An educational proposal for a 21st Century course focusing on fuses and the prevention of arc flash

F. E. Metaxa[1,*], N. M. Manousakis[1], P. E. Sinioros[1], C. S. Psomopoulos[1]
[1]University of West Attica
[*]Corresponding author: fmetaxa@uniwa.gr

***Abstract*— Arc flash events take place in electric power systems. Injuries from those events are very serious and their treatment, as well as the rehabilitation, is very difficult and expensive. Arc flash events also cause damage to infrastructure and to critical equipment. The impacts of the arc flash event should and can be prevented. The use of appropriate fuses is a way of mitigation those impacts. Fuses are fault sensing devices. They are direct acting devices, which respond to magnitude and duration of current. The use of fuses can prevent human injuries as well as equipment damage. In this article we will present a course concerning the prevention of arc flash events by the use of fuses. This course is aimed at the students of higher-education of the 21st century, in electrical engineering.**

***Keywords*-- Arc flash; course; electrical engineering; fuses; higher-education.**

I. Introduction

Distinguished philosophers, psychologists and educational reformers suggested teaching methods even since the 17th century. Of course, there were clear differences in the teaching approach to the methods, depending on the age in which they were formed. In recent years, Internet has led to radical changes in dissemination of information and consequently in access to knowledge. Accordingly, teaching methods can be enriched with modern tools such as simulation programs for conducting experiments with low cost in engineering courses, since equipment is not necessary needed.

In the last centuries, many learning theories have been developed. Based on those theories, numerous scientific works have been published in the literature [1]. Behaviorism, Cognitivism and Constructivism have proved the most effective in providing approaches to teaching.

According to Behaviorism, the definition of learning can be expressed as the acquisition of a new behavior. It is based on the theory that learning occurs through study, reinforcement and repetition [2]. Most important representatives of Behaviorism were Ivan Pavlov (1849-1936), Edward Thorndike (1874-1949), John Broadus Watson (1878-1958) and Burrhus Frederic Skinner (1904-1990). Pavlov was known for his work in classical conditioning which occurs when a conditioned stimulus (CS) is paired with an unconditioned stimulus [3]. Thorndike developed the laws of learning: effect, exercise and readiness. The "law of effect" stated that the strength of the stimulus–response bond depends on the magnitude of satisfaction [4]. According to the "law of exercise", connections between a stimulus and a response are strengthened as they are used [5]. In the "law of readiness", Thorndike claims that when a "conductivity unit" is ready to transfer something, the transfer accomplishment causes a pleasant situation [6]. Watson was the one who used the term “Behaviorism”. He stated the law of frequency: “The more frequent a stimulus and response occur in association with each other, the stronger that habit will become” and the law of recency: “The response that has most recently occurred after a particular stimulus is the response most likely to be associated with that stimulus” [7]. Skinner believed that human learning can be achieved through rewards and punishments. The principals of this particular form of learning which is called operant conditioning are: *Positive Reinforcement*, *Negative Reinforcement*, *Extinction* or *Non-Reinforcement*, *Punishment* [7].

Cognitivism is grounded on mental processes than on observed behavior. Notable cognitivists are Jean Piaget (1896-1980), Benjamin Bloom (1913-1999), Jerome Bruner (1915-2016) and Noam Chomsky (1928-) [8]. Piaget believed that the adjustment to environmental influences is a learning process. The key concepts of this process are: *Schema* which is an internal knowledge structure; *Assimilation* which is the process of inserting new information into previously existing schema; *Accommodation* which is the process of changing schemas under new information or experience; *Equilibration* which is a balance between assimilation and accommodation [9]. Bloom is best known for the taxonomies of learning objectives. According to Bloom, there are three domains of learning: cognitive, affective and psycho-motor. His theory is the most widely used in education [8]. Bruner underpinned that the discovery method leads to knowledge. Based on Bruner’s method, the systems used by the learner in order to understand the information and develop cognitively are: *Enactive representation* (action-based); *Iconic representation* (image-based); *Symbolic representation* (language-based) [10]. Chomsky is known about his linguistic theory [11].

