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Enhancing Product Development Skills of Engineering Students through Diversified Group Activities

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Abstract : The paper aims to examine the effect of diversity on student performance and the skill sets in an Engineering exploration and design project (EEDP) course. The course consists of multidisciplinary modules, and each module is designed and delivered with diversified group activities considering the skill requirement of the product development process. The course aims to develop multidisciplinary product development culture in the first year of engineering studies with a diversified approach. The diversified student project groups are formed with a maximum group size of four. Considering the need statements, week-wise activity sessions within a group are planned so that students can acquire technical and soft skills. The course is designed and taught by a group of four faculties from multiple engineering disciplines using Project-Based Learning (PBL) pedagogy. As a result of this activity, every year, more than 600 students have been trained, and more than 120 prototypes/products have been developed to fulfill the stakeholders' needs. During the student project exhibition, it is observed that students have acquired outstanding product development skills such as project management, teamwork, communication, interpersonal skills, and technical as well as research skills.

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1. Introduction

Engineering education is becoming more crucial as the world faces severe energy, health care, climate, development, and other problems that require practical solutions. Although fundamental engineering theories are not changing, the increasing complexity of engineering problems, changing global needs, and knowledge explosion require professionally competent and skilled engineers. The key competencies such as Innovative thinking, problem-solving, decision-making, collaborative teamwork, communication, and information sharing are essential. Conventional engineering education practices like lectures and practices are insufficient to develop professional, competent engineers (Abdel Meguid & Collins, 2017; Rönnlund et al., 2021).

Engineering education is more focused on content knowledge than students' skill sets. Therefore, engineering education must reestablish the curriculum, emphasizing collaborative and multidimensional projects, group activities, and assignments. Group activities and project-based learning in the classroom benefit from active student engagement, collaborative work, attitude towards learning, increased complex problem-solving skills, team-building activities, and collaboration with team members. Today research on engineering education has introduced lots of innovative tools and techniques to the active teaching-learning process and promotes experiential learning through group activities(Pawar, Kulkarni et al., 2020).

The skill set expected by industry from engineering students is continuously evolving based on technology upgradation. It could be due to the basic level of routine work taken by the computers and automation adopted by the industry (Ra et al., 2019). Now, engineers have to add value in terms of analytics of information available, understanding societal problems, and building solutions. As society and industry are becoming more and more diverse, engineering campuses should build an environment that values various perspectives, backgrounds, and beliefs of students and staff (Avancing Diversity And Inclusion In Higher Education, 2016.; Diversity and Inclusivity | College of Engineering, 2022). Nurturing a campus environment that embraces diversity necessitates careful consideration of all aspects of education, from institute policies to curriculum, teaching-learning practices, assessment plans, etc. So considerable changes must be incorporated into engineering education to develop the necessary skills and competencies required for 21st-century engineers and emphasize student learning by integrating diverse classroom techniques, implementing new active learning strategies, diversified activities using advanced technology, and addressing different learning styles of students (Qadir et al., 2020.; Sidnyaev et al., 2020).

Diverse group activities with heterogeneous group members deliver creative and collaborative learning with a positive atmosphere (Brun & Razmerita, 2011). A diverse environment helps drive the creativity of the students working in a team. Assembling diverse students on a single platform helps to develop critical thinking and problem-solving skills, especially in case of real-life problems. A diverse classroom also helps students learn about other languages and cultures, encouraging them to be intercultural sensitive (Ramos et al., 2010). Diverse classrooms feature socioeconomic class differences, religion, gender, background, ethnicity, athletic ability, personality, and much more (Bécares & Priest, 2015). Research done in the last decade on engineering education indicates that socially diverse groups, such as gender, economy, ethnicity, etc., are more innovative than homogeneous groups. Diversity in the project groups helps the students develop social awareness during project activities, which helps them to understand various perspectives and draw significant conclusions (Emma Lazarus, n.d.) . It also teaches the students how to interact with their peers socially and equips them with a skill set they will use for the rest of life(Wu et al., 2019).

