Full Paper

Abstract:

The need exists for a new approach of engineering training which incorporates the development and the assessment of work-based skills that cannot be imparted and examined via traditional instructional delivery and written examinations respectively. To address this need, this study explores a twenty-week case study to teach employable skills and concept of failure analysis to final year mechanical engineering students in a Nigerian University. The case study worked upon by each group had a plurality of solutions with a view to helping students develop a range of professional, transferable, and team working skills under the guidance of the first two authors. We carried out continuous assessment of the competences gained by our students via fortnightly review meetings, oral presentation, working models, written project reports, and interviews. Students' conceptual understanding was enhanced while they also developed skills in independent critical thinking, formulation, analysis, optimisation and evaluation of the performance of their designs and communication of their ideas effectively. Finally, this study highlights our rationale for adopting the case study and the good practice we have identified, and also discusses our experiences of the adoption and implementation of this type of learning activity.

Keywords: The case study; Nigerian University System (NUS); Materials design and selection; Employable skills.

Introduction

There is a need to ensure that engineering students develop skills that cannot be assessed in traditional written examinations yet are essential for work as engineers; and at the same time bring realism into the study of engineering by integrating previous experience of theory and practice. This necessitates that a new approach of training should be incorporated into the traditional lecture-based engineering curriculum (Heywood, 2005; Stojcevski, and Fitrio, 2008; Holgado-Vicente, Gandia-Aguera, Barcala-Montejano, and Rodríguez-Sevillano, 2012). Such a training programme should equip engineering graduates with excellent planning, communication skills, team working ability and sound analytical and evaluation skills in line with employers' expectations (Stojcevski and Fitrio, 2008; Anderson, Torrens, Lay, and Duke, 2007, Razali and Zainal, 2013). The case study, an innovative educational teaching and learning methodology grounded in social cognitive theory (Bandura, 1997; Mayer, 2007), inspires in students a higher degree of involvement in learning activity (Gibson, 2005; Holgado-Vicente, Gandia-Aguera, Barcala-Montejano, and Rodríguez-Sevillano, 2012, Rodrı´guez, Lavero´n-Simavilla, del Cura, Ezquerro, Lapuerta and Cordero-Gracia, 2015). In social cognitive theory, students are expected to engage in socially mediated group problem-solving processes. The case study is implemented with students learning through engagement with engineering projects similar to that which will be encountered in professional practice (Fernandez-Samaca, and Ramírez, 2010; Holgado-Vicente, Gandia-Aguera, Barcala-Montejano, and Rodríguez-Sevillano, 2012; Wongpreedee, Kiratisin and Virutamasen, 2015). The incorporation of case study learning approach into materials selection and design curriculum is aimed at meeting the need for a new method of engineering training which ensures the development and assessment of work-based skills that cannot be imparted and examined via traditional instructional delivery and written examinations respectively.

Despite the popularity of the case study approach within engineering, its use in the Nigerian materials design and selection curriculum has not become widespread as most educators have limited knowledge of how to incorporate it into their classrooms. In addition, empirical studies on the effectiveness of the case study are limited and the research that does exist had primarily focused on students' perceptions of their learning rather than how it imparts conceptual understanding and employable skills. In this preliminary study, we investigated how the incorporation of the case study alongside the traditional teaching method could impart employable skills and conceptual understanding into students offering materials selection and design curriculum. To achieve this aim, we carried out continuous assessment of the competences gained by our students via students' involvement in weekly review meetings, oral presentation, working models, written project reports, and interviews while they explored solutions utilising various engineering concepts that would be used by an engineer while relating them to documented theory. This research answers the following research questions:

- What employable skills and conceptual understanding are imparted to students offering materials selection and design curriculum when case study is adopted to teach failure analysis?
- What are students' perceptions on the adoption of the case study teaching instruction in materials design and selection curriculum?
- How the case study does impart employable skills and conceptual understanding to students offering materials selection and design curriculum?

Methodology

2.1 Implementation of the case study

The case study took place over 20-week with students spending a period of 5 to 7 hours per week including 3 hours of lecture and 2 to 4 hours of group meeting. During the first lecture, the first two authors presented the course outline and outcomes to final year mechanical engineering class comprising of 80 students in 2009/2010 academic session. Students were informed that the curriculum would have a case study component in addition to the traditional lecture method. Students were distributed into groups comprising of eight members. Each group was asked to look for a failed engineering component. Then, each group was instructed to investigate what caused the failure of the component, develop possible re-design solutions to prevent untimely failure of the components, and thereafter implement the most technologically feasible solution in regards to re-manufacturing.

