledge gap and understands the importance of acquiring the new skill. It's in this stage that learning can begin.
Conscious Competence	In conscious competence, the learner knows how to use the skill or perform the task, but doing so requires practice, conscious thought and hard work.
Unconscious Competence	In unconscious competence, the individual has enough experience with the skill that he or she can perform it so easily they do it unconsciously.

To make ideas concrete, let us cite an example of a project that was assigned to my class – Network Theory 1, a first course in electrical circuit analysis.

Project:
(i) An RC circuit is used in estimating the speed of a horse running a 6 km racetrack. The circuit is a series connection of a 80 V source, a switch, a 25 MΩ resistor and a 25 μF capacitor. The switch closes when the horse begins to run and opens when the horse crosses the finish line. Assuming that the capacitor charges to 65.5 V, calculate the speed of the horse.

Observation: At first sight, the students had no idea of how to address the problem. While they had a strong foundation in mechanics, capacitor charging and discharging, and general circuit behavior, they lacked an ability to connect the various concepts. This would be an example of the Unconscious Incompetence, a lack of awareness of what the skill gap is.

However, when the problem was broken down into individual parts, each addressing a well-defined operation – speed being the ratio of distance over time, computation of the time constant, time taken to charge up to a given value – their performance was better. This was a reflection of Conscious Incompetence.

(ii) The problem was then expanded to apply the technique in the previous problem to assess the speeds of multiple horses on the same track. One approach could be to have three different RC circuits, one for each horse so you can determine which one reaches the finish line first, which one comes in second and which one comes in last. Each circuit is a series connection of a voltage source, a switch, a resistor and a capacitor. The parameters for each circuit are listed below. The switch closes when the horse begins to run and opens when the horse crosses the finish line. Calculate the speed of the horse in each case. Which horse ran the fastest? Which one the slowest? Could one have guessed the correct answer by just comparing the time constants?

Horse	Voltage Source	Resistance	Capacitance	Voltage at finish line	Time Constant	Speed of Horse
Graydar	120 V	30 MΩ	30 μF	88.6 V		
Tiznow	100 V	20 MΩ	40 μF	90 V		
Curlin	80 V	25 MΩ	15 μF	65.5 V		

Observation: Every student was able to complete this task, with some effort. Several stopped at computing and comparing the speeds, while a few went further to respond to the question about comparing the speeds and the time constants. This is a manifestation of Conscious Competence.

(iii) Revisit the previous problem. Is there a different way of configuring the circuit, that can assess all the horses? For instance, is it possible to place all the circuit elements in one circuit instead of dealing with three different circuits? How is the design of the circuit different from the individual circuits approach? Anticipating participation on later courses such as digital design and microprocessor design, does the circuit offer potential for circuit integration?

Observation: A few students attempted at the circuit design with some success, again a manifestation of Conscious Competence.

(iv) Based on the computations, are the circuit parameters realistic? Do they offer realistic times as may be compared with real life horse racing schedules? If not, how would one modify them? What constraints – such as power requirements and limitations, sizes of the components, etc. – might one face in one's choices? How would one optimize the parameters?

Observation: This task has not been posed before. Their successful response will be a manifestation of Unconscious Competence.

Specific Implementations of the Approach to Other Projects To Assess Levels Of Competence

Two specific implementations of the assessment of levels of competence appear below: (i) a junior level course - Physical Principles of Solid State Devices, and (ii) a senior level course – Analog and Digital Communication Theory. Both are projects that are open-ended and were assessed for two separate ABET Outcomes, 7 and 1 respectively. Each project:

- involves wide-ranging or conflicting technical issues;
- has no obvious single solution;
- involves diverse groups of stakeholders;
- includes many component parts or sub-problems; and
- has significant consequences in a range of contexts.

ELEG 3303 – Physical Principles Of Solid State Devices
Spring 2022

Optimum Characteristics of a p-n Diode in a Half Wave Rectifier

ABET Outcome 7
"An ability to acquire and apply new knowledge as needed, using appropriate learning strategies."

Project Assignment Statement
One of the major applications of p-n diodes discussed in class is rectification – conversion of AC to DC. A large signal diode – with a large p-n junction (depletion) region – that allows for increased forward current carrying capacity (forward resistance of a few Ohms) and reverse blocking resistance of few Mega Ohms is needed. Such diodes are useful for low frequency applications such as rectifiers, inverters, battery charging devices, etc. For typical ratings of a diode visit this link:

https://www.allaboutcircuits.com/textbook/semiconductors/chpt-3/diode-ratings/

Consider the following scenario. You are a solid state device expert working for ACME International Microelectronics Establishment (AIME). A customer approaches you to seek your advice on a low cost circuit that provides for a *'reasonable'* rectification of an AC signal. From your experience, you know that she probably needs a half wave rectifier (low cost) that operates under the following conflicting criteria: (i) a diode with capacitance in a given range, (ii) a low forward resistance to keep power consumption by the diode to a minimum, (iii) an output voltage less than the peak input value, (iv) a reverse bias not exceeding the breakdown voltage and (v) an 50 Hz – 60 Hz input frequency. You are expected to investigate a potential diode that meets these requirements.