Rather than the process of actual product development, the process of working in a team is more critical(Osei Boakye, n.d.). Students must understand how to work in a diverse team, assign a task, plan activities, identify short and long-term goals, and how to communicate. It takes time for a group to learn to work together to facilitate equality, interaction, and understanding, especially in diverse groups (Making Group Projects Work with Diverse Students! - Perkins School for the Blind, 2017). So it is essential to conduct diversified group activities in engineering education to acquire the essential skillsets (Vaida & Șerban, 2021). The group size will be around four, balancing diversity, cohesion, active participation, and productivity. Activity groups could be organized randomly instead of grouping by location. Sometimes, the project supervisor may decide on the group considering the diversity aspects. Each group member essentially imparts how to divide tasks fairly, motivates others to participate in each task actively, and assigns the resources in the group. Implementing diverse activity-based education approaches such as activity-based teaching, guided learning, hands-on implementation, industry evaluation, empirical demonstration, project evaluation, and multidisciplinary approach integrated with online tools builds a unique learning path for students; further, it improves the level of teaching-learning practice.

Engineering group-based activities are an excellent way to build the skills required for product development. The engineering design and development process consists of the following steps; Problem Identification, Analyzing Problems, Literature study/Market survey, generation of solutions, Project Planning, Design, Development, Testing, and improve. Basically, the engineering process expects trial and error, learning from mistakes, and improving. Once the product is developed, the next step is to improve the design, which means brainstorming, planning, discussing, redesigning, and testing. At the first-year level, students are unaware of breaking down the project into manageable tasks and allocating these tasks. So in engineering education, a series of group activities must be conducted through a project-based learning approach to impart the essential skills of product development (Kulkarni et al., 2020).

In 4000 institutes, around 1.5 million students are taking admission to engineering programs every year in India (What Are the Bitter Truths about Pursuing Engineering in India? - Times of India, January 2018). These students come from very diverse demographic, economic backgrounds, and socio-cultural. Many of them cannot shift from school to the demanding engineering education environment because of emotional preparedness, background, socioeconomic culture, etc. Each engineering student joins the engineering program for different aspirations, expectations, and reasons (Pramod et al., 2021). India is a vast country, and socio-cultural and socioeconomic differences deeply affect the students' overall personality in terms of self-efficacy and flexibility for academic and emotional adjustment to the new learning environment. These differences play an essential role in students' attitudes toward their studies and their relationship with their faculty and peers. Research indicates a substantial relationship between a family's socioeconomic status and students' academic achievement (Lathigara et al., 2021). Students from diversified backgrounds get admitted to engineering institutes, where the educational policies adopted in school and engineering institutes are different. It is essential to bring these diversified students to cope up, build their higher-order skills to analyze, teach creativity, and teach flexibility in teaching and evaluation. Although autonomy provides more flexibility to design and update the curriculum, when it comes to implementing it in classroom teaching, the conventional mode of teaching and evaluation still dominates the educational system (Brintha et al., 2021).

As a result of globalization, the industry's working environment is characterized by enormous competition, prominence on quality, high-performance work culture, automation, and diversification in products and services (Kyove et al., 2021; Patrick & Kumar, 2012). Modern industry is looking for Job-ready graduates. It is observed that graduates' technical skills are considered necessary, but soft skills are considered more important for employability. Technical graduates lack higher-order cognitive skills such as working in diverse groups, analyzing, logical reasoning, evaluating and creating, and solving problems (Tulsi, 2015). Next-generation engineers should creatively solve complex challenges related to the environment, energy, and health care; these engineers need to work in a collaborative team that is culturally and philosophically diverse with an understanding of multiple disciplines. The growing pace of innovation in terms of products and business models is also likely to make an engineer's job quite challenging. Therefore, engineers must learn to work with ambiguity, diversity of disciplines, and humility regarding their skills and abilities (Samavedham & Ragupathi, 2012). Cognitive diversity in a team working towards a common goal makes it possible to perceive different perspectives, supplement one another, and make a reciprocal contribution toward achieving the goal. Applying conceptual ideas in a team to enhance the hands-on experience is one of the tactics (Itagi et al., 2021).