Typical damaged engineering components investigated by the groups included pruning shears, sign boards, door keys, car door handle e.t.c. The choice of these components was premised on the need to organise the case study around course contents and available facilities. Moreover, students were encouraged to take responsibility for defining their learning experience and planning project activities and collaborate via learning teams. Prior to implementing the case study, each group was requested to prepare planning schedule.

The first two authors assessed the planning schedules and offered suggestions on how planning schedules could be improved upon.

Table 1: Oral presentation assessment scheme used in this study

	Poor	Fair	Good	Very Good	Excellent
Presentation skills					
Introduction	0.5	1	1.5	2	2.5
Structure	0.5	1	1.5	2	2.5
Content					
Relevance of material	1	2	3	4	5
Depth of research	1	2	3	4	5
Comprehension					
Grasp of content	2	4	6	8	10
Response to questions	2	4	6	8	10
Working model	1	2	3	4	5

Students were informed that it is required that they demonstrate the results of their learning through a product at the time of presentation and submission of written report twelve weeks after the first lecture. They were also informed that the assessment criteria would comprise of oral presentation/working model (Table 1) and group written reports (Table 2) developed in accordance with Gibson (2005). For oral presentation/working model assessment scheme, the main emphasis was on comprehension of the researched material (Table 1) while the written report (Table 2) emphasised on methodology, understanding and content of the case study. We concur with Gibson (2005) that our students should be rewarded for taking on and completing technically difficult projects, hence, these assessment criteria were adopted for examining all the prime learning targets which students were expected to have met upon their exposure to the case study.

Table 2: Written report assessment scheme used in this study

	Poor	Fair	Good	Very Good	Excellent
Presentation skills					
Layout, references, language e.t.c.	1	2	3	4	5
Methodology and Understanding					
Comprehension, analysis	2	4	6	8	10
Synthesis, organisation of ideas	2	4	6	8	10
Evaluation, objectivity	2	4	6	8	10
Content					
Information evaluation, fieldwork	1	2	3	4	5
Laboratory/manufacturing work, modeling, creativity	1	2	3	4	5
Mathematical skills and software design	1	2	3	4	5

Meanwhile, each team appointed one leader and met weekly to specify various time-lines and discuss approaches of implementing their case study with the leader allocating different tasks to each team member. With the support of the first two authors, the team leaders ensured team interactions and unhindered communications with a view to achieving timely and successful implementation of the case study. Each team also met the first two authors fortnightly for briefing on the progress attained and the challenges being encountered. During the briefings, we recorded in a notebook our observations of the nature of involvement of the team members for analysis. Each group was commended by the authors when significant progress was made while suggestions were offered to the groups in overcoming their challenges.

Two weeks after the submission of the written reports, oral presentation took place during which members presented their case study and clarified their involvement, conceptual understanding and employable skills acquired. Typical clarifying questions asked included the following:

- Why is failure analysis important to your training as an engineer? (Conceptual understanding, formulation)
- How would you describe failure analysis?
- How did you carry out failure analysis? (Analysis)
- On the basis of your experience from the case study, identify the factors responsible for the occurrence of component failure. Clarify how these factors influence component failure? (Conceptual understanding, analysis, evaluation)
- What suggestions did your group propose in preventing untimely failure of components? Which of the suggestion(s) did your group implement and why? (Conceptual understanding, analysis, evaluation, optimisation)
- Using your experience from the case study, how did you incorporate re-design into manufacturing? (Conceptual understanding, formulation)
- Describe how your group re-manufactured the working model? (Conceptual understanding, formulation)

These questions were validated by a senior Professor of materials science and engineering whose comments were used to alter and improve the questions before they were administered to students. Five students from each group were also interviewed with a view to gaining insight into students' perception of the incorporation of the case study into materials selection and design curriculum. Typical questions asked were as follows:

- What do you like about case study on failure analysis of engineering components?
- How do you plan to use what you have learnt during case study in professional practice?
- What do you perceive to be the role of the tutors in the case study?
- Which of case study or traditional lecture method do you prefer? Give reasons.
- What do you dislike about case study?
- How do you think your experience of case study could be improved upon?

