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The Impact of Implementation and Evaluation of Engineering Exploration Activities in a First-Year Engineering Course

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Abstract: The engineering exploration (EE) plays a vital role in technical education as engineers are envisioned for solving real time societal problems. This paper explores the outcome of introducing a course on EE for the students of first year engineering of KLE Dr. M.S.S.C.E.T., Belagavi campus under KLE Technological University, Hubballi, Karnataka, India. An impact analysis of offering the course to the students of multidisciplinary branches of engineering has been carried out based on student performance data. The course offers the hands-on training in various modules such as, Project Management (PM), Engineering Design (ED), Platform Based Development (PBD), Motor Sizing and Battery Sizing (MSBS), team building, sustainability, and ethics. The significance of activity-based learning is emphasized for understanding and applying decision making process to arrive at multiple solutions for a given technical problem. The data from participation and performance of students in activities of each module is analyzed to assess the idea for including this course in the curriculum. On comparison to the in-class training the team and individual activity-based approach in the course enhances the participation of the students in the learning and exploring the multidisciplinary skills of engineering.

Keywords : Decision Making; Engineering Design, Engineering Exploration, Platform Based Development; Project Management. learning.

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1. Introduction

EMBEDDED in every engineering discipline and at the core of engineering practice, design is synonymous with engineering and is at the heart of the engineering process (Mourtos NJ et al., 2012). Activity-based teaching-learning describes the range of pedagogical approaches that involve learning by doing hands-on experiments or activities encourages students not only to actively participate in the teaching-learning process but also helps in developing soft skills (Rajendra et al., 2019).

The ED process is mainly comprised of five principles: 1) Specification: From the need statement given by a customer, a full and detailed specification of the problem is carried out to define a problem statement. Based on the objectives, functions, and constraints the problem statement is elaborated to generate multiple product designs, 2) Concept generation: By considering all the necessary specifications, multiple alternative concepts are figured out for a problem statement. 3) Concept selection: The concept which has highest potential to become a product is selected using a standard concept selection procedure using Pugh chart, 4) Detail design: In this step, the virtual design in the form of 3-D modelling is generated for the selected model and a detailed study of the model with engineering design specifications and knowledge of materials to confirm implementation feasibility. 5) Manufacture: Once this detail design stage had been completed the construction phase could begin. This phase can be likened to prototype manufacture prior to mass production of products.

The process of the engineering design varies from one model to another or an institution to the other. A five-step ED process, as depicted in Fig. 1a, is adopted in the execution of identified real-world problems which eased students' learning ability and skill development.

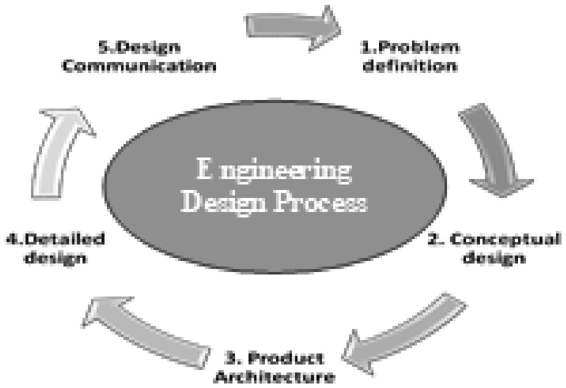


Fig 1a: The detailed ED Process in EE course

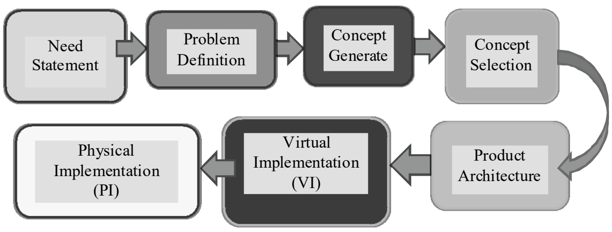


Fig.1b: Block diagram of the project management process

The necessity to introduce EE course to the first-year curriculum was to transfer the students' innovative ideas into real-time products. A detailed block diagram of PM process of the course is depicted in Fig. 1b., More explicitly, the goals of the course activities are to assist learners:

1) Establish role of an engineer as a problem solver in the intended discipline,

2) Apply multi-disciplinary knowledge and skills for future career path,

3) Learn to build engineering systems using design process,

4) Explore project management to analyze engineering solutions from ethical perspectives,

5) Connect with students, faculty, and mentors within engineering.

