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Teaching digital electronics course for electrical engineering students in cognitive domain

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Abstract

Digital electronics course is one of the very fundamental courses for the students of undergraduate programme of electrical and electronic engineering (EEE) and the other undergraduate engineering disciplines. Therefore, 'digital electronics' shall be taught effectively, so that students can apply the knowledge learned to solve their real-life engineering problems. A teacher needs to adopt new teaching methodologies to attract current generation of students, and thus, to prepare them with practical knowledge and skills. Skills in the cognitive domain of Bloom's taxonomy revolve around knowledge, comprehension and critical thinking of a particular topic. This makes teaching and learning more effective and efficient. In this paper, the teaching method of 'digital electronics' course for the undergraduate EEE students in the cognitive domain has been described with an example. Class performance evaluation in two different cohorts shows that the students' results improve after using this approach.

Keywords: Bloom's taxonomy, cognitive domain, digital electronics course, teaching methods.

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1. Introduction

The current age is the digital age. At present, all offices, industries, educational institutions, business organisations etc., are being digitalised. Therefore, most of the engineering disciplines incorporate digital electronics course as a compulsory course in its curriculum. This course has many direct practical applications. Without the knowledge of this course, it is not possible for an engineer to design and develop any electronics circuits or systems or any electronic controllers that are controlled or operated by digital signals, and it is one of the most desired outcome of engineering education, especially in the 21st century (Attarzadeh, Gurkan & Benhaddou, 2006). Therefore, 'digital electronics' course is a core course requirement in the undergraduate curriculum of the electrical and electronic engineering (EEE) programme. It is designed to teach the students number systems, Boolean algebra, basic logic gates and their construction and working principles. Besides, combinational and sequential circuit design, various types of logic families, analogue-to-digital and digital-to-analogue conversion processes, and computing various digital electronic circuit parameters are taught in this course (Floyd, 2009; Sedra & Smith, 2004).

Learning is an activity that leads to change and control of what is being taught, while teaching is a practical activity or an action, be intentional and conscious to assist learning. Teachers should act an essential role as a facilitator in the process of teaching and learning. It is believed that providing students with a solid theoretical background greatly improve their ability to solve a variety of practical engineering problems (Tsividis, 1998a, 1998b). But the modern trend in teaching electronics is to complement lectures on theory and laboratory exercises with the computer simulation of digital electronic circuits (Tsividis, 2007). The rapid development of emerging technologies in the past few years has changed the way the students learn. It is important for us to re-visit the importance of electrical engineering education in today's educational perspective. Electrical engineering teachers face great difficulty when they teach electronics course as traditional teaching methods which are no longer adapted to the demand of the professional life of the students due to the complexity of the new technologies (Papadimitriou, 2012). So, the digital electronics course shall be designed and taught in such a way, so that the students are prepared to master every course topic related to 'digital electronics' properly (Choi & Saeedifard 2012).

Any engineering programme should be mandated by an accreditation agency (such as, in USA, it is Engineering Accreditation Commission (EAC)/Accreditation Board of Engineering and Technology (ABET) and in Bangladesh, it is Board of Accreditation of Engineering and Technical Education). Accreditation of an engineering programme is judged with respect to the defined programme outcomes. Any well thought course required for an engineering degree should be able to contribute towards fulfilling the programme educational objectives, which are mandated by the ABET criteria 2000 (EAC/ABET, 2004).

Currently, the education system is undergoing rapid changes. Various new methods are introduced and used. Further, it makes teaching more effective and learning highly significant. An important goal of the undergraduate curriculum in engineering is to develop the integration, design and evaluation capabilities of the student. As shown in Figure 1, B. S. Bloom, in 1956, characterised the six cognitive levels in the hierarchy as shown in Figure 1. The highest level of cognitive skills, synthesis and evaluation, rely on comprehension, application and analysis capabilities in the knowledge domain; and are consequently the most difficult and challenging to teach. However, to prepare undergraduate courses to be effective in designing engineering systems in the industry, it is important to ensure an adequate coverage of these higher-level skills, rather than limiting their education to one based on just lower-order skills (Lewin, Seider & Seader, 2002).