Buhari et al., (2021) used descriptive statistics to evaluate the relationship between the course and the corresponding graduate attribute. The courses in the B. Tech curriculum were mapped with the twelve graduate attributes with respective weightage. The study was conducted at three different universities and observed less attainment (<40%) and coverage of few graduate attributes such as conducting an investigation of complex problems, engineers and society, environment and sustainability, and; Project management and finance.

From the third year onwards, capstone projects and mini-projects are offered in the traditional engineering curriculum (Pawar & Patil, 2021), where students get opportunities to transform theoretical knowledge into real-life problems and go through fewer hands-on activities during academics. In order to transform conceptual learning into experiential learning, project activities should be initiated at the first stage of the engineering curriculum to enhance technical and project development skills and build confidence (Chikkamath et al., 2017; Gadola & Chindamo, 2019)

Education is considered the foundation of modern society and industry. It provides significant indications about the development of a country. In a diverse country like India, the major challenge in the education system is to provide quality education to all to accommodate the diversity in the population. Diversity is at the forefront of everybody's thoughts in today's ever-changing society and political atmosphere. Studies have shown that starting diversified activities in the classroom will give students numerous advantages. A diversified classroom helps students understand how to work in a diverse team, plan activities, distribute work, and respect each group member (Bécares & Priest, 2015). Therefore, to create an experiential learning environment and understand the importance of diversity in the early engineering stage, the course EEDP was introduced in the engineering curriculum's first year. During the course implementation, a diversified group has been created considering the gender, economic background, interest, capabilities, and cast of the student. A series of multidisciplinary group activities have been planned in this course so that students can work in a diverse group and acquire product development skills. Diversity is maintained in the various stages of course implementation, and its impact on student learning is presented.

2. Course Overview

The EEDP course is an innovative course offered for first-year engineering to transform students' ideas into real-life products. The course came through as an outcome of year-long deliberations among the senior management, First-year Board of Studies members, senior faculty members from other disciplines, and consultations with industry experts and educationists. It comprises several group activities such as problem-solving, engineering design process, multidisciplinary engineering skills, project planning, communication, teamwork, ethics, and ensuring the sustainability of the project idea. Facilities like; Learning Studio and Thinkering laboratory are exclusively developed for this course. The Learning Studio is intended for an activity-based teaching process, whereas the design of the Thinkering Laboratory assists in product/prototype development, as shown in Fig. 1a and 1b, respectively.

The course's primary goal is to expose the students to the product development process through their direct involvement in the teaching-learning process through collaborative activity-based instructions. Implicitly, the engagement of first-year engineering students in the learning process is crucial in terms of excitement, retention, and satisfaction.

The course objectives aimed are as:

- Nurturing a product development culture in the campus.
- Orient student thinking to solve a complex problem using a multidisciplinary approach.
- Promote a diversified need-based thinking approach in the First year.
- Converts the student ideas into real-life commercial products.
- Ensuring equal opportunities by forming project groups with gender and socioeconomic diversity.

A separate course leader has been assigned to implement this course in the first-year curriculum. The role of the course leader is to coordinate the activities of course structure design, planning and implementation, using activity-based instructions in collaboration with faculty teams from various disciplines. Furthermore, they are responsible for planning and arranging the necessary facilities/tools in Learning Studio and Thinkering Laboratory.