Your task is to explore the optimum characteristics of such a diode.

Submit a brief report on your approach to addressing this task. What you plan to do, how you would interpret the customer's need and how you would proceed to find at least one choice of a diode that meets her requirements.

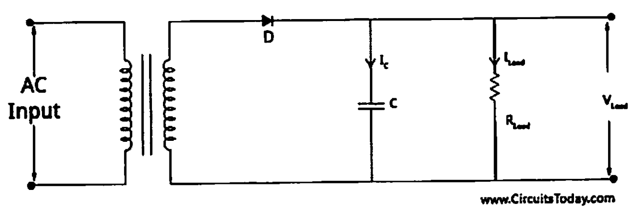
To facilitate analysis, consider the following steps:

1. List the general characteristics of p-n junction diodes – forward current, forward voltage, reverse resistance, capacitance, temperature stability, among others.
2. Investigate the literature to explore at least three different diodes that, when a diode is made out of it, provides the optimum range of capacitance values.
3. Compute the relevant quantities for these diodes that meet the customer's requirements.
4. Write a concise but detailed report of your findings along with a summary and a rationale for your choice(s)/recommendations.

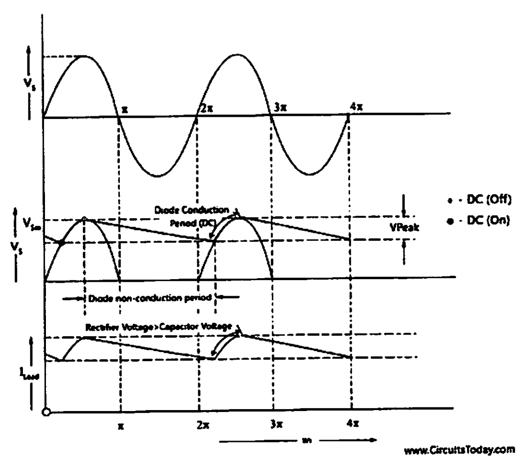
Project Description

As discussed in class, a typical half wave rectifier and its output are shown in the figures below. (https://www.circuitstoday.com/filter-circuits)

Half wave Rectifier with Capacitor Filter



Half wave Rectifier with Capacitor Filter - Waveform



To get a ‘reasonable’ DC output, you need VPeak difference as small as possible. As long as the RC time constant is much greater than the period (inverse of the frequency of the input signal), the capacitor will stay mostly fully charged thus delivering a near DC output. If the load resistor is small, a higher current will flow through the circuit resulting in a faster capacitor discharge. So, to maintain a large time constant, a high load resistance as well as a high capacitance are needed. However, there are limits on the size and cost of the capacitor. Typical capacitance range is between 10 pF to 100 pF. A high resistance will also result in a high power dissipation, adding to the already existing power loss due to no output in the negative half cycle.

For this project, focus on the diode capacitance that depends on a set of parameters, such as: the doping concentrations, the dielectric used for the diode and the temperature. Hence choose the appropriate circuit parameters that meet the stated requirements.

ELEG 4300 – Communication Theory
Fall 2022

Source Coding Efficiency Under Higher Order Extensions

ABET Student Outcome 1
“An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.”

Project Assignment Statement
This project addresses the enhanced efficiency of source coding under higher order extensions of the source alphabet. It involves an understanding the basic principles of Information Theory, working knowledge of Matlab, experience with the Huffman Coding algorithm, knowledge of probability and an understanding of redundancy in the English language. With a more diverse student population, the project could be expanded to comparing source coding in different languages.

This is an extension of the Project 1. You have been introduced to the concept of block coding (encoding a sequence of symbols of an alphabet) as opposed to the encoding of single symbols. As discussed in the class, such encoding will provide for more accurate and efficient error detection and correction after transmission through a channel.

Project 1 dealt with single symbol Huffman Coding. Project 2 deals with Extended Huffman Codes. For instance, for a source emitting two symbols A and B, the second order extension involves coding messages AA, AB, BA and BB (2^2 in number). The third order extension involves messages such as AAA, AAB, etc. (2^3 in number). The probabilities of such strings are computed by multiplying the individual probabilities.

For this project, use the Matlab code you have developed in Project 1 to perform third, fourth and fifth order extensions of a source message.

1. Choose an alphabet a set of at least six (6) symbols with assigned probabilities.
2. Compute the third, fourth and fifth order extension probabilities.
3. Using the built-in algorithm, derive the Huffman Code for each extension.
4. Compute the following quantities: (i) Average length of the codeword; (ii) The code efficiency; (iii) The Compression Ratio; (iv) Speed of computation.

Write a brief but comprehensive report on your work.

Formative And Summative Assessments

In addition to a summative assessment at the end of the semester (see next page for a sample), formative assessments were carried out during the semester. This was done by introducing the project at simpler levels, first by demonstrating the relevance of parameters and quantities to be computed, then increasing the rigor, depth and open-endedness in two more project assignments. The typical timeline followed appears below. The expectation was to have the students slowly develop the needed expertise in programming and understanding of the relevant concepts and the connections among them, and finally enhancing their competence to address the final semester project. Additionally, formative assessments were conducted in quizzes and tests, where a later test included a problem from a previous test, but in an expanded format, so as to assess the knowledge and competence acquired in the meantime.