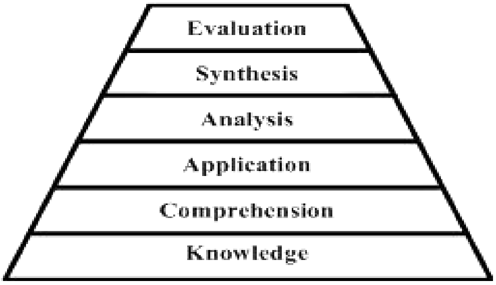

Figure 1. Levels in cognitive domain

In engineering education, there is a shift in emphasis from professional skills to process skills (Felder & Brent, 2004). These skills include problem analysis and problem solving, project management and leadership, analytical skills and critical thinking, dissemination and communication, interdisciplinary competencies, intercultural communication, innovation and creativity, and social abilities (Kuru, 2007). Critical thinking is a crucial skill that the students need to develop during their undergraduate study, in order to deal with the real-life and authentic EEE problems (Reif & Scott, 1999; Thomas, Davis & Kazlauskas, 2007).

Various problem-based learning methods are adopted in many engineering universities around the world. They use cognitive methods of teaching and learning as found in the literatures for teaching electrical circuits as well as analogue, digital and power electronics courses (Bhuyan, 2014; Bhuyan, Khan, & Rahman, 2014; Lili, 2010; Mantri, Dutt, Gupta & Chitkara, 2008; Nerguizian & Rafaf, 2009; Podges, Kommers, Winnips & Joolingen, 2014; Rashid, 2008; Wang, 2009; Wang, 2013). 'Digital electronics' is a very important course of an undergraduate EEE programme, and its traditional teaching methods are no longer suitable to meet the demand of the professional life. Traditional teaching methods either start by explaining a theory and showing few examples or giving an example to introduce a theory. However, one of the both methods is chosen and fixed by the teacher independently. In a traditional classroom, students are passive listeners most of the time. They come to the classroom unprepared and just listen to the instructor and take notes. This classroom environment lacks interactions between faculty and students, and between students themselves. If students actively participate in the classroom learning activities, they will be more cognitively engaged and as a result be able to achieve a better understanding of new materials (Papadimitriou, 2012). Thus, there exist problems in teaching methods of 'digital electronics' course, and hence, it needs improvement.

In this paper, teaching method of the 'digital electronics' course for the undergraduate students of any engineering programme specially for the EEE programme in cognitive domain has been described with an example from the designed course contents. Student performance has been shown through statistical data after the course evaluation is completed.

2. Constraints of teaching digital electronics course

We, the human beings, have limited memory; so, we forget things very easily. If we learn and know certain things, those things decay almost exponentially from our memory unless the things are repeated. Thus, it does not matter what we teach, students will either forget or the materials will become obsolete, even before they graduate. Therefore, we should design and teach engineering courses to develop student's abilities. Because, finally the will need to apply their engineering knowledge in practical field.

For example, we can rate the student's knowledge of the subject materials as zero at the start of the class. On the final day, students should have the highest knowledge of the subject materials and we can rate the student's knowledge as logic 1 at the start of the exam. But, after one or two years, that knowledge would decay almost to logic 0, the same logic value as the start. The logic knowledge pattern can be described as {0 1 0} (Rashid, 2004).

On the other hand, a student who never attended a class and earned no knowledge, his logic states of the knowledge can be described as {0 0 0}. But there is difference between a student who started with 0 knowledge, gained the highest knowledge (logic 1), and then, forgot the knowledge (logic 0); and another student, who started with 0 knowledge, did not gain any knowledge (logic 0) and no knowledge to forget (logic 0) (Rashid, 2004). It has been observed that students gain some experiences through learning environment. So, teaching and learning process of a course should be conducted to enrich the students with some practical experiences in designing and analysing.