This course has been offered since August 2018 (Academic Year 2018-19). It is delivered at odd as well as even semesters with a batch size of 60 students. The contact hours are four per week. A total of 24 sessions (02 sessions/week, each of 2 hr.) are planned and delivered throughout the semester. First-Year Engineering students and faculty members from all branches (Mechanical, Automobile, Electrical,

Fig. 1a : Learning studio: Teaching-learning process

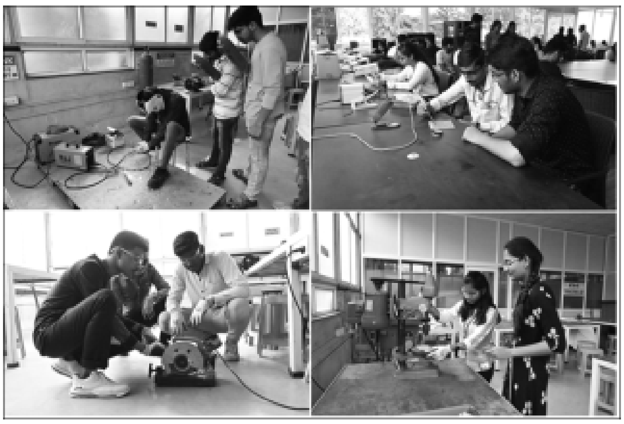

Fig. 1b : Thinkering laboratory: Product development platform

Civil, Computer, Information Technology, and Electronics Engineering) are actively involved in this activity. The students are offered the opportunity of experiential learning. The course is designed to be very interactive, where students can participate in various hands-on activities. At the end of the course, students have to complete a project. A project exhibition is organized at the end of the semester to showcase the learning outcomes and the skills. Industry experts are invited to evaluate the student projects and products.

3. Course Implementation

The course aims to develop innovative product development skills at first-year of engineering through diversified group activities. In addition to teaching, it is a process of evolving a new approach to develop next-generation engineers (Pawar, etal., 2020). The course is designed for 24 contact sessions with two credits such that; students should get hands-on experience in product development. The various multidisciplinary modules have been incorporated into the course, such as Introduction to engineering, engineering design process, Mechanisms, Project Management, Platform-Based Development using Arduino, and Data Acquisition and Analysis. Fig. 2 presents the flow chart of the course implementation with a diversity approach.

Around 240 students from various disciplines are divided into four divisions; each division is divided into 15 heterogeneous groups with a maximum of 4 students in each group. Each semester around 60 heterogeneous student groups are formed by considering the student interest, gender and capabilities so that all students will get equal opportunities to develop their skill sets. A special seating arrangement is provided for the group and hands-on activities. The statistics of student diversity in the project group are presented in Fig. 3. The student gender diversity, economic diversity, caste diversity, and international-level student diversity have been considered while forming the project groups. The 72% male candidate and 28% female candidates have been grouped in such a way that there will be one female candidate in each group. In economic diversity, students' backgrounds have been considered, such as lower-income, average-income, and higher-income groups, and equal weightage has been given while forming the project groups. As India is the most diverse country in terms of religion and caste, it is also considered while forming student project groups. Care has been taken so that the project group should consist of only one student of the same cast.

The course is planned into two sections: teaching product development skills through activities in Learning Studio and product development in Thinkering Laboratory. Considering the multidisciplinary nature of the course and the requirement for active engagement of students, a team of 4 multidisciplinary instructors has been formed. The diversity in the faculty team is presented in Fig.4. The instructor teams have been given special training through workshops. In collaboration with the industrial experts, the faculty team identifies the need statement for the project. It is expected that the student project group should provide the best solution to the provided need statement by applying a multidisciplinary approach.

