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Engineering Design in New ABET Engineering Criteria: Understanding, Implementation and Assessment

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***Abstract*—ABET Foundation has made a major adjustment in the Students Outcomes (SOs) in engineering criteria for accrediting engineering programs. This shift in SOs has driven engineering programs to adopt engineering design topics in their curriculum to fill the soft skills gap of students through understanding the learning materials and to motivate them to improve self-learning skills. Active Learning Approaches (ALAs) are often used as a learning culture to deliver the learning materials to increase classroom effectiveness and to maximize students' benefits. As an extension of the learning process, it is important to present appropriate assessment tools to measure the achievement of the course outcomes. Specific assessment of student attainment of engineering design objectives is an important part of the program curriculum and vital to accreditation of engineering programs. Direct and indirect measures assess and evaluate the level of outcomes attainment throughout the course of the educational process. Course survey is conducted to students regarding the level of their satisfaction in achieving Course Learning Outcomes (CLOs). Analysis of the survey results along with the students' grades will be employed as a basis for continuous improvement in teaching and learning practices in engineering programs. It is obvious from this study that the students enjoyed the course activities and they have become more positive about the gained skills and realize their importance. Additional results and discussions of the role played by engineering design in enhancing soft skills, in the engineering programs, will be presented.**

Keywords— Engineering design; ABET; Accreditation; Student outcome;, Active learnin;, CLOs

I. INRODUCTION

Engineering programs seek to achieve higher levels of soft and professional skills of their graduates through an ongoing process involving a periodical assessment and continuous improvement process. A well-known way of ensuring and demonstrating the high quality of engineering education is through evaluation carried out by accreditation bodies like Accreditation Board for Engineering and Technology (ABET). ABET is considered one of the highly respected bodies that administer the academic accreditation process for engineering programs worldwide. The outcome assessment process, based on ABET Criteria, focuses on what the students learned and what they can do at the time of graduation [1]. The outcome assessment process is defined as a systematic collection, review, and use of information about educational programs undertaken for the purpose of improving student learning and development [2]. Consequently, a continuous improvement process must be built and run-in place.

ABET Foundation has made a major adjustment in the SOs in engineering criteria for accrediting engineering programs. Some of the SOs have been incorporated and some important adjustments have been made for the others [3]. Understanding these adjustments is essential for engineering programs, not only for those who seek ABET accreditation but also for those previously accredited by it. One of these important adjustments is that related to engineering design in the second SO of Criterion 3 and the associated soft skills [1]. In these adjustments, the design concept has been shifted in the previous ABET Criteria to engineering design concepts, which may require the engineering programs to adopt new course/s in their Curricula. This new philosophy needs more studying and understanding for its application to be effective and beneficial for engineering programs as well as for their graduates. In the meantime, it must admit that there are many engineering programs that have adopted engineering design as a mandatory course before ABET makes these adjustments due to the need for these programs to enhance the design skills and the accompanying soft skills of their students [4]. The course was introduced basically to fill the soft skills gap through understanding the learning materials and motivating students to improve their self-learning skills. The importance of soft skills in engineering education has been raised by faculty and industry [5].

Engineering design is the process of devising a system, component, or process to meet desired needs and specifications within certain constraints. It is an iterative and creative decision-making process in which basic and math sciences and engineering sciences are applied to transform resources into solutions [3]. It also includes identifying opportunities, developing requirements, conducting analysis and synthesis, creating multiple solutions, evaluating solutions against requirements, considering risks, and making trade-offs with the aim of obtaining a high-quality solution under certain conditions. Possible constraints may include some or more of the following: accessibility, aesthetics, codes, constructability, cost, ergonomics, scalability, functionality, legal considerations, maintainability, manufacturability, or marketability, policy, regulations, standards, sustainability, or usability [1,3].

Active Learning Approaches (ALAs) were usually employed as a learning technique for this course in which incorporates active learning, teams, problem-solving, and quality principles [6]. This learning style is completely different from the techniques most students have practiced and become

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accustomed to since the beginning of pre-university education in which information flow, usually, has one way starting from the instructor and ending at the students [7]. Thus, the learning materials should develop in such a way as to enhance students' understanding and to assist the faculty who will be delivering these materials. Active learning is an instructional method that engages students in the learning process in which the whole educational process is centered around the student. It requires students to do profound learning activities and to think about what they are doing [6]. While this could include some traditional activities such as homework, in practice, it refers to activities that are introduced into the classroom. However, the core elements of active learning modules are student activities and engagement in the whole learning process [8].