Constructivism, as a learning theory, belongs to the field of cognitive science. For constructivists, learning is a result of mental construction [12]. Well known constructivists were Lev Vygotsky (1896-1934) and Dewey (1859-1952). Vygotsky’s concept was *the cultural mediation of thinking*, since he believed that culture is the most important factor in cognitive development [13]. Dewey founded his educational theory on the *quality* of experience which is based on the principles of *interaction*, concerning the relation of previous experience to present situation, and *continuity*, concerning the impact of previous on future experiences [14].

All these learning techniques have been applied, from time to time, to different levels of education. According to Bologna process guidelines, learning theories have been implemented in higher education. In OECD's (Organisation for Economic Co-operation and Development) report in 2008, practices in assessment of learning outcomes in higher education have been described. The learning objectives are being assessed by the use of Bloom's taxonomy [15].

Engineering education requires both theoretical and practical training. Engineers should possess the knowledge in such a way to be able to solve complex problems, compose and analyze situations in order to arrive at safe conclusions. They should also develop critical thinking to be engaged in research of new fields of science. Education should, therefore, enable them to respond to new challenges. Bloom's taxonomy is a valuable guide for academic to structure courses, as well as confirm student's ability at all required levels [16]. This paper proposes a course for a pro-graduate curriculum in higher education, based on Bloom's taxonomy aiming to learning objectives in cognitive domain and focusing on arc flash prevention and fuses. The effects of arc flashes can be destructive for the electrical equipment and fatal for humans.

The rest of the paper is organized as follows: Section II of this paper presents Bloom's taxonomy, whereas Section III provides the theoretical background of arc flash. Section IV describes a novel proposal of a course focusing on fuses and the prevention of arc flash. Finally, Section V concludes the paper.

II. Bloom's Taxonomy

Bloom and his colleagues built a taxonomy of educational objectives which is a classification of the goals of educational systems in three major domains: cognitive, affective and psychomotor. Taxonomy in cognitive domain helps academics evaluate student's mental skills. In affective domain, assessment concerns feelings and attitudes, whereas the evaluation in psychomotor domain concerns physical skills. The proposed course is structured on the cognitive domain. According to Bloom's taxonomy, the major categories of cognitive processes are: Knowledge; Comprehension; Application (basic thinking skills); Analysis; Synthesis; Evaluation (higher thinking skills), as described in Fig. 1 [17].

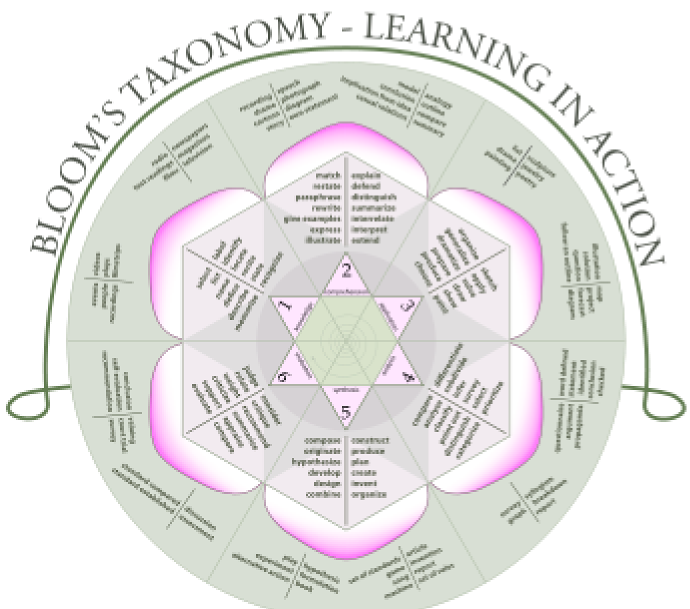

Fig.1. Bloom's taxonomy chart.

III. Arc Flash Hazard Background

A. *Arc flash*

Arc flash is a dangerous condition that is related with the unexpected releasing of extremely amounts of energy in presence of an electric arc within electrical equipment and has as a result the emission of intense light, heat, sound, and blast of arc products consisting of vaporized copper, steel, or aluminum components. Arcing takes place during the breaking down of the insulation between the live conductors and is strait related with many reasons like aging, surface tracking, treeing phenomena, and human errors due to maintenance of electrical equipment in the energized state [18].