2. Designing digital electronics course

One of the desired attributes of an engineer (Bloom, Engelhart, Furst, Hill & Krathwohl, 1956; Swain, 2001; White, 2001) in the global marketplace in the new knowledge economy is that an engineer should have good understanding of engineering fundamentals and design/manufacturing processes. Therefore, any undergraduate course should be designed in such a way, so that the students are able to design the systems both analytically and numerically. Keeping this in mind, 'digital electronics' course is designed in the following way.

2.1. Course contents

This gives the complete description of the course. The course contents should be designed in such a way, so that the students get a deep knowledge and develop their skills to apply the knowledge in their fields and course objectives are achieved. Incorporation of too many topics in the course may impede the students' learning objectives. So, the optimal contents for 'digital electronics' course are set as follows:

Introduction to number systems and codes. Analysis and synthesis of digital logic circuits: Basic logic functions, Boolean algebra, combinational logic design, minimisation of combinational logic. Implementation of basic static logic gates in CMOS and Bi-CMOS: DC characteristics, noise margin and power dissipation. Power optimisation of basic gates and combinational logic circuits. Modular combinational circuit design: Pass transistor, pass gates, multiplexer, de-multiplexer and their implementation in CMOS, decoder, encoder, comparators, binary arithmetic elements and ALU design. Programmable logic devices: Logic arrays, field programmable logic arrays and programmable read-only memory. Sequential circuits: Different types of latches, flip-flops and their design using ASM approach, timing analysis and power optimisation of sequential circuits. Modular sequential logic circuit design: Shift registers, counters and their applications.

2.2. Course objectives

Learning objectives or instructional objectives are statements of what students should be able to do, if they have acquired the knowledge and skills the course is supposed to teach them. The objectives of 'digital electronics' course have been set as follows:

1. To study the number systems and its conversion processes.
2. To construct various digital circuits using logic gates.
3. To design and implement the combinational logic circuit.
4. To design and implement the sequential logic circuit.
5. To design and implement digital logic systems.
6. To study the various digital electronic circuit parameters.
7. To familiarise with the various logic families.
8. To study various analogue-to-digital and digital-to-analogue conversion processes and associated circuits.

2.3. Course outcomes

Course outcomes or learning outcomes reflect the degree to which the programme has met its objectives; outcome indicators, the assessment instruments and procedures that will be used to determine whether the graduates have achieved the outcomes. After successful completion of the 'digital electronics' course with a minimum grade of 'C+', the students will be able to

1. Design simple digital logic circuits using basic gates.
2. Write Boolean expressions for digital electronic circuits and implement it with minimum number of ICs.
3. Draw various digital electronic circuits using logic gates' symbols.
4. Design and implement digital electronic circuits and controllers for various applications.
5. Design and implement ADC and circuits.
6. Measure various parameters of digital electronic circuits and systems.

3. Bloom's taxonomy

The idea for this classification system was formed at an informal meeting of the college examiners attending the 1948 American Psychological Association Convention in Boston, USA. At this meeting, interest was expressed in a theoretical framework which could be used to facilitate communication among examiners. This group felt that such a framework could do much to promote the exchange of test materials and ideas about testing. In addition, it could be helpful in stimulating research on examining and on the relationships between examining and education. After considerable discussion, there was an agreement that such a theoretical framework might best be obtained through a system of classifying the goals of the educational process, since educational objectives provide the basis for building curricula and tests and represent the starting point for much of our educational research (Bloom, 1994).

Bloom's Taxonomy is a classification of learning objectives within education proposed in 1956 by a committee of educators chaired by Benjamin S. Bloom. Although named after Bloom, the publication followed a series of conferences from 1949 to 1953, which were designed to improve communication between educators on the design of curricula and examinations (Orlich, 2004).

It refers to a classification of the different objectives that educators set for the students, i.e., the learning objectives. Bloom's taxonomy divides educational objectives into three domains: Cognitive, affective and psychomotor (sometimes loosely described as knowing/head, feeling/heart and doing/hands respectively). Within the domains, learning at the higher levels is dependent on having attained prerequisite knowledge and skills at lower levels (Anderson et al., 2001). A goal of Bloom's taxonomy is to motivate educators to focus on all the three domains, creating a more holistic form of education. A revised version of the taxonomy was created in 2000 (Krathwohl, 2000).