This paper presents a framework for introducing an engineering design course to engineering programs curricula and focuses on how to plan and deliver the learning materials, assess the students' attainment of the CLOs, as well as developing and improving the learning process.

II. Student Outcomes: A New Language

In the latest ABET criteria, they have used a new language to define the SOs of engineering programs. After the number of SOs was 11, they have become 7, and the language used to describe the knowledge, skills, and attributes that the students should acquire at the time of graduation has changed significantly. These new SOs will effectively enhance the program's educational objectives. Accordingly, the attainment of these new SOs prepares engineering graduates to enter the professional practice of engineering. The SOs were published on the ABET website and their matches with the previous SOs are found in Table 1. In this table, the first one is for old SOs and the second column introduces the new SOs, which are applied from the 19-2020 ABET cycle (approved by the Engineering Area Delegation (EAD) on October 20, 2017) [3].

Table 1: Matching of previous and current SOs of Criterion 3 in ABET engineering criteria [3].

Previous SOs in Criterion 3. Pervious Language EAC Criteria effective up to 2018-19 Cycle.	**Current SOs in Criterion 3. New Language Approved by EAD October 20, 2017, for application starting 2019-20 cycle.**
(a) an ability to apply knowledge of mathematics, science, and engineering. (e) an ability to identify, formulate, and solve engineering problems.	1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.	2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
(g) an ability to communicate effectively.	3. an ability to communicate effectively with a range of audiences.
(f) an understanding of professional and ethical responsibility. (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context. (j) a knowledge of contemporary issues.	4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
(d) an ability to function on multidisciplinary teams.	5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
(b) an ability to design and conduct experiments, as well as to analyze and interpret data.	6. an ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgment to draw conclusions.
(i) a recognition of the need for, and an ability to engage in life-long learning.	7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	Implied in 1, 2, and 6.

As shown in this table the SOs for the engineering programs were decreased from 11 to 7 in new ABET criteria, and the second SO was allocated for learning the engineering design as an alternative to design skills in the previous criteria. Furthermore, the term engineering design has been mentioned in the other criteria which indicates the necessity of understanding what engineering design is and how to learn, assess and improve it continuously.

III. ENGINEERING DESIGN PHILOSOPHY

The main philosophy of having engineering design topics in the engineering curriculum is to have the students learned and practiced the engineering method. The engineering method is “the use of heuristics to cause the best change in a poorly understood situation by using the available resources” [9]. Engineering design based on ABET definition is the process of designing (or creating) a system, physical component, or process to meet desired needs and specifications within specific constraints. It is a decision-making process (often iterative), in which basic sciences, mathematics, and engineering sciences are applied to optimally convert resources to meet the stated goals [4].

The course learning materials are of use for all engineering disciplines; thus, the student should expect to focus on the process of problem-solving and to develop confidence in his abilities to solve problems. There must be an engineering design project in which the students learn, work together, and share their skills and knowledge to achieve engineering design goals. The project addresses an open-ended problem and follows certain standards within specific constraints. Accreditation bodies such as ABET usually focuses on the use of teamwork in problem-solving processes and performing design [2]. Lumsdaine et al [10] have identified twelve steps as

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a part of the engineering design process. Davis et al [11] have identified six types of activities that comprise the design process. Some others have named eight steps for defining the process [12] as shown in the chart in Fig. 1. Hence, engineering design can be described as a process that engages students in a creative effort toward producing a design product that meets stated requirements within realistic constraints. The incorporation of engineering design topics in the program curriculum is considered a new experience that needs a mechanism for building the necessary expertise among the faculty to achieve the goals of this adjustment. It needs to build experiences among the faculty and to practice on how to present the learning materials in an active learning classroom. It also needs to spread the culture of engineering design among the rest of the faculty members who do not involve in its teaching and among students in general.

The engineering design in the curriculum must contain most of the following features: development of student creativity, use of open-ended problems, development, and use of modern design theory and methodology, formulation of design problem statements and specifications, consideration of alternative engineering solutions, feasibility considerations, production processes, concurrent engineering design and a detailed description of the system [13]. Moreover, it is necessary to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact.