All the sessions of the course delivery were well planned by considering the need statements of each project group so that students can acquire the necessary skills during activity sessions and apply those during product development stages. The balanced student groups (by gender and discipline) are formed heterogeneously with a maximum of four students in each group. The activity kit was designed for each session by considering team size which ensured active participation of every individual of the team.

The remaining paper content is organized as follows: part 2 of the paper explains the literature review. Next, in part 3, we explain the methodology of the course. Section 4 explains the results and discussion. The last section concludes the work.

2. Literature Review

The review of engineering education in EE using various state of art pedagogies in the context of Indian and foreign universities are briefed in this section.

Magna and Jong (2018) published a thorough study that examined the incorporation of modelling and simulation practices in engineering education. Several themes are addressed in this project, including i) approach towards course design, ii) pedagogy and practices of implementing modelling and simulation, and iii) evidence of learning. Among the outcomes of modelling and simulation experiences are: enhanced students' abilities to understand fundamental concepts, demonstration of the acquired knowledge, visualization of complex concepts and application of skills, and encouraged creativity among students. The study was concluded by the author pointing out that modelling and simulation have not been measured rigorously enough to understand their impact.

Magna et al (2011), the study investigated how the computational tool literacy and the problem-solving process relate. As a result of the students' projects and challenges, scaffolding for both student learning and computer literacy was found in how the projects followed problem-solving phases. Moreover, different approaches are needed to solve the varying challenges associated with computation was suggested.

As reported in the study, participation in both traditional lectures and laboratories enhanced participants' ability to recall facts and behaviors of the model and to apply those facts and behaviors.

Magna et al (2017) present a study on the achievement of disciplinary knowledge when engaged in modelling and simulation; the results find that students learnt from running the simulation multiple times to test their ideas.

Shik et al. (2015) discussed how modelling and simulation contribute to the problem-solving abilities of students. In the study, the IPS framework and modelling and simulation are used for problem solving. Based on the findings of this study, the author opines that modelling and simulation can be highly helpful in solving issues that arise in real-world situations and can be used to help teach and validate concepts.

Using the adaptive expertise framework for problem-solving, Lyon et al. (2019) analyzed the cognitive and metacognitive knowledge of students involved in the integration of simulation and modelling. Students in intermediate categories presented less conclusive results, as the results indicated the action and implementation-oriented category represented the abilities of novices, whereas the other category represented the abilities of experts. According to the author, despite the various workflows, most students were able to develop working code.

An ABET-accredited survey of engineering schools and universities across the United States concluded that Julie D. Burton and Daniel M. White (1999) found eight methods for teaching design to freshman engineering students. In addition, Reverse Engineering, Creating Something Useful, Large- and Small-Scale Projects, Case Studies, Competitions, Non-Profit Projects, and Re-Designs of Local Projects are used as methodologies.

Kinda Khalaf et al., 2013 describe a course to introduce students to early ED education through a design-and-build approach. The course adopts project-based learning (PBL) pedagogy and prescriptive design cycle as a mode of design teaching.

A course for undergraduates in electric sciences has been designed and delivered according to Sanjay E. et al., 2015. As pedagogical methods for teaching, they used domain-specific case studies, laboratory activities and activities-based learning.

They present their approach to integrating product design (IPD) into teaching for postgraduate students in Y Patil et al., 2016. Lab sessions were used to introduce design tools, such as the Industrial Design Sketching and the Six Sigma techniques, with MINITAB software; and course projects were the result.