Bloom also considered the initial effort to be a starting point, as evidenced in a memorandum from 1971 in which he said, 'Ideally each major field should have its own taxonomy in its own language – more detailed, closer to the special language and thinking of its experts, reflecting its own appropriate sub-divisions and levels of education, with possible new categories, combinations of categories and omitting categories as appropriate' (Krathwohl, 2000).

Skills in the cognitive domain revolve around knowledge, comprehension and critical thinking of a particular topic. Traditional education tends to emphasise the skills in this domain, particularly the lower-order objectives. There are six levels in the taxonomy, moving through the lowest-order processes to the highest. Through these six processes, a student gains knowledge and skills and is able to solve real-life problems of their fields of interest. Therefore, to teach the 'digital electronics' course for the undergraduate engineering students, cognitive domain has been selected for effective teaching and learning process.

4. Teaching method in cognitive domain

To illustrate the teaching and learning method of 'digital electronics' course in cognitive domain an example of 'Implementation of basic static logic NAND gate in CMOS circuit' has been selected (Sedra & Smith, 2004) from the course content of this course. The student will first learn about MOS transistor's construction and working principle, and then, form the CMOS from the NMOS and PMOS transistors. Then, the student will design and draw the NAND gate circuit using CMOS.

One such circuit is shown in Figure 2, where one dc voltage source is used to bias the transistors, and two binary switches are used to apply the logical input signals at the gate of the transistors. They will also derive the Boolean expression and find the truth table of the two-input NAND gate.

Finally, they will implement the NAND gate in the laboratory using CMOS, and test the circuit by applying various input combinations of logic signals to verify its truth table. Students will also be asked to measure various circuit parameters like propagation delay, threshold conditions, bias current, output voltage and current, noise margin, static power dissipation for various combinations of logical input signals etc.

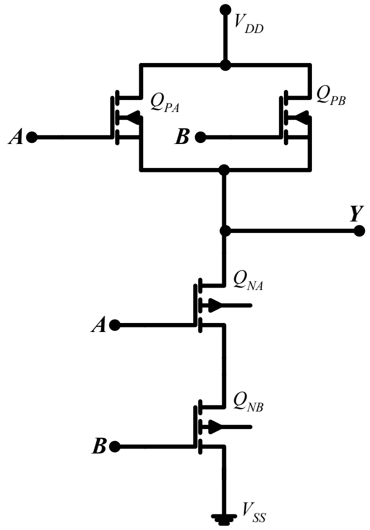

Figure 2. A two-input CMOS NAND gate circuit

How the educational objectives are achieved for this particular problem at six different cognitive levels is assessed in the following sub-sections to demonstrate the student's learning processes and skills upon the course contents. To get the student feedback about their learning, several questions will be asked to them and answer has to be taken and recorded in their work book, so that the actual learning objectives and outcomes are achieved for each of the cognitive level.

4.1. Knowledge

At this level, students are provided with sufficient knowledge so that they can list or state the problems, and also, they exhibit memory of previously learned materials by recalling facts, terms, basic concepts and answers. Knowledge may be of different categories, such as:

- Knowledge of specifics – terminology and specific facts
- Knowledge of ways and a means of dealing with specifics – conventions, trends and sequences, classifications and categories, criteria and methodology
- Knowledge of the universals and abstractions in a field – principles and generalisations, theories and structures

Question: Write down the truth table and Boolean expression of a two-input CMOS NAND gate circuit, or what do you mean by the term CMOS?, or draw the logic symbol of a two-input NAND gate.

4.2. Comprehension

At this level, students demonstrate understanding of terms and concepts and explain the concept in their own words and also interpret the results. Here, students demonstrate the understanding of the facts and ideas by organising, comparing, translating, interpreting, giving descriptions and stating main ideas and also by extrapolation.