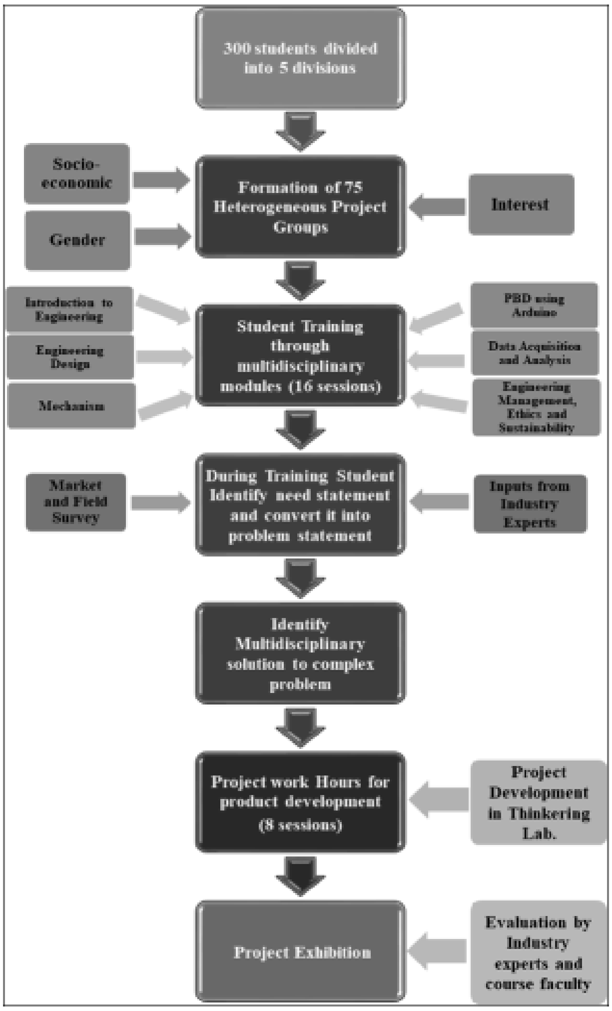

Fig. 2 : Flow chart of the course implementation with diversity approach

Teaching-learning process planned in the learning studio is divided into six modules, and each module is designed with a learning kit used during actual session delivery. To start with, students are introduced to the role of an engineer as a problem solver. To get the experience, hands-on activities such as poster preparation and presentation on 21st-century challenges, converting plain paper into a hollow sphere, solving a rubik cube, etc. The 2nd module deals with the engineering design process where the concept of a need statement and conversion of a need statement into a problem statement considering customer needs, constraints, functions, and objectives are inculcated initially. Then engineering design process, multidisciplinary facets of design, problem analysis, generation of multiple solutions, and selection of the best solution are delivered with group activities such as bridge development using popsicle sticks, Decision matrix, etc. In parallel with course delivery, students identify the need statement with assistance from the supervisor and convert it into a problem statement.