IV. Learning Process and CLOs Assessment

As mentioned previously, ALA is used as a learning technique to deliver the learning materials to increase classroom effectiveness. This learning technique incorporates all the learning modules presented in the learning pyramid [4,14]. In the beginning, most students will find the active learning class to be different; some students immediately will embrace it; many students will try the method without real conviction; few students will find this approach annoying [7]. To resolve such an issue, instructors must pay more effort to a) helping skeptics see enough rationale and tools to be at least willing to experiment with methods, b) helping those willing, but not convinced, to be more comfortable with the methods and appreciate this culture of learning, c) help the believers to involve their classmates in this process [6]. Creating an active classroom is an entirely different matter to integrate active learning into a value structure: changing habits learned and enhanced over a lifetime is difficult not only for students but also for faculty. This transition needs time and effort to spread the new culture and to build a solid foundation among the whole academic community. This is essential to help both faculty and students focus on the important issues and continually remind all the participants that our goal is student success in the learning process and engineering curriculum. There are three dimensions were defined for the learning domain that is fundamental to team-based engineering design: a) engineering design process, which includes; defining, performing, and managing steps to create and deliver a technological product that meets or may exceed customer expectations, b) Teamwork, which includes; organizing and managing the activities and resources of a group of students to achieve results beyond what can be done individually, and c) design communication, that may also include; managing and exchanging information needed to support effective design [5].

High-quality engineering programs must have the engineering design topics distributed along the curriculum with significant numbers of students face special challenges in assessing students' capabilities and providing meaningful feedback to improve its learning process [9]. Table 2 shows the distribution of mini-design projects to the design courses. As shown, there is at least one mini-design project per academic level and ends with a capstone design project. Students must master these dimensions to be successful in achieving engineering design learning outcomes. The learning materials may include the following topics to cover all elements of engineering design processes: Engineering design or how engineers approach and solve problems; process and product design, Working in teams, Presentations; organization and assessment of technical work, Preparation of brief reports on assigned work, Quality principles, Design project, Reverse engineering, Self-regulation or the behaviors associated with taking personal responsibility for time management, Modeling and finally Engineering ethics [9,10]. The presence of this thought in the study plan makes it more professional and increases its coherence and strength, without being a burden on it by adding new courses.

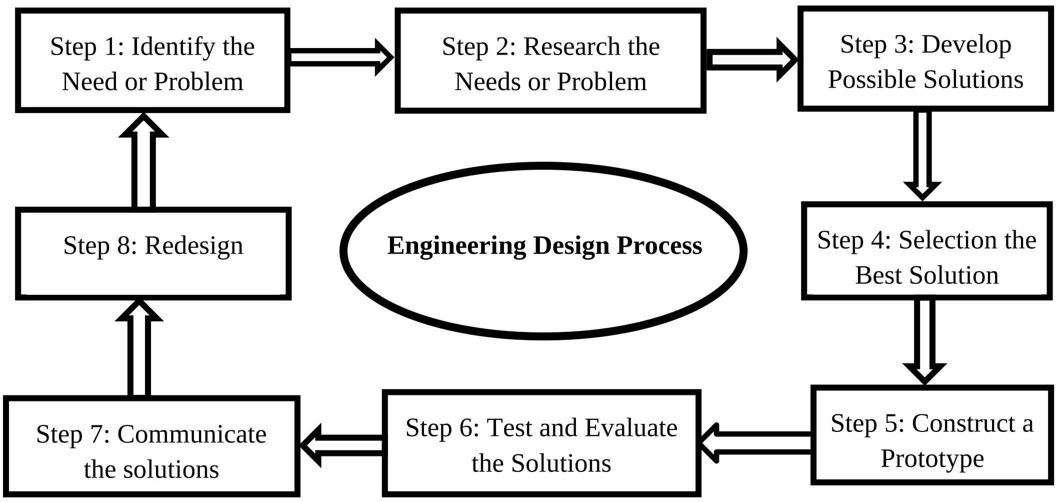

Fig. 1 Schematic representation of the engineering design process [12].

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As an extension of the learning process, it is important to present appropriate assessment tools to measure the student attainment of CLOs. Table 3 shows proposed assessment methods for engineering design topics. The existence of such a specific method is necessary to be consistent with the learning modules in which this course is presented. Direct and indirect measures assess and evaluate the level of CLOs attainment throughout the learning process. These relate to the skills, knowledge, and attributes that students acquire through their progress in the program. Table 4 presents different tools that may be employed to directly assess the attainment of students to the CLOs. Despite that influence of engineering design is existed in all SOs, emphasis in this paper is placed only on the measurement of SO_2, SO_3, and SO_5.