Question: Draw and describe the working principle of a two-input CMOS NAND gate circuit.

4.3. Application

At this level, students apply the learned information to solve a problem, to calculate or to solve for the required value. The students also solve problems to new situations by applying acquired knowledge, facts, techniques and rules in a different way.

Question: Implement the CMOS NAND gate circuit, or test the logic output of the circuit for different input combination of logic signals.

4.4. Analysis

At this level, students break things down into their elements, formulate theoretical explanations or mathematical or logical models for observed phenomena, derive or explain something by identifying motives or causes. They make inferences and find evidence to support generalisations. They also do analysis of elements, analysis of relationships or analysis of organisational principles.

Question: Measure the circuit parameters and analyse the results with the theoretical results or values of the data sheets of the NAND gate.

4.5. Synthesis

At this level, students create something combining elements in novel ways; formulate an alternative to the existing design. They also compile information together in a new pattern to produce a unique communication, or to propose a set of operations or to derive a set of abstract relations.

Question: Write down the truth table and Boolean expression of a three-input CMOS NAND gate circuit, or write down the truth table and draw the logic circuit of a four-input complex Boolean functions $Y = \overline{A\left(B + CD\right)}$ using CMOS.

4.6. Evaluation

At this level, students make and justify the values obtained by judgment or select an appropriate value among the various alternatives, and also, determine which one is better and explain its reasoning, analyse the values critically for accuracy and precision. They also opine by making judgments about information, validity of ideas or quality of work based on a set of criteria or evidences.

Question: Compare the values of circuit parameters of two-input CMOS NAND gate to that of the three-input TTL NAND gate.

5. Course outcome achievement in cognitive domain

Learning achievement reflects the quality of education of an educational institution, where teachers are directly involved in achieving it. To determine the achievement of the course outcomes in the cognitive domain, it is first necessary to analyse the educational objectives and corresponding learning abilities of the students at different levels of the cognitive domain. These are given in Table 1.

Table 1. Achievement of Bloom's taxonomy of educational objectives in cognitive domain

Cognitive level	Educational objectives	Learning ability
1	Knowledge	List, cite
2	Comprehension	Explain, paraphrase
3	Application	Calculate, solve, determine
4	Analysis	Classify, predict, model, derive, interpret
5	Synthesis	Propose, create, invent, design, improve
6	Evaluation	Judge, select, critique, justify, optimise

Classroom-based assessment or authentic assessment is considered as many kinds of assessment schemes that can be used to evaluate students learning achievement to cover all levels of cognitive domain. Course outcome achievement is measured through the continuous assessment of all the students in the 'digital electronics' course. This is a three (3.0) credit, three (3.0) hour course and two (2) classes of 1.5 hours duration which are conducted per week in a semester of 12 weeks excluding the mid-term and final examination weeks. For the continuous assessment, the following marks distribution is followed.

Marks are given for attendance if a student is present at least in 75% of the classes conducted in the course, and if a student is present in 100% of the conducted classes, then he/she gets 10 marks and for each 5% less attendance, 0.5 marks are deducted from 10. Two assignments – one on IC minimisation for various combinational logic circuits and another on logic circuit design and implementation using CMOS are given each having 12.5 marks. Two class tests are taken each having 25 marks. Besides, one course project, having 25 marks, on digital electronic circuit/controller design was given for each group comprising four to five students, and the project was received at the last week of the semester with a project report and a power point presentation of 10 minutes, each member of the group getting around 3 minutes. Best three marks from the class tests, assignments and project have been counted. One and a half hour mid-term examination is taken in the middle of the semester. Student has to answer any three out of four questions given. Comprehensive semester final examination is taken with duration of two hours at the end of the semester, and a student has to answer four out of five questions given. Questions on Boolean expressions and theorems on digital logic circuit circuits, description of construction and working principles of digital logic circuits, digital logic circuit design using BJT and MOSFET, design and operation of ADCs and DACs, circuit parameter measurement and analysis are given both in mid-term and final examinations. Questions are set in five (5) basic types, such as, factual, convergent, divergent, and evaluative and combinations of these four (4) types to determine the performance of the each individual student in a particular cohort appropriately.

