Use of 'CAD tools' & 'Engineering Standards' by Under Graduate students in a 'Cornerstone Project' for 'Capstone Project' and Graduate Attributes

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Abstract: The achievement of outcome-based education (OBE) for higher education in engineering is measured by accreditation agencies and relies on the attainment of graduate attributes for the assessment of Program Outcomes, which are measured in the course of Capstone Project in the final year. Cornerstone projects are introduced in preceding years to prepare the students for the Capstone Project. A Cornerstone Project was designed and executed in the fourth semester in a design course to introduce the students to the use of modern 3D CAD tools and the use of Engineering Standards. This paper presents the intervention along with the analysis of the direct evaluation of 184 students and survey-based indirect evaluation of the project by 53% of the students. The effect of this project-based intervention on the student learning for higher order skills, experiential learning, cooperative learning, collaborative learning, and problem-based learning is discussed.

Keywords: OBE, Engineering Standards, Engineering Education, cornerstone project, capstone project, graduate attributes.

1. Introduction

The assessment of Outcome Based Education (OBE) for higher education (HE) in engineering relies on the attainment of graduate attributes which are defined by accreditation agencies like NBA, ABET as Program Outcomes (POs) (NBA, 2023). The course of UME793 Capstone Project (CP) in final year B.E. Mechanical Engineering ("BE-MEE 2020 revised v2 Scheme," 2020) is the project-based course, which is based on the knowledge and application of the Engineering Design Process (Yousef Haik et al., 2017). The students apply the knowledge of Sciences and Engineering courses studied in earlier years. The students are required to innovate and designing novel products which are based on real-life needs of real customers from society and industry. Thus, it is the preferred course for assessment of the attainment of the graduate attributes for the program.
One of the concerns of ABET accreditation in 2016 was that the students had not clearly demonstrated the use of design standards like ISO, ASTM, BIS, IEEE in their Capstone Projects. One of the student's course learning outcome (CLO) for the course of Capstone Project mentions the "*using applicable design/ industry standards*". Thus, in 2016 design standards were purchased in the Institute Library and students were shown the types of standards in printed form and available online ("Free Standards Download,") in the courses of Machine Design (MD) and Advanced Machine Design (AMD) in the fifth and seventh semesters respectively. A review of Capstone Projects in 2020-21 revealed that even though many design courses relied on the use of books and references, which are based on standards used by the Industry, the mere demonstration of their existence in the courses was found to be ineffective without application in case studies which the student can experientially learn from.
It was decided in 2021-22 by the teachers from the field of Design in Mechanical Engineering Department who teach Capstone Project, MD, AMD and UME412 Computer Aided Design and Analysis (CADA) to introduce the use of design standards in the fourth semester project-based course of CADA as a cornerstone project.
One of the challenges to this implementation was that academic teaching, research and student projects work in the laboratory environment use design tools only up to Technology Readiness Level-Four (TRL-4) as defined by NASA (Tzinis, 2015). Only TRL-5 to TRL-9 required an exposure to industrial standards based design (HQ, 2015; NASA, 2022).

Further, the availability of standards for a large cohort of students from the Institute Library was a problem, as the standards are not accessible online. For copyright security they are loaded as a single license on a standalone PC and the PDF copy of a standard has to be requested specifically. Another challenge was that the teaching was entirely in online mode when the planning was done in 2021, while the intervention was planned for the course to be conducted in Jan-June semester of 2022 which at the time was assumed would be online.

2. The intervention

To start the intervention a study of the course of UME793 Capstone Project for Mechanical Engineering ("BE-MEE 2020 revised v2 Scheme," 2020) was done. The course contents mention the scope of the project to include "*As a part of design process, the student groups should preferably exhibit the design improvements through iterations leading to an optimized design while following the relevant standards*". This fits well partially with the course of UME412 CADA ("BE-MEE 2020 revised v2 Scheme," 2020) where the project requirements mention "*The projects should be preferably based on experiential learning activities done. CAE analysis will be used to evaluate and redesign the system to optimize it for conditions of use.*" The course of CADA also has a CLO "*The student will be able to evaluate design and create an optimized solution using commercial CAD, CAE software for required analysis of mass properties, stress & deflection, temperature distribution etc. under realistic loading and constraining conditions*".

It was planned that the course of CADA would introduce the use of standards in project(s) which are open-ended, need skills of using modern technology of 3D CAD software for design and analysis, encourage peer-learning and self-learning, and address higher order Blooms Taxonomy (Benjamin S. Bloom, 1956) skills of analysis, reflection and creativity using experiential learning by the student.