Electrical arcs are created when current passages through what has previously been air and are initiated by flashovers or by introducing conductive materials. The current flows through the ionized air and the vapor of the arc terminal material. The voltage drop that is created is highly depended on the length of the arc as well as the voltage of the system. The current path presents a resistive behavior, which means that the power factor is equal to one. Considering a large solid or stranded conductor, the voltage drop varies from 0.016 to 0.033 *V/cm*. These voltage drops are significantly lower in comparison with voltage drops in an arc varying between 5 and 10*V/cm* of arc length for virtually all arcs in open air.

Currently, there are three major guides for arc flash calculations: NFPA 70E, IEEE 1584 Guide, and IEEE 1584a. According to IEEE 1584 Guide and considering three - phase electrical systems operating at 0.208 to 15 *kV*, with a nominal frequency 50 or 60 *Hz*, an available short - circuit current with range 0.7 – 10.6 *kA*, and a conductor's gap equal to 13 – 152 *mm*, the arcing current I_α can be calculated, in *kA*, by (1) and (2):

$$\log_{10} I_\alpha = K + 0.662\log_{10} I_{bf} + 0.0966V + 0.000526G + 0.5588(\log_{10} I_{bf}) - 0.00304G(\log_{10} I_{bf}),\ V < 1kV \quad (1)$$

$$\log_{10} I_\alpha = 0.00402 + 0.983\log_{10} I_{bf},\ V \geq 1kV \quad (2)$$

where G is the conductor gap in *nm*, K is a constant equal to -0.153 for open air arcs and -0.097 for arc in a box, V is the voltage of the system, and I_{bf} is the bolted, rms symmetrical, three-phase fault current in *kA*. Eq. (5) is valid for arcs in open air as well as in a box. The 85% of I_α is used to find the second arc duration which accounts for variations in the arcing current and the time for the overcurrent device to open.

B. Fuses

Fuses are fault sensing and interrupting devices. They are single - phase devices, direct acting, which respond to magnitude and duration of current. Fuses can be categorized as *current-limiting fuses*, *low voltage fuses*, *high voltage fuses*, *and electronic fuses* [18].

– *Current-Limiting Fuses*

Current - limiting fuses have as target the equipment damage reduction by interrupting the rising fault current before it reaches its peak value. Considering the current limiting range, these fuses operate within 1/4 to 1/2 cycle. This type of fuses can be classified as:

1. *Backup Fuses*. They have a minimum to maximum interrupting current range. The most characteristic type of this class is the type R fuses, which are connected in series with another interrupting device, e.g., medium voltage starters.
2. *General Purpose Fuses*. They are used for the interruption of all currents down to the current that leads to melting of the fuse element in no less than 1 hour.
3. *Full - Range Fuses*. They are used for the interruption of all currents from the rated interrupting current to the minimum continuous current that causes melting of the fusible element. Each fuse of this type is applied at the maximum ambient temperature specified by the manufacturer.

– *Low Voltage Fuses*

Low voltage fuses are classified into two distinct types, *current - limiting type* and *noncurrent - limiting type*. Current - limiting fuses may interrupt currents up to 200 *kA* rms symmetrical. They are designed for specific applications, whereas their size and mounting dimensions vary, and they are not interchangeable. Classical types of this class are the CC, T, K, G, J, L, and R fuses. Noncurrent - limiting fuses, have a low interrupting rating of 10 *kA*. Their usage in not quite popular in industrial power systems, while they can be replaced by with current - limiting fuses. A representative type of this class is the H fuse.

– *High Voltage Fuses*

High voltage fuses are divided into two distinct categories, *distribution fuse cutouts* and *power fuses*. Distribution cutouts are exclusively used for outdoor pole or cross - arm mounting and applied on distribution feeders and circuits up to 34.5 *kV*. The interrupting ratings are relatively low (5.00 *kA* rms symmetrical at 34.5 *kV*). Power fuses are primarily installed stations and substations and divided to expulsion - type fuses and current - limiting fuses. Expulsion - type fuses can also be divided to fiber - lined fuses having voltage ratings up to 169 *kV* and solid boric acid fuses having voltage ratings up to 145 *kV*, respectively. High voltage current - limiting fuses are available up to 38 *kV* having comparatively much higher interrupting ratings.