Data Analysis

This study employed qualitative analysis of data mainly from oral presentation, interviews and observation notes. Students' responses and group's written reports were assessed based on the assessment criteria employed by Gibson (2005) (Tables 1 and 2). For instance, a score of 2 was awarded if the student was unable to demonstrate a grasp of content of the failure analysis of a component; 4 was assigned if the student showed some grasp of failure analysis, but was unable to apply the concept of failure analysis to a given real life problem (i.e., fair understanding); 6 was assigned if the student exhibited good grasp of failure analysis, but was unable to apply the concept of failure analysis to a given real life problem in a clear and succinct manner (i.e., good understanding); and a score of 8 – 10 was assigned if the student accurately applied the concept of failure analysis to a given real life problem in a clear and succinct manner with no false starts (i.e., very good/excellent understanding) (Table 1).

Table 3: Coding scheme adapted from Gibson (2005) for this study

Evaluation	Ability to make a judgement of the worth of something
Analysis	Ability to break a problem into its constituent parts and establish a relationship between each one
	Apply an understanding of the importance of human and environmental factors in design and manufacturing
Formulation	Ability to apply rephrased knowledge to novel situations Ability to define problems and develop design specifications
Conceptual understanding	Ability to recall and rephrase knowledge Ability to apply the fundamentals of engineering science and mathematics to real life engineering problem
Optimisation	Have the ability to generate and develop alternative solutions to design problems and then make informed and/or most desirable choices as to the preferred solution Ability to combine separate elements into a whole
Communication	Ability to employ transferable skills such as oral and visual skills, team working, the ability to "learn how to learn", and the ability to synthesise and apply acquired knowledge to the solution of problems A good understanding of, and familiarity with, modern Information and Communication Technologies (ICT) to express ideas
Critical thinking	Ability to generate and develop alternative solutions to design problems and then make informed and/or most desirable choices as to the preferred solution
Time management	Ability to complete a given assignment according to schedules
Conflict management	Ability to mediate and bring cohesive relationship.

Students' responses were divided into categories of conceptual understanding and employable skills (e.g. conceptual understanding, formulation, analysis, evaluation, and optimisation e.t.c.) for analysis (see Table 3 adapted from Gibson (2005)). Furthermore, observation notes were analysed by describing students' interactions during oral presentation and interview, details of participants, and the events witnessed. This assisted in identifying the relevant emerging themes. Meanwhile, analysis of observation notes included our reflections on the relationships formed between the participants in the same group, thoughts on what the participants said and how it was said, and reactions. Therefore, the existence, meanings and relationships of words that related to the development of conceptual understanding and employable skills were explored and noted during the process of analysis. The interview data were also analysed by categorisation. To ensure objectivity in the coding process, validity and reliability aspects were also considered. Two coders (the third author and another expert in education research methods) participated in the categorisation process. The coders separately searched for items in various data which demonstrated each item of the coding scheme in Table 3 and then compared and discussed their selections. After coding, the inter-rater reliability was calculated (Holisti's coefficient) for both coders. After the computation of the inter-rater reliability, the coders discussed any controversial cases until they reached 100% agreement.

Results

3.1 Nature of imparted employable skills and conceptual understanding

The use of the case study enabled students to develop hands-on-skills and transform from "passive learners" to "team members who engage in active learning". For instance, student P's response (group VIII) "*I like the case study of failure analysis ----- because I was actively* *involved in the planning and analysis of the failure of the damaged cutlass, its re-designing and re-fabrication. ------- Better than lecture method in which lecturers just talk all through -----.* Ummm! ------- I could think through and understand failure analysis better than using lecture notes alone -------" to the question "which of case study or traditional lecture method do you prefer?" also supported this claim that students transformed from "passive learners" to "team members who engage in active learning".

The development of hands-on- skills is evident in the re-manufacturing of pruning shear with heavy metal handle by group I. According to student A (group I), pruning shear was re-manufactured by using the following procedure:

- Heavy metal handles were cut off from the pruning shear by using hack-saw
- Wooden handles from another damaged pruning shear were carefully removed using hand tools (Figure 1)
- The pruning shear blades were then sharpened using grinding machines
- The pruning shear blades were fastened to the wooden handles using a thin metal sheet in order to reduce weight of the pruning shear for effective cutting operation.