The project was jointly decided by the teachers of the course of MD, AMD and CADA. The teachers of the courses of MD and AMD had experience of searching for appropriate Industrial standards so they would facilitate the teachers of the course of CADA with appropriate freely available Bureau of Indian Standards (BIS) design and testing standards, along with their online URLs to be used by the students in online mode teaching of the course, to work on the project.

3. Execution of the intervention.

The execution of the intervention required collaboration by the course teachers of four different courses of the design thread in BE Mechanical Engineering. The courses of CADA, MD, and AMD progressively teach different parts of the engineering design process (Yousef Haik et al., 2017) which is central to the implementation if the course Capstone Project.

A project was jointly planned for the students after the basics of the course in mechanical components is covered along with the basics of 3D modeling using CreoParametric CAD-CAM-CAE commercial software for design of such mechanical components and make their assemblies. The planned project was launched as one of three projects in the course of CADA, as the second project which addressed a CLO on design analysis and optimisation. Details of the launched project-2 are in Appendix. The Project presents the student with an Industrial problem as posed by a client Industry which expects the student to redesign a product as per the Bureau of Indian Standards (BIS) used in India for making the design acceptable to the BIS certification so that it can be sold in the Indian market.

The project was open-ended in that the final design specifications which the solution would converge to were obtained from a number of different dimensional and material standards as defined by two BIS standards given along with the project assignment. The student was required to study the two specifications and using the licensed CreoParametic and CreoSimulate 3D CAD-CAE software for design and analysis arrive at an optimised design conforming to the requirements of the Industrial client. An example of the expected 3D modeling and loading to be achieved by the student is shown in the Appendix in Figure 5 while Figure 6 in the Appendix shows the results of the analysis expected from the design software.

The project was launched on 17 April 2022 and the submission was in the CAD Lab of MED after 12 days in the week from 29 April to 5 May 2022 giving the students a minimum period of 12 days for doing the project. The students were free and encouraged to do self-learning, experiential learning and peer-learning. It was open-book in that they could consult any resource available to them for learning about the standards, their application and practice the design and analysis. The students could do the 3D modeling and simulation, analyse the results reflect on the changes and come up with creative solutions to optimise the design within the required constraints of the problem using their personal PCs. The software and its license was

made available to all students for work from home or at residences on campus.
The project was to be executed on Creo Parametric 3D CAD SW and the details were launched from the LMS of the course along with e-content for self-learning. The final design, analysis and optimisation of design and design report in PDF works had to be done only on the PC allocated with individual secure login in the MED CAD Laboratories. Students were not allowed to use the laboratory PCs beyond their allotted time in the time table to ensure uniformity in resource allocation. All submissions were taken on the server of the department CAD Laboratories only. No data from any personal PC was allowed to be transferred to the LAB server for submission during the designated class time. Any type of data transfer from any port of the PCs were also disabled. This ensured a plagiarism free submission made only by the individual student.

4. Evaluation and effectiveness of the intervention.

The evaluation of the intervention was done by two means direct and indirect.

4.1. Direct evaluation

A direct evaluation of the submissions by the students in the Project-2 assignment uploaded on the server of the MED CAD laboratories. The evaluation was done as per the breakup of marks in Appendix-3 by a single faculty member to ensure a uniform evaluation.
The evaluation result of 184 students was compiled and summarised in Table 1.
As seen from the Table 1 the range of marks scored in the project was skewed to the higher marks. As standard deviations are small the spread of marks is not far from the average marks. The overall average marks at 64% can be better while the average at 49% for the use of design standards and 67% for Simulation definitely need to be improved in future. As the comfort levels of the students are maximum in the well-practiced 3D modeling and with calculation and improvement of the Factor of Safety (FOS) the average marks of 99.5% and 82% are very good in these aspects.

Table 1 Summary of evaluation of the Project-2

Measure	**Total (20)**	**P2 Redesign to IS 9181-1988 (5 marks)**	**P2 Modelling (2 marks)**	**P2 Analysis (6 marks)**	**P2 Design changes for better FOS with justification (2 marks)**	**P2 Report and justification (5 marks)**
Max	18.5	4.5	2	5.5	2	5
Min	8	2	1.5	2	0	2
Av	12.80	2.45	1.99	3.33	1.64	3.39
Std Dev	1.98	0.80	0.05	0.71	0.60	0.64

These results show that there is scope for improving the student's application of design standards in the future conduct of the course. This analysis of the evaluation of the Project-2 also prompted questions in the students survey conducted as an indirect evaluation of the intervention, which is presented next.