Table 2 – Typical timeline of assessment (A: Assigned, D: Due, F: Feedback)

Project	A	D	F	A	D	F	A	D	F
	Week 3	Week 5	Week 6	Week 6	Week 8	Week 9	Week 10	Week 15	Week 16
Project 1									
Project 2									
Project 3 (Final Assessment)									

Conclusion

This paper addressed the issue of assessment of learning from a more quantifiable approach to assessment of ability/competence. Four levels of competence have been addressed: unconscious incompetence, conscious incompetence, conscious competence and unconscious competence. Three specific implementations of these concepts through project assignments in three different courses – sophomore level, junior level and senior level – were discussed. Results from the assessments were shared with the faculty teaching the pre-requisite courses, so that a vertical alignment in terms of steadily demonstrating increase of competence may be established. Future work will continue these efforts, in addition to stressing the transference of skills and competences across the subjects and disciplines.

END OF SEMESTER COURSE OUTCOME ASSESSMENT REPORT
ELEG 3033-P01 – PHYSICAL PRINCIPLES OF SOLID STATE DEVICES
(ELECTRICAL ENGINEERING MAJORS)
SPRING 2022 SEMESTER
Report Prepared by: Dr. A. Anil Kumar
Report Date: May 16, 2022

Outcome 7: ***"An ability to acquire and apply new knowledge as needed, using appropriate learning strategies."***						
Semester	**Analysis Type**	**# of Students**	**Expected Class Average**	**Expected Percent of students at or above average**	**Class Average**	**% Students meeting Expected Average**
Spring 2021	**Direct**	**23**	**70**	**70**	**70**	**65%**
SPRING 2022	**Direct**	**15**	**70**	**70**	**70**	**50%**
Implementation Summary	**Items implemented from previous report or after meeting previous instructor**	Topics covered were mostly the same as in the prior semester, with the exception of a less detailed discussion of MOS structures. More time was spent on the details of p-n junction diodes, including explicit device applications. A **novel item included for the first time** is a Panel Discussion on Global Issues pertaining to solid state devices – industrial, economic, political and social issues, in addition to the engineering and scientific aspects. The book used was–Solid State Devices, 2nd Edition, by B.S. Nair and S.R. Deepa. While the book has an excellent set of worked out examples in each chapter as well as a large set of problems at the end, it lacked adequate introduction to the quantum principles. Will be searching for a different book.				
Perceived Problems	**Perceived problems are directly related to the PC and the sub items under them**	Problems related to principles of physics and chemistry continue to plague this course, especially: inability to recall Bohr's model, molecular formation, electronic structure of atoms, and basic quantum concepts such as quantization and spin. Reduced active participation during class as well as almost no show during office hours. More review sessions were conducted to compensate.				
Plans for Addressing Problems	**Plans to address specific measures to address PC and their sub areas**	Measures to be implemented: 1. Identified instructors in Chemistry and Physics teaching pre-requisites to work proactively address knowledge shortcoming. Make them aware of what is expected of EE majors to learn and retain. 2. Offer to cover 1-2 of their lectures on applications of concepts. 3. Seek another textbook to replace the current one.				
Overall Trend over Periods	**Ascertain if there were improvements over previous semesters**	A few improvements over the previous semester. The panel discussion on Global Issues relating to solid state devices was received with more enthusiasm. The session was more active and interactive. Political issues such as tariffs on China, reliance on global production of semiconductor chips, varied access to rare earth materials were among the topics discussed. Several relevant documents and videos were posted on the course website. However, since this course deals with non-intuitive quantum concepts, requiring a modern physics course as a prerequisite (ex. TAMU-CS) might make this course more approachable. The current practice of covering the quantum concepts and devices, all in one semester, results in an excess of cognitive load.				
Were Expectations Met?		**YES**				

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A. ANIL KUMAR

Dr. Kumar obtained his Ph.D. in Physics from the Indian Institute of Science, Bangalore, India. After working on various research projects on device modeling and communication theory aspects, he focused on what he recognized as proper preparation in STEM disciplines at the middle and high school levels, imperative for better college-level performance. He worked with multiple school districts on state and national standards, relevance of science in the global economy, and expanding opportunities for students, teachers, and faculty in STEM disciplines. For over five years, he directed Project XLR8 (ACCELERATE), a high school redesign project, funded by the Thurgood Marshall College Fund, with support from the Bill and Melinda Gates Foundation. He is currently working on a monograph on redesigning education. For his work in public education and his achievements in research, he was one of five faculty members in the TAMU System to have received the Distinguished Achievement Award from the Board of Regents, a recipient of the Thurgood Marshall College Fund's Outstanding Achievement Award for School Reform and the Harmony Public Schools Public Servant Award. He, along with two colleagues from Mathematics, is finalizing a book of Higher Mathematics for Science and Engineering. His current interests include researching the future of higher education and learning in the age of artificial intelligence and machine learning. https://www.pvamu.edu/sites/hb2504/cvs/All/aakumar.pdf