Figure 1: The pruning shear manufactured group I after testing.

Students' response to the clarifying question "why is failure analysis important to your training as an engineer?" established that they developed employable skills in formulating engineering problem. Student G's response (group IV) that "investigating component failure is important because experience need to be gained from studying which factors (either wrong material selection, poor design criteria, or poor manufacturing practice) resulted in a failed part so that re-occurrence could be avoided in future. This is helpful in saving financial resources that would be used for re-manufacturing" affirmed this assertion. Another student H from the same group mentioned of "the need to save lives as inappropriate design and poor material selection could cause destruction of lives and properties as evident through the recurring incident of collapsed buildings in various parts of Nigeria as at 2010."

Moreover, each group developed scheduled plan of activities detailing how they would progress with various activities assigned to each member within a specific period of time. Table 4 shows the scheduled plan of activities developed by group I detailing how they would progress with the case study on the failure analysis of a pruning shear. Hence, students learnt the art of effective time management as we noted that each group worked within the planned schedule.

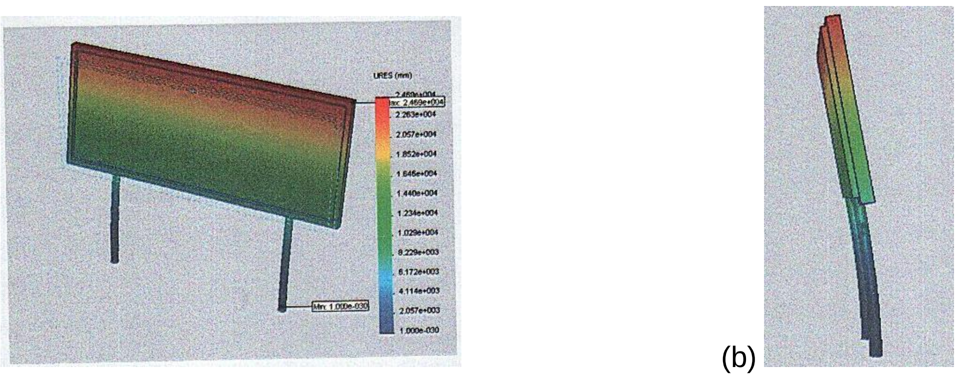
Table 4: Schedule of Activities for Group I on the case study for Failure Analysis of Pruning Shear.

	Week 1-2	Week 3-6	Week 7-10	Week 11-14	Week 15-18	Week 19-20
Activity	Visitation to the accident site for to gather pre-liminary data on failed pruning shear	Analysing pre-liminary data to find out causes of failure of pruning shear	Re-designing of failed part. Planning for re-manufacturing of pruning shear	Re-manufacturing of failed pruning shear and testing.	Writing of reports; Submission of written reports and working models of pruning shear	Oral presentation

The development of conceptual understanding, independent critical thinking and optimisation skills by the participants were quite evident in responses of student M from group VII who re-designed a wind damaged signboard to the following questions during the oral presentation:

- What suggestions did your group consider in re-designing the damaged signboard
- Describe the suggestion(s) your group implemented
- Explain why you have implemented your chosen suggestion?

In proposing solution options to re-design the damaged signboard, student M claimed that his group members employed mathematical/analytical techniques in re-designing the signboard. According to student M, "*we reasoned that if the previous manufacturers had determined the environmental wind resistance in Minna, as well as the appropriate geometrical and material parameters to withstand the wind resistance and the atmospheric corrosion, incessant damage of the signboards wouldn't have been occurring in the University. Therefore, we thought it wise to use modeling techniques (Figure 2) to determine geometrical and materials parameters to withstand the wind resistance in Minna environment*."



(a) (b)

Figure 2: Displacement diagram of the billboard when wind stress was applied (a) front view
(b) side view

He also pointed out that mathematical equations were used to estimate the wind resistance exerted on erected structures by using wind parameters associated with Minna town. The group also considered what effect the wind resistance may have on various geometries of the signboard. Some of the geometries considered included rectangles of various dimensions (thicknesses, length, breadth) and triangular shapes. Geometrical parameters were inserted into equations for the optimisation of the wind resistance of the signboard. Thereafter, a rectangular signboard with optimised dimensions was chosen as the appropriate one to withstand the wind resistance in Minna town.