– *Electronic Fuses*

Electronic fuses are a new development incorporated to control and interrupting module and mainly provides electronically derived time – current characteristics, current sensing, and energy to initiate tripping. Their ratings are up to 1.2 *kA* and 25 *kV*.

IV. Course Proposal

The proposed course is deployed in the area of electrical engineering and consists of the following sections:

1. The arc flash.
2. Equipment upon which arc flash may occur.
3. Impact of arc flash on human and electrical equipment.

4. Methods of preventing the effects of arc flash – Standards.
5. Fuses.
6. The use of fuses for the prevention of arc flash hazards.

Students are divided in six groups. Each group comes up with a presentation of a specific section described above, under the guidance of the academic. The sources upon students will build their presentations may be: literature review, reliable online resources, simulation software programs etc. A discussion about the presented subject, between the academic and the students, follows each presentation. The learning outcomes for each section are confirmed by the following evaluation process, according to Bloom's taxonomy:

1st Section: The arc flash

Knowledge: Describe what the arc flash is.
Comprehension: Explain what happens when the arc flash occurs.
Application: Write the formula that shows the energy released during the arc flash. What factors depend on energy?
Analysis: Draw the current chart in relation to time.
Synthesis: Create arc flash using simulation software.
Evaluation: What are the effects related to arc flash?

2nd Section: Equipment upon which arc flash may occur

At the high voltage laboratory facilities of the Department of Electrical and Electronics Engineering of the University of West Attica, the arc flash is presented to the students by laboratory teachers. Students receive measurements over time. To meet educational needs of this section, students visit the facilities of Testing Research and Standards Center.

Knowledge: Describe two cases-examples of electrical configurations or/and installations in which arc flash occurs.
Comprehension: Select one of the above mentioned cases and explain the reasons causing the arc flash event.
Application: According to IEEE 1584 Guide, compute the incident energy in the cases be implemented during the experimental process.
Analysis: Draw the current chart in relation to time during the experimental process.
Synthesis: Propose ways to prevent arc flash in experimental applications.
Evaluation: Compare the chart you plotted with the data from the experimental application with the corresponding theoretical one.

3rd Section: Impact of arc flash on human and electrical equipment

Knowledge: Name three effects of arc flash either on human or on the electrical equipment.
Comprehension: Describe the possible effects of arc flash in every specific case given to each group of students.
Application: Present in the classroom the effects of the arc flash on the equipment and humans using a simulation program in each of the above cases.
Analysis: Classify the impacts reported from the most serious to the most harmless.
Synthesis: Propose a technical improvement of the equipment to prevent arc flash for each one of the above cases.
Evaluation: Estimate the economic impact for each of the above cases, considering the above classification and the financial cost per damage occurred from arc flash events.

4th Section: Methods of preventing the effects of arc flash – Standards

Knowledge: Name three methods to prevent the effects of arc flash in accordance with Standards.
Comprehension: Select one of the above methods and summarize it.
Application: Choose a method of preventing the phenomenon as described in Standards, for each case given to the previous section.
Analysis: Analyze how the specific method you selected will prevent the arc flash in each case.
Synthesis: Propose amendments to Standards for the most effective protection of the equipment.
Evaluation: Compare the cost of applying the method to prevent the phenomenon with the cost of repairing the damage.

5th Section: Fuses

Knowledge: Identify and categorize the different types of fuses according to their classification.
Comprehension: Select three types of fuses and describe the electrical configurations or equipment that could be applied.
Application: Simulate an electrical installation according to a given diagram and propose its optimal protection by selecting the most appropriate types of fuses.
Analysis: Analyze the characteristics of fuses that have been selected in each case.
Synthesis: Propose a guide to select criteria for the correlation of fuses and electrical configurations.
Evaluation: Estimate the cost of fuses for the electrical installation you worked on.

6th Section: The use of fuses for the prevention of arc flash hazards

Knowledge: From the presentation of the fuse types, name the most suitable to prevent the effects of arcing in electrical equipment.
Comprehension: Give two examples of implementation.
Application: A diagram of an electrical installation is given to each student group where specific fuses have already been selected.