Table 2: Proposed engineering design chain in the study plan.

Year	Level	Introductory Design Course I	Introductory Design Course II	Major Design Course	Major Design Course	Major Design Course	Major Design Course	Senior Design Project
Year 1	Level 1	Eng. Design I		Other courses				
	Level 2		Eng. Design II		Other courses			
Year 2	Level 3			Mini Project 1		Other courses		
	Level 4	Other courses			Mini Project 2		Other courses	
Year 3	Level 5	Other courses				Mini Project 3		
	Level 6	Other courses					Mini Project 4	
Year 4	Level 7	Other courses						Capstone Design Project
	Level 8	Other courses						

Table 3: Course assessment methods

Course Topics, T	Assessment Methods							
	Class Activities						Final Exams	
	Assignments	Quizzes	Reports	Mini Project	Oral/Group Discussions	Class Performance	Project Final Report	Final (Oral Presentation)
T1	√							
T2		√		√		√		
T3				√	√	√		√
T4	√		√	√		√		
T5		√			√	√		√
T6			√	√		√		√
T7		√		√	√	√		
T8	√		√			√	√	
T9		√			√	√		
T10	√			√	√	√	√	√
	10	20	10	20	10	10	10	10
	80						**20**	
	100							

Table 4: Mapping of assessment tools *vs* student outcomes (SOs).

SOs	**Class Activities**							**Capstone Design Project**	**Major Written Exams**	
	Assignments	**Quizzes**	**Reports**	**Presentations**	**Mini-Projects**	**Oral/Group Discussions**	**Lab. Performance**			
SO-1										
SO-2			√	√	√	√	√	√	√	√
SO-3			√	√		√	√	√	√	√
SO-4										
SO-5	√					√	√	√	√	√
SO-6										
SO-7										

V. ATTAINMENT OF CLOS

Fig. 2 shows the average grades distribution of engineering design students for three consecutive years. The figure is a typical grade deduced from the direct assessment of student assignments and activities. As shown the average grades distribution has followed the normal distribution curve tending to the left side and the number of failing students is almost zero. It has also been found that the average overall grade for the students is around B+. This result is expected according to the nature of the course as all students' activities and assignments are subject to the concept of a continuous improvement process. Therefore, when a student fails to fulfill the expectations of an assignment, he/she's been asked to resubmit it after the correction based on a specific checklist. Spreading this culture is necessary for the students because that is what they will face in engineering fields after graduation.

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A course survey was conducted to measure the level of student's satisfaction with CLOs attainment. A typical example of a course survey is found in Appendix A. The survey was done at the end of each semester and was filled out by 229 students, which confirms the validity and reliability of the results obtained. The result of this survey indicates the extent of students' satisfaction with their attainment of CLOs. Figs. 3 show results of students' survey on their satisfaction of CLOs attainment; a) average score per CLO, and b) percentage of students achieving satisfactory/exemplary levels (SAELs). The result of students' satisfaction with achieving CLOs was ~80% for all CLOs, and ~85% for SAELs, which support the previous result regarding the course grades. Figs. 4 show results of students' survey on their satisfaction of SOs attainment; a) average score per SO, and b) percentage of SAELs. The result of the student survey of their satisfaction was ~89% for all SOs, and ~95% for SAELs. These results showed a high degree of student satisfaction with their attainment of the stated CLOs and SOs.