4.2. Indirect evaluation

An indirect evaluation of the impact of the intervention was done using an online google-form survey of the students after the final result was declared and the start of the next semester. A total of 97 of the students responded to the survey see Figure 1. A few results relevant to the Project 2 intervention are shown below.

Figure 1 Response by 97 students to the feedback survey.

The online survey was done for the whole course covering three projects and continuous evaluations on laboratory work. The survey was divided into sections covering areas of the learning experience in the course as a part of the scheme of courses in the Mechanical Engineering program, shown in Figure 2, Experience of the teaching-learning and guidance, Experience of the project-based course and individual project, shown in Figure 3, Assessment, workload on the student during the course, and organisation of the course.

Figure 2 Student opinion on the Learning in the course as compared to other courses.

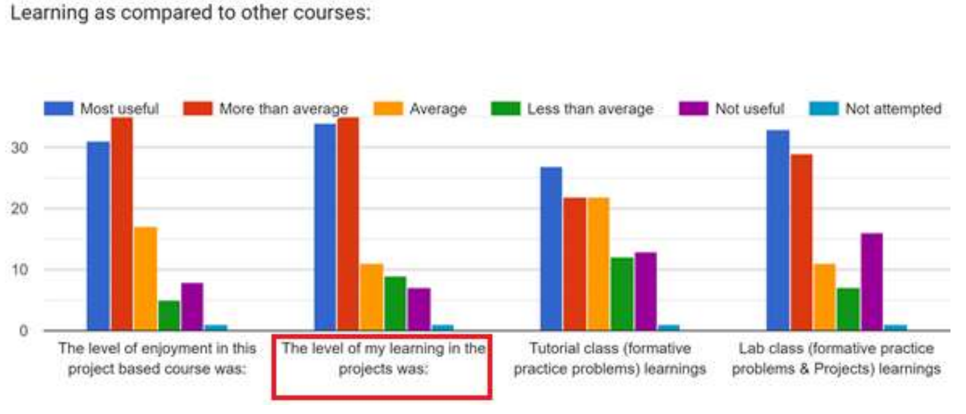
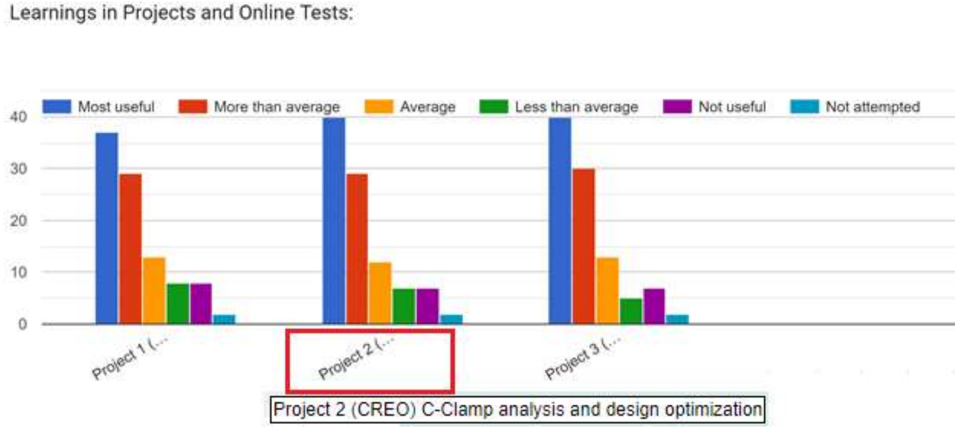
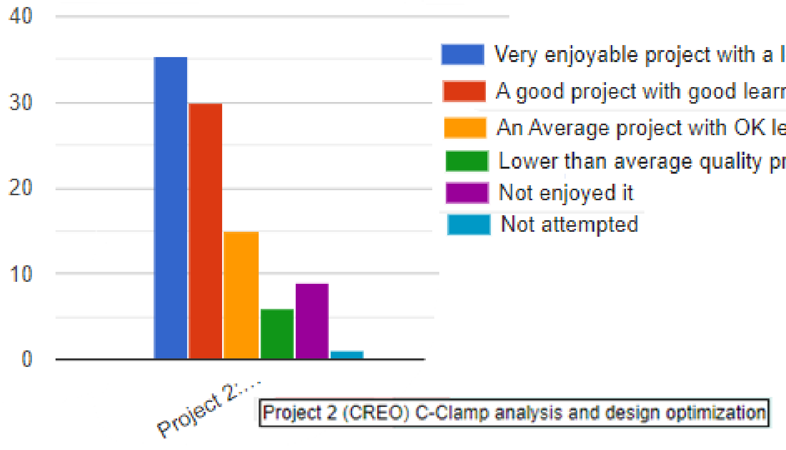


Figure 3 Student opinion on their learning in the Project-2 intervention specifically.