3. Methodology

An introductory EE course will be taught to 600+ first year students at the Institute. The odd semester of academic year 2021-22 has reported an overall strength of 102 students from mechanical science stream. The initial sessions of the course were focused on discussion on various engineering disciplines and their roles in solving societal problems. However, through a series of insightful activities and assignments, students are groomed with mindset to consider a solution for problem using different branches of engineering. The branch chosen by a student and its alignment with other branches is the primary goal of these activities. This ensures a link between student's choice of discipline and career interest.

In the following section, a typical EE course activity is highlighted, and its impact analysis is presented to understand the effectiveness. Student teams are allotted a pre-approved list of projects need statement, and an appropriate activity for each module of the course. Since these activities typically include normal classroom training, a three-hour session is divided into two parts so that students get sufficient time to perform the activities. Student groups and faculty from multidiscipline were encouraged to provide this content.

A student group maintains a GitHub documents after involvement in an activity. A team-based and individual GitHub profile enables every student to effectively use the tool by writing a short (~250 words) description. The repository content mandatorily needs introduction of the team members, description of the activity and its solution with necessary sketches, graphs, and tables. The faculty evaluate these electronic portfolios and periodically grade the students. The combined assessment approach provides an affluence of quantitative and qualitative data about student experiences. All course data were collected throughout the academic semester through assignments in electronic portfolios. After the completion, subsequent activities were grouped based on the following three criteria:

1) A team based or individual activity,

2) Activity based on selected engineering discipline's role in the course project.

3) Link between in-class training and hands-on laboratory session.

A. Course Design

As mentioned earlier, participants from various engineering disciplines were merged while designing the course to ensure equal involvement of every stream. Table I reports the number of students and team size in the EE course activity. The course design is based on project based experiential learning of every module with hands-on approach. Hence, the team size was restricted to cater to the needs of course design such as involvement in activities and task completion duration. The course design considers the number of participants in each group.

Table 1 : Streamwise Study Participants For Odd Semester 2021-22

Discipline	No. of Participant	Team size
Mechanical Engineering	20	5
Civil Engineering	60	7
Chemical Engineering	40	7

As shown, data for all the first semester disciplines were collected and they represent a relatively small percentage of the overall intake of first year. Hence, only a randomly selected subset of the teams was considered for the analysis of impact of the course. At this time, few repositories were not considered as they were reported incomplete or with errors. The course activities were first divided depending on the suitability for students to perform as shown in Table II. For illustration, we consider an activity of a survey of local societal issue which needed to be addressed using multidisciplinary engineering approach. This was an individual activity categorized as "medium" level with a certain schedule mentioned to perform. The activity index in such case was 38.09%, highest as shown in the table. An activity of defining variety of ways to build the course project with level "none" was reported lowest activity index as the knowledge of sensors and actuators was limited and there was a demand of additional laboratory training.

Table 2 : Level For Activity Level And Index By Sample Group

Level	Level Description	Activity Index (%)
High	Date and Time declared, or In-class completed	7 (33.33)
Medium	Scheduled date but more time to complete	8 (38.09)
Low	One scheduled date and time	5 (23.81)
None	Not completed anything	1 (4.76)

From the EE course activities, dates and times were maintained for each student for analysis purpose. After assigning the outcome of the activity, the information was linked to the attendance record, all entries were anonymized. Table III shows the number of reported events representing each category.

Table 3 : Course Content Based On Each Module And The Assigned Session Duration

Module No.	Module Name	Session duration in hrs
1.	Introduction to Engineering and Engineering study	03
2.	Engineering Design	09
3.	Mechanisms	09
4.	Platform based development	15
5.	Project Management	03
6.	Motor Sizing and Battery Sizing	03
7.	Engineering Ethics	03
8.	Sustainability in Engineering	03
9.	Course Project	27

Many activities in the curriculum were high accessibility type, representative of activity date and time were purely based on the module content delivery.

A. Module Content and Delivery

In this section, we discuss elaborately the necessity and conduction, content of each module and its delivery based on activities. Table IV depicts the activities and expected outcomes.