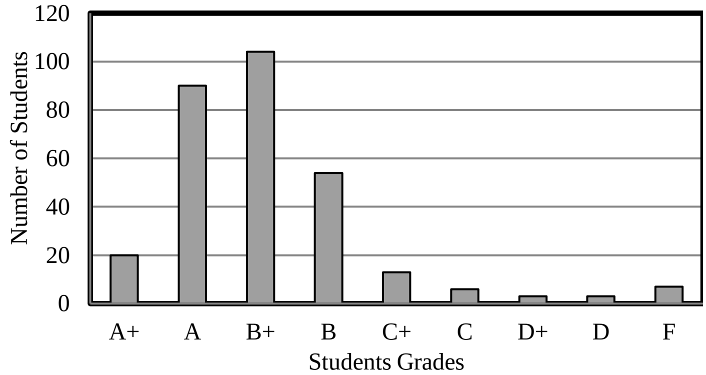

Fig. 2 Typical student overall grades of engineering design course

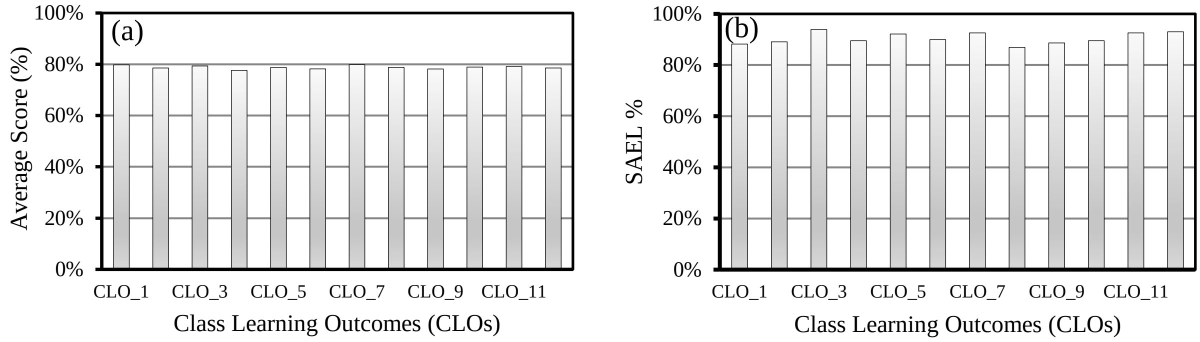

Fig. 3 Results of students' survey; a) average score per CLOs, and b) Percentage of SAELs.

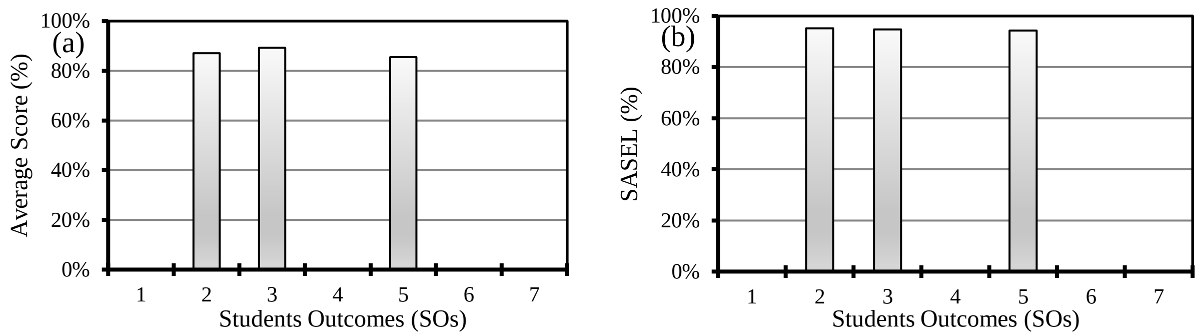

Fig. 4 Results of students' survey; a) average score per SO, and b) Percentage of SAELs.

VI. CONCLUSIONS

This paper was aimed at presenting a proposal for understanding, implementation and assessment of engineering design based on our accumulated experiences. This may help the engineering program curriculum, objectives, and outcomes to be in alignment with ABET accreditation Criteria. Based on these discussions and analysis, the following recommendations have been presented:

- The first stage is offering an introductory course in early levels so that the students learn the basic concepts of engineering design process and applying them in enough activities to make sure they gain at least the minimum level of the necessary skills.
- The second stage is presenting series of mini projects in design courses in the following levels in which they are

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practicing the engineering design to solve an open-ended problem. In these mini design projects, the students are practicing the basics concepts they have learned in the first course. This should be culminated with a comprehensive design project at the end of the study plan. Coming to this stage, the students should show up their learned skills in applying engineering design in addition to the corresponding soft skills.

- The final stage is establishing successive prerequisites in the study plan that include sequencing and integration of design courses at successive levels up to the final level.

CONFLICT OF INTEREST

The authors have no conflicts of interest.