The survey also focused specifically on the students learning and made them reflect on their quality of learning from this Project-2 as a part of the project-based course. As seen in Figure 4 the student's learning along with a reflection on their joy in learning was assessed. This helped in the assessment of the student-centric, propensity of life-long learning, aspects of the project-2 by using a metacognitive reflection on the project being relevant to their training to be a Mechanical Engineer.

Figure 4 Student opinion on the quality of the Project-2 in a project-based course.



While the above measures using direct evaluation and online survey are sufficient to show the positive effect of the intervention. There were aspects of the conduct of the intervention in a hybrid online and offline mode which needed to be studied for the future implementations. Thus, there were questions in the survey which prompted students to give opinions and suggestions for improving the future implementations. Direct feedback in face-to-face discussions was also taken from the group of instructors and teaching assistants attached to the course. A few salient learnings from these feedbacks are given below.

1. The online start of the semester and offline from 24 Feb 2022 onwards was a switch which disrupted the learning of the students, especially when the classes were engaged only offline and many student were hesitant to attend offline classes. The online content was not sufficient to prepare them for the projects like Project-2.

2. It takes time to learn and practice the basics for building 3D models in a CAD software. Due to the higher expectations from students learning in offline mode of classes the pace of offline teaching was greater than

the online teaching which the students were accustomed to since 2020. This shift in the 'gear' of teaching and the expectations from the students many students struggled and lagged behind, some loaded the software on their personal PC only after the middle of the semester.

3. Feedback from teachers of lectures, tutorials and laboratory classes of the course also showed that the students were not prepared for such a skill intensive course so soon after studying their first three semesters only in the online mode. The low numbers attending classes from the beginning then suddenly shifted to a high demand for the limited laboratory PCs to be made available beyond working hours only to attempt (or take help in attempting) the projects unsupervised!

5. Conclusions

Active learning (Bonwell and Eison, 1991; Mello and Less, 2013) advantage is a strength of the intervention for this project-based course linked to Experiential Learning Activities (ELC) which help motivate the student to even do cooperative learning, collaborative learning, and problem-based learning in projects of the course (Holzer and Andruet, 2000; Michael Prince, 2004) which are linked to industrial requirements of designing using standards. There was a positive influence of the intervention on enhanced 'motor learning' for neural systems (Weaver, 2015), (Moore, 2005) for the students. There is still scope for adding a detailed rubrics for the evaluation of the different skills being assessed in the intervention ("Rubric Best Practices, Examples, and Templates – Teaching Resources," 2022).

This collaborative intervention of adding a project in the fourth semester course of UME412 CADA which makes students use Industrial standards will prepare the student for the similar requirement in the Capstone Project in the final year and use in courses like MD, ADM. Assessment of this impact on future courses needs to be further assessed once the students study the course.

The long term impact, learnings and future implications or improvements of this intervention are:

1. With use of design standards the students are better prepared to work in the industry during Project semester internship.
2. A positive effect on accreditation which assess the use of design standards in senior year Capstone Projects to assess the program

outcomes and for assessment of the attainment of the graduate attributes for the program.

3. The first time such a cross-courses collaboration has been attempted to better deliver a student learning outcome. This example has definitely boosted the confidence of the faculty members in doing such a collaboration and serve as a successful example in how such interventions benefit the students and the teaching-learning environment.

The results shown in **Error! Reference source not found.** are very encouraging as they show a high learning along with pleasure which would lead to long-term learning in the area. This would help in meeting the aim of introducing the Project on the use of 'CAD tools' & 'Engineering Standards' by under graduate students in a 'Cornerstone Project' for their use in 'Capstone Project' which would help in the measurement of the Graduate Attributes for accreditations.