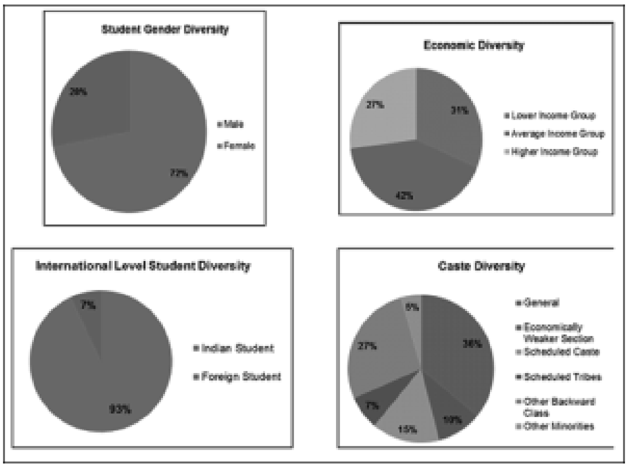

Fig. 3 : Statistics of diversity in student project groups

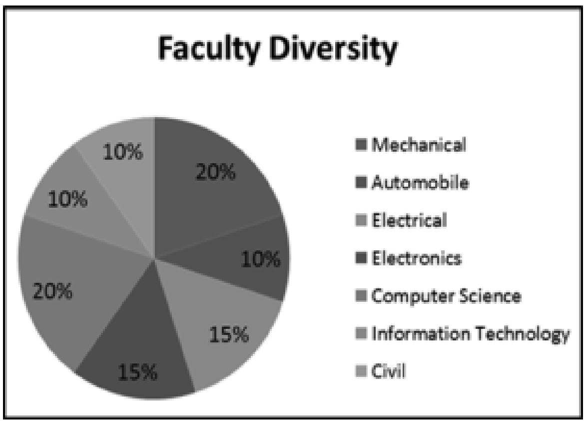

Fig. 4 : Diversity in the faculty group

In the 3rd module, students are introduced to the concept of mechanisms that cover essential components of a mechanism, degrees of freedom or mobility, four-bar chain, crank rocker mechanism, slider-crank mechanism, and power transmission devices. These concepts are anticipated to help students in project building and encourage them to look at the project's multidisciplinary approach.

In the 4th module, platform-based learning exposes students to an embedded system with Arduino, motors, motor drivers, batteries, and all necessary interfaces required to build automation in their final project. Module 5 deals with data acquisition and analysis. Project Management is covered in module 6; it gives the importance of teamwork in project management, planning projects using relevant project management tools like a checklist, timeline, and Gantt chart, and applying documentation skills to prepare, store and share project reports. The various activities conducted in the learning studio are presented in Fig. 5.

4. Course Evaluation

The course has the feature of continuous in-semester evaluation. Students are evaluated and graded at the end of each module and activity. Continuous student assessment is made using evaluation rubrics which are explained to and shared with the students at the beginning of the semester. The evaluation rubrics are mapped with the course outcomes for calculating attainment. The course outcomes of the EEDP course are as follows;

At the end of the course, the student should be able to:

1. Explain the role of an Engineer as a problem solver.
2. Design engineering solutions to complex problems utilizing multidisciplinary systems approach.
3. Examine a given problem using the process of engineering problem analysis.
4. Build simple systems/prototypes using engineering design and development process.
5. Analyze engineering solutions from ethical and sustainability perspectives.
6. Apply the basics of engineering project management skills in project development.

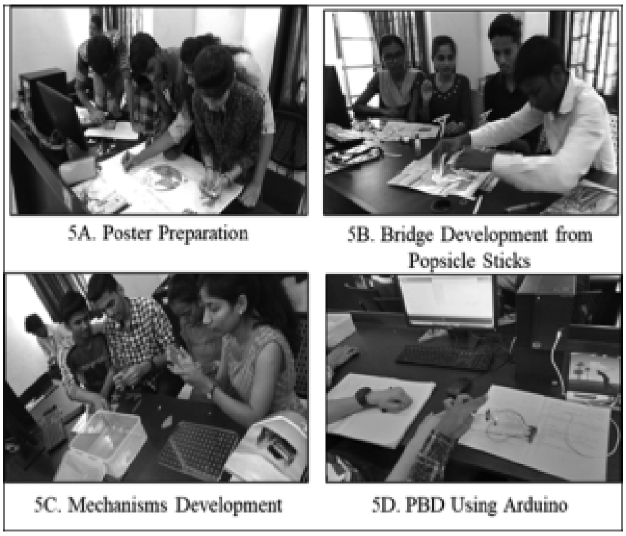

Fig. 5 : Sample group activities conducted in the learning studio

Table 1. Evaluation scheme

Assessment Type	% Weightage
1. In-semester assessment (ISE)	**80**
1.1 Engineering Design	10
1.2 Mechanisms	10
1.3 Platform-based development	15
1.4 Data Acquisition and Analysis	10
1.5 Project Management, Engineering Ethics and Sustainability	10
1.6 Course project reviews (2 Reviews/semester)	25
2. End-semester assessment (ESE)	**20**

The course assessment is divided into two parts; In semester assessment (ISE) and end-semester assessment (ESE). The 80% weightage is assigned to the ISE, whereas the 20% weightage is to ESE. ISE evaluation is further divided into the course modules and project reviews, and for each module and course project review, a separate assessment rubric is designed. The detailed assessment plan is presented in Table 1. The evaluation rubric designed for assessing the course project review-I is presented in Table 2.