The percent of attainment of these outcomes ensure

Table 4 : Activities And Expected Outcomes

Activity No.	Activity	Outcome
1.	Identifying Engineering Problem	Appreciate use of multidisciplinary approach
2.	Ethics in engineering	Core strength of the study is to eradicate unethical practices
3.	Identifying relevant objectives, functions and constrains for a certain need statement	Interact with customer and define problem statement for a given need statement
4.	Concept generation using functional chart	Understanding of multiple approaches to solve a single problem
5.	Concept selection using systematic approach	A systematic way to choose the design having highest potential to become a product
6.	Case study on sustainable solutions	Focus on dropping carbon footprint and address sustainability in society, environment, and economy.
7.	Identify functional blocks in a system Electronic and mechanical systems	Study of sensors, actuators, motors, controller, programming, application development and basic mechanisms required to implement the project
8.	Project virtual implementation	Simulation using 3D modelling
9.	Physical implementation of the project	Development of working prototype of the model.

the content delivery and used as a marker for performing the impact analysis of the course. The student teams involved in development of working prototype of the project models are shown in Fig. 2.

Fig. 2: Student teams involved in development of working prototype of the project models

The module content delivered as in-class training is demonstrated in the laboratory in the form of development of working prototype of the project. In the laboratory, students work on building mechanical systems and electrical and electronics functions of their projects. The content is designed to link the in-class training with hands-on sessions.

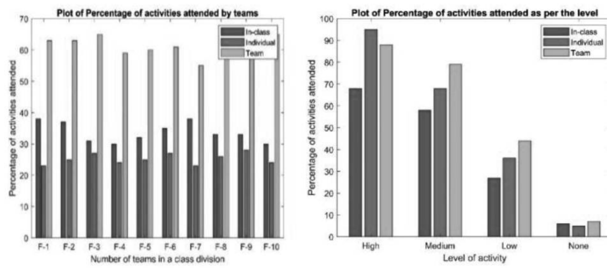
A. Rubrics and Evaluation

It is evident that using rubrics to evaluate the activities in the course enables to assess improved learning outcomes. This study investigates about the student's ability to write better arguments as per rubrics. The data for rubrics evaluation is maintained uniform through regular interaction of project mentors. A sample rubric table based on criteria is as shown in the Table V and rubrics are depicted for an activity of design of one diverse conceptual design for the need statement assigned to the students.

Based on the above example, it can be inferred that, in all three levels of activities, the engagement of the student varies and hence the evaluation of the criteria under consideration results in different attainment levels.

4. Results And Discussions

In this section, we present the results based on activities of modules and levels of achievements in the course. A significant outcome is based on the initial criterion in which a team formation is done for the project activities.



(a) (b)

Fig. 3. (a) Percentage of activities attended by the teams, (b) Level wise activities attended by teams

The results indicate that in case of the number of activities with varied level, the attainments were in equal number. Fig. 3 indicates out of total 21 number of in-class, individual and team activities, the ten teams achieved considerable percentage of activities.

Additionally, the data are broken down by student teams. Although there is a large difference between the individual and team activities a high suitability activity is accounted for improved attendance at the team activities, which was a major success of this course.

The student participation in team-based activities

Table 5 : Criteria For Defining Rubrics For A Sample Activity

Criteria	Excellent	Good	Needs improvement
Diversity (1 point)	Student can ideate a diverse solution that is unique. (2 points)	Student can ideate a diverse solution that is partially similar. (2 points)	Student is not able to ideate a diverse solution which is unique design in the team. (0-1 point)
Feasibility (2 points)	Design specific to criteria. (2 points)	Design with minor variation. (1 point)	Wage design (0 point)
Innovative (1 point)	Significant creativity (1 point)	Good creativity but not the best (2 points)	No creativity (0 point)

was above 95% and for individual activity the lowest participation was below 7%. The all three rubrics criteria defined for the highest percentage of participation are shown in Fig. 4. This categorical requirement of these rubrics indicates highest achievement for in-class activities.