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REFERENCES

[1] https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/

[2] C.A. Palomba and T.W. Banta, "Assessment essentials: planning, implementing", and improving assessment in higher education, San Francisco, CA: Jossey-Bass Pub., 1999

[3] https://www.abet.org/wp-content/uploads/2018/03/C3_C5_mapping_SEC_1-13-2018.pdf

[4] Al-Badrawy A. Abo Al-Nasr, "Role of Engineering Design in Enhancing ABET Outcomes of Engineering Programs at Taif University", Inter J of Applied Science and Technology, (Vol. 6, Issue 1), (June 2017), pp. 9-15

[5] G. Backlund, and J. Sjunnesson, "Training Young Engineers to See", AI & Society, 27(4), 2012, pp. 509-515

[6] R.M. Felder and R. Brent, "Active Learning: An Introduction", ASQ Higher Edu. Brief, 2(4), Aug. 2009

[7] S.A. AlYahya, Al-Badrawy A. Abo El-Nasr, "Outcomes based assessment of the engineering programs at Qassim University for ABET accreditation", Proc. of Inter. Conf. on Interactive Mobile and Computer Aided Learning (IMCL), IEEE, (2012), pp. 22-31

[8] D.C. Davis, K.L. Gentili, M. S. Trevisan, R. K. Christianson, J. F. McCauley, "Measuring Learning Outcomes for Engineering Design Education", 2000 Annual Conf. (2000), pp. 1-7

[9] G. Pahl and W. Beitz, "Engineering Design: A Systematic Approach", 2nd ed., 2013, Springer

[10] E. Lumsdaine, M. Lumsdaine, and J.W. Shelnutt, "Creative Problem Solving in Engineering Design", McGraw-Hill Inc., 1999, p. 328

[11] D.C. Davis, K.L. Gentili, M. S. Trevisani and D.E. Calkins, "Engineering Design Assessment Processes and Scoring Scales for Program Improvement and Accountability", J. Eng. Edu., April 2002, pp. 211-221

[12] https://www.linkengineering.org/Explore/EngineeringDesign/5824.aspx

[13] N.A. Najar, S. Abdullah, "Fundamentals of Engineering Design", JKERT Foundation, (2017), p. 11

[14] S. Freeman, B. Jaeger and R. Whalen "Active Teaching, Active Learning: Infusing the Design Process in a First-Year Course", 2006 Annual Conference & Exposition, June 21, (2006), pp.1-18

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Appendix A
Students survey for feedback on the CLOs

Course Title:	**Introduction to Engineering Design I**	**Course Code:**	……
Program offering the course:	…………………	**Semester:**	…..
Course Instructor:	**Prof.** ………	**Acad. Year:**	……

Notes:

1- The purpose of this survey is to obtain feedback to help us improve your learning skills. All questions pertain to the course itself, not to the teacher. The **Class Learning Outcomes, CLOs**, as mentioned in the course syllabus are listed below.

2- Using the following Scale of Rating: **10=*Strongly Agree* --------> 1=*Strongly Disagree***; please mark your choice for each of the following statements.

CLOs	Questions regarding the CLOs. In this course, I acquired the following:	Scale of Rating									
		1	2	3	4	5	6	7	8	9	10
CLO_1	develop and exhibit the behaviors associated with taking personal responsibility in an active learning environment and practice elements of active learning as well as apply active learning techniques such as Engineering Journal, Process Check										
CLO_2	explain quality, costumer, expectations, and process as well as demonstrate the ability to meet customer expectations										
CLO_3	develop team norms and use effective team tools such as team agenda, minutes and process check as well as Boggle method, affinity process, deployment flowchart, multi-voting ...etc.										
CLO_4	Apply the engineering design process in various industrial or social problems										
CLO_5	explain problem definition techniques such as exploring the problem, present state/desired state, Dunker diagram, statement restatement, KT Problem Analysis and apply them on semester design project.										
CLO_6	explain and apply problem solving strategies such as using heuristic, perceiving problems, potential problem, real problem, …etc. Osborn's Checklist, random stimulation, fishbone diagram as well as apply them on semester project.										
CLO_7	explain situation analysis, problem analysis, decision analysis, potential problem analysis and apply these techniques on semester design project.										
CLO_8	Demonstrate the fundamentals of organizing and presenting technical work using modern engineering tools in their written and oral presentations										
CLO_9	explain planning components such as Gantt chart, deployment chart and critical path management and apply them on semester design project.										
CLO_10	Use organization techniques such as bookkeeping (Design Notebook), using checklist, etc.										
CLO_11	search and collect information and rearrange it for a given topic										
CLO_12	explain ethical issues, safety considerations, and environmental, social, and cultural impact and evaluate them on semester design project.										

Your comments are very useful to use for improving this course. Please provide them below.

………
………
………

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