5. Impact And Results

As part of the EEDP course, around 540 students develop more than 120 innovative multidisciplinary projects/prototypes yearly. Sample projects developed by the students are shown in Fig. 6. So far, four design project exhibitions have been arranged, and industry experts have been invited to evaluate these projects and finalize the best one. Glimpses of the project exhibition are shown in Fig. 7. Students are encouraged and motivated to present their prototypes/products on state and national platforms. Eight project groups have presented their project at the state and national levels. Currently, 04 project groups are in the process of converting their prototypes into commercial products. Two project groups have got selected in Ideathon 2020 organized by RIT, Sakharale, and are eligible to receive INR 1 lakh funding from Maharashtra State Innovation Centre for Entrepreneurship Development.

The quality of the EEDP course is enhanced by conducting training programs for the faculty team(Baligar et al., 2019; Kaushik, 2020). Generally, two such programs are conducted in a year. Total 20 faculties are trained through this program. A multidisciplinary team of 04 faculties delivers the course (e.g., Mechanical + Electrical+ Electronics + Computer Engineering) (Hein & Sorby, 2001; Pawar et al., 2020)

In the last two years, more than 1150 students have

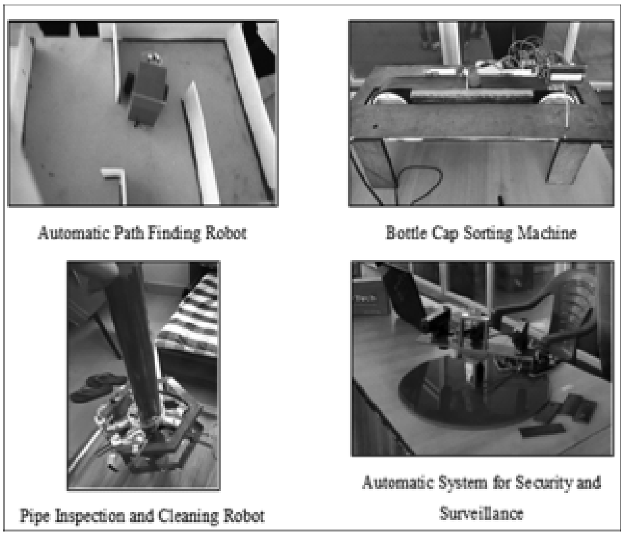

Fig. 6 : Sample projects developed by students

Fig. 7 Glimpses of the project exhibition

Table 2 : Evaluation Rubric: Course Project Review I

Sr. No.	Criteria	Grade Points			
		1	2	3	4
1.	**Study of the Existing Systems and Literature**	Minimal explanation of the specifications and limitations of the existing system, Incomplete information	Moderate study of the existing system and collects some basic information	Good study of the existing systems and collected information	Detailed and extensive explanation of the specifications and limitations of the existing system
2.	**Objectives, Constraints and Problem statement**	Objectives and constraints are either not identified or not well defined; Problem statement isn't specified.	Incomplete justification to the Objectives and constraints; Steps are mentioned but unclear. Problem statement s defined but not clear.	Good justification to the objectives and constraints; Problem statement is specified	All objectives and constraints are well defined; Problem statement is clearly specified
3.	**Proposed Solutions using a multidisciplinary approach**	Minimal explanation of the proposed solutions. Identified few solutions.	Average explanation of the proposed solutions. Identified few solutions and haven't applied multidisciplinary approach.	Applied multidisciplinary approach. Identified 4 solutions and applied criteria for best solution.	Detailed and extensive explanation of the proposed solutions with multidisciplinary approach. Identified 4 solutions and applied criteria for best solution. Selected best solution.
4.	**Methodology and Project Planning**	Incomplete and improper specification. plan is difficult to follow	Steps are mentioned but unclear. Plan is not clearly defined.	Methodology to be followed is specified. Good project plan	Steps to be followed to solve problem are clearly specified. Project plan is well-defined.
5.	**Communication and presentation**	Improper organization of project proposal. Information was well communicated with limited effectiveness.	Basic organization of proj ect proposal. Information was well communicated with some effectiveness.	Good organization of project proposal. Information was well communicated with considerable effectiveness.	Proposal is well organized and clearly written. Information was well communicated with high degree of effectiveness.