Based on the accumulated score, final grades of the course are awarded as per grading policy given Table 2. It is to be mentioned that this uniform grading policy is approved by the University Grants Commission of Bangladesh.

As a case study, two different student cohorts (1 and 2) of the 'digital electronics' course, having almost equal class sizes (46 and 45 respectively), are considered in two different consecutive semesters (Spring 2015 and Summer 2015 respectively) of EEE Department of Green University of Bangladesh. In cohort 1, traditional teaching approach is followed in pring 2015 semester and in cohort 2, teaching is given in cognitive domain in Summer 2015 semester by the same course teacher in 'digital electronics' course.

Table 2. Uniform grading policy

Marks out of 100	Grade	Grade point
80–100	A+	4.00
75–79	A	3.75
70–74	A–	3.50
65–69	B+	3.25
60–64	B	3.00
55–59	B–	2.75
50–54	C+	2.50
45–49	C	2.25
40–44	D	2.00
<40	F	0.00

At the end of the final examinations of the two cohorts in two different semesters, statistical analyses of the grade points are calculated and are shown in Tables 3–6.

Table 3. Grade distribution of cohort 1

Grades	Number of students
A+	1
A	2
A–	2
B+	7
B	8
B–	4
C+	3

C	5
D	2
F	7
I	5
Total	46

Table 4. Grade distribution of cohort 2

Grades	Number of students
A+	6
A	2
A–	3
B+	7
B	8
B–	5
C	5
C	4
D	3
F	2
I	0
Total	45

From the tables, it is observed that the statistics have improved in cohort 2, where cognitive process is applied for teaching the students than that in cohort 1. Comparing Tables 3 and 4, it is observed that the number of students getting the lowest grade (i.e., 'F') and incomplete grade (i.e., 'I') has decreased due to the less chance of missing the classes. On the other hand, number of students getting the upper grades (i.e., A+/A/A–) has increased in cohort 2 than that in cohort 1.

Table 5. Statistics of grade points of cohort 1

Statistical parameter	Value
Mode	0.00
Median	2.75
Mean	2.15
Quartile1	0.50
Quartile3	3.19
Standard deviation	1.36
Average deviation	1.14

Table 6. Statistics of grade points of cohort 2

Statistical parameter	Value
Mode	3.00
Median	3.00
Mean	2.89
Quartile 1	2.50
Quartile 3	3.25
Standard deviation	0.86
Average deviation	0.61

Comparing Tables 5 and 6, it is observed that the mode, median, mean, quartiles etc., have also increased in cohort 2 than those in cohort 1. That is, class CGPA has increased and therefore, average class performance has improved due to the enhancement of knowledge and skills on the subject matter of the entire course. Besides, standard and average deviation have reduced in cohort 2 than those in cohort 1. It is because of the increased number of group study and group project works. So, the cognitive process of teaching 'digital electronics' course seems to be better.

6. Conclusion

Engineering graduates must be well prepared in the changing global competitive knowledge-based industry. Like all of us in the world, engineering graduates must have the ability for knowledge management. Therefore, universities are facing challenges as well as opportunities for creating and transferring knowledge to the students to transform them as an efficient and smart engineer.

This paper describes the teaching and learning process of 'digital electronics' course for engineering students in cognitive domain by giving a practical example. This domain includes the recall of knowledge and cultivation of intellectual skills. Certain cognitive processes, such as, problem solving, critical thinking, reasoning, analysis and evaluations are very important in engineering tasks. Since 'digital electronics' is an elementary core course in the curriculum of undergraduate engineering, therefore, this course must be taught in such a way so that the students are able to develop their knowledge and skills on logical operations, Boolean theorems, interpretations and use of data sheets, design, implementation, testing and analysing various types of digital electronic circuits, controllers as well as systems in their practical life engineering tasks.

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