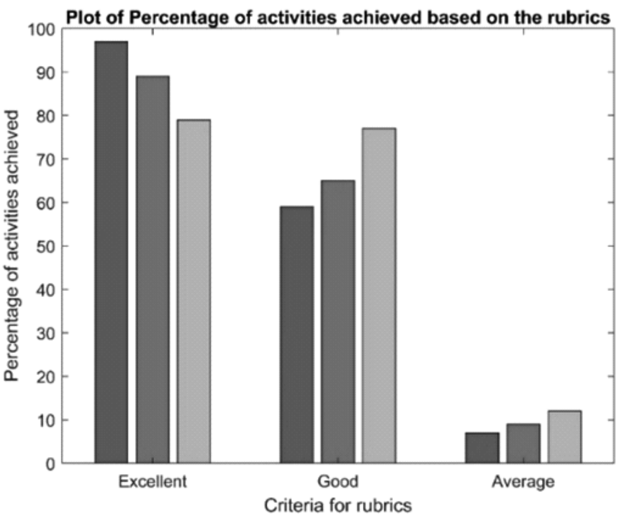


Fig. 4: Percentage of activities achieved based on rubrics

The student teams performing PBD module activities have reported 23% higher attainment as compared to an individual activity after 4 weeks of in-class training. This is an indication of overcoming teamwork barriers such as language, communication skills and realize team player's role. This is likely to be a key point for the students to participate in more team activities in their future semester's course projects.

With the introduction of step-by-step project development modules, the success rate in EE course activities drastically enhanced with higher percentage of participation and success rate. Fig. 5 (a) and (b) show four major phase of exploration course project development stages with impact analysis of in-class, individual and team success rates. It is reported that, a highest percentage above 90% success in activities where a continuous connection of in-class training with laboratory session was done. This enabled a new practical opportunity in teams, to explore the field of engineering across all student groups.

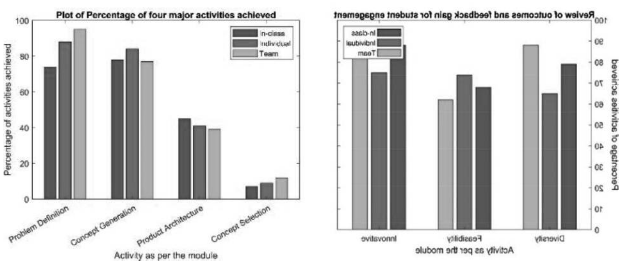


Fig. 5. (a) Percentage of achievement for 4 major activities, (b) Plot of Outcome and feedback gain

The course content division as in-class and laboratory training also resulted in disconnect in the understanding the essence of activities. The time frame to complete the laboratory activities resulted in performance drop in case of individual activities which were focused on specific modules. In future semesters', we aim to shuffle the in-class session with laboratory sessions based on the results obtained to have a strong link between training of modules and activities. A prudently built lesson plan can fully describe student performance in activities in all three categories. Finally, we would like to expand this study on increased student count during the spring semester EE course.

5. Conclusion and Future Scope

In this paper, the impact analysis of including the EE course in the first-year curriculum is presented based on performance data analysis. It is reported that the efficacy of the course is based on the activities included in various modules of the course. In comparison with in-class training, the involvement and hence performance of the students has increased with individual and team activities of ED and PBD modules by 23%. The explorations outside of the classroom provides a strong indicator of understanding the engineering and project management concepts. A large variety of activities were attended by the students with unique approaches for the sample groups. At the course commencement, activities on fundamental engineering knowledge and team development were the most effective events attended by the students. Therefore, these modules should be wisely framed to present the most effective information about engineering to the multidisciplinary students. In summary, the activity-based learning has a positive impact to the course and will continue to deploy activities on EE concepts in future. While the results presented in this paper are based on performance assessments and feedbacks, the data summarized here could be obtained using statistical tools to present data analysis on higher student intake.

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