Student M also explained that tables of comparative analysis of various materials were drawn up on the basis of mechanical properties, cost, availability, and atmospheric corrosion resistance with a view to making an appropriate choice of material to produce the signboard. Students' realisation that previous manufacturers did not consider appropriate material and geometric constraints for signboards to withstand wind resistance in Minna illustrate the development of conceptual understanding as well as independent critical ability. Moreover the use of comparison tables depicting various factors affecting the durability of the signboard shows that students are able to carry out evaluation in order to optimise the functionality of the signboard.

Analysis of students' description of concepts such as failure analysis, re-design of engineering components, mechanical properties, and corrosion, during the oral presentation revealed that they had correct understanding both at individual and group levels. Since the aim of engaging students in the case study is to help them improve conceptual understanding at individual level, it is evident that participation by student F (a member of group III) helped him to describe failure analysis as "*the collection of data to determine the cause of failure of an engineering part. It is useful in developing new products and to improve the functionality of manufactured parts.*" The student attributed his ability to define this concept correctly to obtaining the right answer when he asked *what happened prior to, during, and after the occurrence of failure* during site visit. Moreover, he claimed that the brainstorming sessions he had with his colleagues to (i) ascertain the factors responsible for failure and (ii) proffer and implement appropriate solutions for re-designing and re-manufacturing of the failed component were also helpful in understanding the concept of failure analysis. Finally, examination of the groups' written reports revealed that relevant concepts were correctly defined, while the layout, comprehension, analysis, evaluation, and mathematical techniques presented in each of the reports were adjudged to be very good. Table 5 shows that students' academic performance was better during 2009/2010 academic session when both the case study and traditional lecture method were used as instructional delivery technique in comparison to 2008/2009 session when only traditional lecture method was used to deliver materials design and selection curriculum.

Table 5: Students' performance in materials design and selection curriculum over two sessions.

Grades	Excellent	Very good	Good	Fair	Poor
2009/2010	2%	17%	32%	34%	15%
2008/2009	-	10%	25%	32%	33%

Students' perception of the adoption of case study

Table 6 obtained via students' interview reveals that students held positive perceptions about the adoption of the case study for teaching failure analysis as they claimed that it enabled them to think critically about failure analysis of engineering components and relate the lecture notes to the reality. A student was also of the view that the public speaking skills acquired from her participation in the case study will help her to function well in a sales environment while another student was of the opinion that his working in a team with members of diverse interests and abilities will help him to function well in a multi-cultural working environment in the future. Students believed that the use of the case study in teaching failure analysis helped them to take control of the learning process while the tutors only facilitated the learning process. Students expressed preference for the case study over the traditional lecture delivery method because it helped them to think through and understand failure analysis much better than they would have done with the use of traditional lecture method alone. Nevertheless, some students complained about the rigorous nature of undertaking case study, longer hours of group meetings as well as group members who were not committed to the group goal.

Table 6: Students' perception of the adoption of the case study for teaching failure analysis

Likeness about the case study accident	"I liked the fact that we visited the sites in my group, -----, to gather data for failure analysis. This was quite helpful in

	aiding one to think through the right questions to ask to determine the cause of failure and proffer solution for re-designing and re-manufacturing. All these activities helped me to relate information from lectures and text books to the reality."
Professional practice	"---- my involvement as a group leader as well as the presentation aspect of the case study assisted to develop confidence in my ability to lead and to talk with others. Realising as a leader that I need to defend my contribution to the group work helped me to summon courage to talk publicly. I hope to use these skills in marketing for a manufacturing company." "Working in my group also helped me to become familiar with other members of my class I had not talked to in the past. I got to know more about them, especially, their strengths as individuals. I'm happy that this experience had prepared me to work in a multi-cultural working environment in future."
Role of tutors	This case study is quite different from the lecture method because it provided opportunity for students to explore failure analysis through practical experience instead of have having a lecturer teaching something that would have been difficult to understand. The group meetings promoted frank discussion about failure analysis. I think students were able to master the learning process through the case study of failure analysis while the lecturers facilitate the learning process."
Preference for the case study or traditional lecture method	"I like this case study more than lecture method because it helped to appreciate the reality of failure analysis of engineering components and learn from other members of my group." "I like this case study of failure analysis because I was actively involved in all the activities such as planning, analysing, re-designing, and fabricating our damaged cutlass. It is actually better than the lecture methods where the lecturers just talk all through while we (students) only listen and talk less. Ummm, I'm happy with the case study; I could think through and understand failure analysis better than I would have done if only lecture notes were just dumped on me. Yeah! Doing stuff like this is good."
Dislike and suggestion for improvement	"This case study is too rigorous for me. It did

	not allow me to have time to study other subjects adequately. Should this case study be brought into other courses, it will create serious problems for students. The numbers of students in my group are too much as some were not just committed to the group goal with only half of the group working on the case study."