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Appendix: Intervention Project

UME412 Computer Aided Design and Analysis (CADA)- 2022

Project 2: Design and analysis of a C-clamp

Project definition

The company you are working has received a work order from an industry which manufactures C-clamps. One of the models of a heavy duty C-clamp the industry wants to launch in the Indian market is not designed to BIS specifications. You have been assigned the task to analyse the existing design of the C-clamp, redesign it to conform to BIS specifications of design, testing and material. The part drawings of the existing C-clamp design is supplied and given to you by your Industry supervisor as shown in Fig. 18.48. Ref (K. L. Narayana et al., 2006)

Your job is to find if the existing design conforms to Indian Standard IS 9181-1988 (Bureau of Indian Standards, 1988), and modify it if it does not. Your work specifically is to find the max. load carrying capacity of the C-clamp frame given in the drawing. Use FEA based simulation on Creo Simulation (ProMechanica). Suggest a design changes to improve the FOS. The material used for the parts is given in the BOM,. you have to select the standard material using IS : A570 (Part 2)-1979 'Schedules for wrought steels: Part 2 Carbon steels (unalloyed steels)' (Bureau of Indian Standards, 1979) keeping a suitable FOS. Optimise the design for minimum weight.

Marks distribution:

1. Redesign to IS 9181-1988 (5 marks)
2. Modelling & Analysis (8 marks)
3. Design changes for better FOS with justification (2 marks)
4. Report and justification (5 marks)

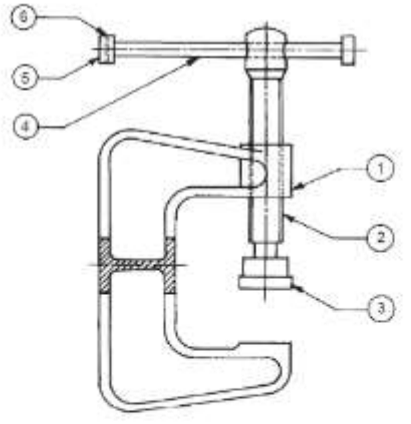
The submission is to be in soft-copy form in one PDF file titled **"Rollnumber_Project2"**. The pdf should be briefing the above so that at a quick glance the reader is aided by pics/images and their descriptions to arrive at a understanding of the project. Report should be made as if submitted to the industry you work for and should be brief and to the point while not missing any detail.

C-clamp

A C-clamp is used to hold a component for further work, such as inspection or working on it. It consists of a frame 1 into which the screw 2 is inserted. The pad 3 is attached to the screw 2 by means of a cheese head cap screw 7. The screw 2 is operated by a tommy bar 4 inserted in the corresponding hole in it. The collar 5 is fitted at the end of the tommy bar, by using the pin 6. The work is clamped between ... pad mounted on the screw.

Parts list

Sl. No.	Name	Matl.	Qty.
1	Frame	CI	1
2	Screw	MS	1
3	Pad	MS	1
4	Tommy bar	MS	1
5	Collar	MS	1
6	Pin	MS	1
7	Cap screw	MS	1



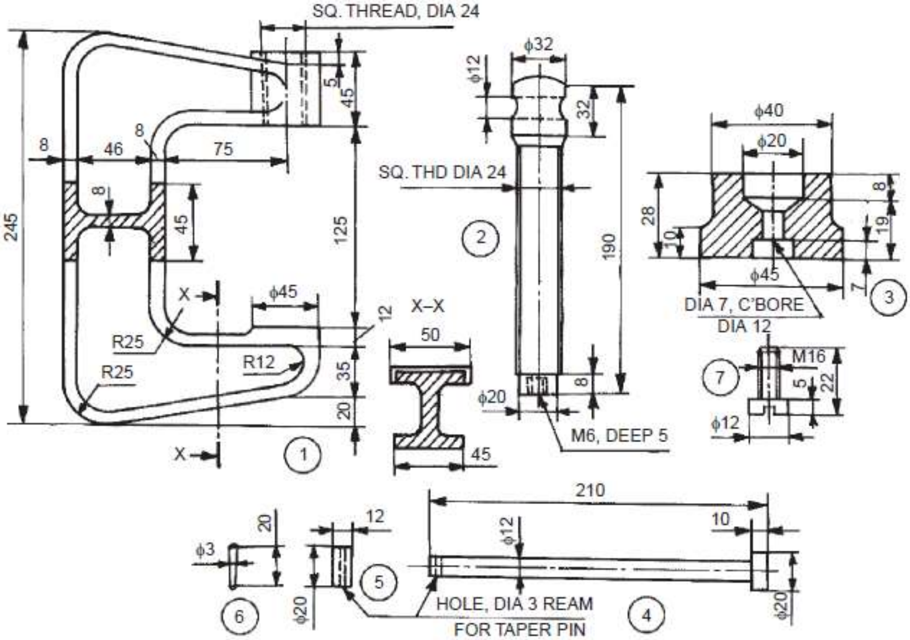


Figure 5 A 3D model expected output of the project with load simulation.

Figure 6 Expected results of CAE analysis