- Simulate the arc flash using simulation software.
- Assess the impacts.

Analysis: Among the presented cases, choose the most dangerous one for the equipment and/or humans.
Synthesis: Relate the cost of the potential damage restoration with the cost of fuses for the case selected above.
Evaluation: Justify, theoretically, the type of fuses selected in each diagram given, for the prevention of arc flash hazards and considering the corresponding Standards.

The course is completed with a final project about arc flash prevention considering a real case. The data of each case are given to every group. Students should make a technical and financial report analyzing the facts and proposing prevention methods.

V. Conclusions

This paper introduces a newly developed course to be taught in higher education focusing on fuses and the arc flash prevention, and helps the future electrical engineers to gain real-world knowledge. The course is designed based on Bloom's taxonomy and covers six sections. It approaches the arc flash effects on the electrical equipment as well as on humans, in technical and financial terms. Moreover, a research project is assigned to students in order to give them the chance to apply the knowledge that they have gained throughout the course.

References

[1] C. Mustafa, "Constructivist Approaches to Learning in Science and Their Implications for Science Pedagogy: A Literature Review," *Int. Jour. Environmental and Science Education*, vol. 3, no. 4, pp. 193-206, Oct. 2008.
[2] U. G. Singh and T. Obafemi, "Educators' Teaching Strategies in eLearning Environments," in *Proc. 3rd IEEE International Conference on Computing, Communication and Security (ICCCS)*, Kathmandu (Nepal), 2018.
[3] C. J. Weibell. Principles of learning: 7 principles to guide personalized, student-centered learning in the technology-enhanced, blended learning environment. *Phd Dissert*., Brigham Young University, US, Jun. 2011.
[4] J. A. Nevin, "Analyzing Thorndike's law of effect: The question of stimulus-response bonds," *J. Experiment. Analysis Behavior*, vol. 72, no. 3, pp. 447–450, Nov. 1999.
[5] A. P. Karadut, "Effects of E. L. Thorndike's theory of connectionism rudiments ondeveloping cello playing skills for beginners," in *Proc. Int. Conf. Education and Educational Psychology (ICEEPSY)*, 2012.
[6] M. Knowles, The adult learner: A neglected species (5th ed.). Houston, TX: Gulf Publishing Company, 1998.
[7] A. Pritchard. Ways of Learning: Learning theories and learning styles in the classroom (2nd ed.). Routledge. 2008.
[8] T. Bates. Teaching in a digital age. University of British Columbia. 2015.
[9] G. Brown and C. Desforges. Piaget's Theory (1st ed.). Routledge. 2006.
[10] D. Bakhurst and S.G. Shanker. Jarome Bruner: Language, Culture and Self (1st ed.). SAGE. 2001.
[11] N. Chomsky. Aspects of the theory of Syntax Noam Chomsky. (50th ed.). MIT press. 2015.
[12] S.O. Bada, "Constructivism Learning Theory: A Paradigm for Teaching and Learning," *J. Research & Method in Education*, vol. 5, no. 6, pp. 66–70, Nov. – Dec. 2015.
[13] L.C. Moll. L. S. Vygotsky and Education. Routledge. 2014.
[14] M. Schmidt, "Learning From Teaching Experience: Dewey's Theory and Preservice Teachers' Learning," *J. Research Music Education*, vol. 58, no. 2, pp. 131–146, Jun. 2010.
[15] M. J. Rosa and A. Amaral. Quality Assurance in Higher Education, Contemporary Debates. Palgrave Macmillan 2014.
[16] R. M. Felder and R. Brent, "THE ABC'S OF ENGINEERING EDUCATION: ABET, BLOOM'S TAXONOMY, COOPERATIVE LEARNING, AND SO ON," in *Proc. American Society for Engineering Education Annual Conference & Exposition,* 2004.
[17] K. Aainsqatsi – Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=4000460
[18] J. C. Das. ARC FLASH HAZARD ANALYSIS AND MITIGATION. John Wiley & Sons, Inc., Hoboken, New Jersey. 2012.