Discussion of Results

In agreement with Gijselaers, (1996); Graaff and Kolmos, (2003); and Majeed (2014), learning about the concepts of failure of engineering components entails rigorous analysis through case study because it takes a lot of time to master the learning process (Table 6); coupled with its inter-disciplinary nature which demands that students employ prior knowledge gained across the subjects of manufacturing/production, material selection, design, corrosion, applied mathematics, modelling/simulation, and mechanical testing to carry out the given tasks successfully. The application of the inter-disciplinary knowledge is seen in the solution options proposed by student M from group VII to re-design the wind damaged signboard (Figure 2).

Hence, the rigorous and inter-disciplinary nature of the case study is able to facilitate the development of conceptual understanding, analytical thinking, evaluation, optimisation, and problem formulation skills in the participants (Heron, 2000; Banks, 2004; Gibson, 2005). This finding could be attributed to the fact that (i) emphasis on syllabus was replaced with establishment of learning outcomes; (ii) meetings, seminars, and presentations complemented formal lectures; and (iii) assessment was undertaken through a variety of complementary methods (Stojcevski and Fitrio, 2008; Majeed 2014). Table 6 shows that case study provided group members with similar goals with opportunity to direct their own learning process, develop leadership skills, and learn from one another within a team. Therefore, outcomes from this study have further confirmed that learning principles such as problem based learning, student directed learning, activity-based learning, and inter-disciplinary learning which are embedded in the case study facilitate the development of conceptual understanding, analytical thinking, and team working skills in students (Rodrı´guez, Lavero´n-Simavilla, del Cura, Ezquerro, Lapuerta and Cordero-Gracia, 2015; Loyens, Jones, Mikkers and van Gog, 2015). The use of assessment methodology which requires that students meet (i) regularly as a group to brainstorm; (ii) with their tutors to present their contribution to the group projects as well as demonstration of re-designed and re-manufactured components is seen to have promoted awareness and development of hands-on-skills (Figure 1), time management and planning skills (Table 4), communication skills, and ability to work in a multi-cultural working environment among students (Table 6). Finally, these outcomes confirm that the case study make learning more interesting and motivating for students while allowing them to relate to real world situations. This is similar to findings from Raju and Sankar (1999); Garg and Varma, (2007); Razali and Zainal, (2013); Majeed (2014); and Wongpreedee, Kiratisin and Virutamasen, (2015) who reported that the rigorous nature of the case study brought real world problems to the classroom while it also helped students to improve on their communication skills, ability to think critically, and apply the concepts and skills learned in the course in comparison to traditional lecture approach.

Conclusions and Recommendation for future work

This study employed the case study to impart employable skills and conceptual understanding of failure analysis of engineering components into final year mechanical engineering students in a Nigerian University. The case-based approach developed took into account problem formulation, team working and communication skills, oral presentation, and the use of hands-on activities to manufacture working models. These aspects are integrally related to give the student a suitable learning environment for knowledge acquisition, and employable skills development. Case study facilitates the use of facilities already available in the University without requiring specialised ones. Consequent upon the implementation of the case study, students' conceptual understanding of failure analysis was enhanced while they also developed skills in independent critical thinking, formulation, analysis, optimisation and evaluation of the performance of their designs and communication of their ideas effectively. Students are more self-dependent and organised as they were able to schedule meetings and activities by themselves, and consult their tutors, through their own initiative. The use of hands-on activities enabled students to understand the subject in a different way from the traditional lecture because they believe these activities are suitable to motivate learning. In the future, we aim to investigate the effects of adopting the case study over-time on students' employable skills and conceptual understanding, the various roles of tutors in facilitating greater student retention using the case study, the role of learning environments and resources in implementing the case study in mechanical engineering curriculums as well as comparison among the case study approaches for mechanical engineering and the case study approaches that integrate several engineering courses.

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