been trained, and more than 240 prototypes/products have been developed to fulfill the stakeholders' needs. Recently, during COVID times, the second-year students who successfully completed this course and were inspired by the same; designed and developed Dr. Sanitor, a manually operated sanitizing machine. This project secured 1st rank in the 'National Level Online COVID–19 Innovation Challenge' organized by Sri Krishnadevaraya University AIC-SKU, Andhra Pradesh State. The fact that a diverse group of students belonging to different castes, gender, and socioeconomic strata could develop, commercialize and sell around 500 such units through their start-up called 'Bubblebyte' speaks about the impact of the course outcomes.

The Institute has invested more than 50 lakhs towards establishing Learning Studio (55×32 feet) and Thinkering Laboratory (60×30 feet). The students' responses showed that 68% of the students rated this activity 10 out of 10 and offered suggestions for further improvement. The students were seen spending more time in Thinkering Laboratory after regular college hours. During the project exhibition, it was observed that students were highly motivated and enthusiastic about showcasing their products to the audience professionally. The students are found to have developed a sense of teamwork and appreciation for diversity.

6. Future Development

The course team is planning to extend the Engineering Exploration and Design course activities to the subsequent semesters of engineering, where the conceptual courses could be linked to the product/prototype development practices. A different platform for interested students is being developed to extend their project ideas/prototypes at the commercial level and help to prepare the business plan. The facilities in the Thinkering Laboratory, in the form of various tools, equipment, and software like 3D printers, PCB machines, Laser cutting machines, etc., are envisioned to be scaled up to maximize access to the student project groups. The Institute would like to extend the facility for school children in the vicinity to raise their interest in engineering and appreciation of product development. The Institute has initiated extending this course project beyond the campus and offering support to interested colleges to deploy similar courses. In the first phase, the Institute intends to mentor around ten nearby institutes to be able to deploy the course.

A separate entrepreneurship track has been designed for interested students. The Institute, in particular, wish to provide financial and technical support to underprivileged and girl students who possess the potential to incubate and commercialize their ideas and prototypes. As a future plan, the Institute foresee this initiative culminating in a regional innovation and incubation hub for the students and outside entrepreneurs to convert their ideas into growing businesses and make society prosperous and self-reliant.

7. Conclusion

The impact of deploying diversified group activities in course delivery towards the enhancement of students' product development skills has been elaborated in this paper. Although this implementation is time-consuming, complex, requires more planning, and requires more faculty members, its results outperform conventional teaching-learning practices. The study provides proper insights into the planning of the course with a diversified approach and its impact on student performance.

The findings of this implementation indicate that student engagement and academic performance improved with a series of diversified group activities. The students' responses showed that 68% of the students rated this activity 10 out of 10 and offered suggestions for further improvement. Student feedback reveals they are very positive about implementing these activities and show great dedication and enthusiasm during project development and exhibition. Therefore these diversified group activities were found to have a much more impact on enhancing the competencies and skills of students, such as creativity, problem-solving, higher-order thinking, teamwork, leadership, communication, project planning, sustainability of the project, and ethics.

In addition to the Engineering exploration course, students can be motivated to organize inter-college or state-level events, societal events, workshops, conferences, and project exhibitions in diversified groups to explore project management activities in a multidisciplinary environment.

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