INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

A Comprehensive Framework for Research-based Learning to Elevate Undergraduate Research

Rekha Sharma[1*], **Urvi Sharma**[2]

1 Associate Professor, Department of Computer Engineering, Thakur College of Engineering and Technology, Mumbai, Maharashtra, India
2 Management Trainee, Vodafone Idea Limited, Mumbai, Maharashtra, India

OPEN ACCESS

Received: 12-05-2024
Accepted: 04-10-2024
Published: 30-10-2024

Citation: Sharma R, Sharma U (2024) A Comprehensive Framework for Research-based Learning to Elevate Undergraduate Research. Indian Journal of Science and Technology 17(40): 4225-4242. https://doi.org/10.17485/IJST/v17i40.1618

* **Corresponding author**.

rekha.r.sharma73@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Objectives: This study proposes a comprehensive framework for Research-based Learning (RBL) that actively engages undergraduate students from diverse disciplines in collaborative research, and aims to enhance their problem-solving and research skills. **Methods**: RBL was introduced in the 2020-21 curriculum for six engineering branches at Thakur College of Engineering & Technology (TCET), Mumbai, and was expanded to include three additional branches in 2023-24. It comprises four courses namely RBL1, RBL2, RBL3, and RBL4, spanning from the third to the final year. RBL activities were designed and implemented for over 4,300 students from 2020 to 2024. **Findings**: The outcomes of RBL activities were analyzed based on students' achievements at the end of each semester. Application of the framework across different engineering branches for 4 years produced tangible outcomes in the form of an increase in in-house publications, participation in project competitions, and improved students' skills contributing to individual growth and institutional branding. The number of publications in TCET increased from 133 to 274 from 2022 to 2024. The total prize money received by students through participation in different project competitions amounted to INR 9.44 lakhs. The effectiveness of the framework is evaluated through online feedback surveys. A survey of 605 students consisting of 5 questions yielded 87.76% positive responses, while a survey of 83 teachers consisting of 9 questions showed positive feedback ranging from 90% to 96.4%. The successful research outcomes and positive feedback from students and teachers support the implementation of the framework in other institutions offering degree programs. **Novelty**: The RBL framework is integrated into the undergraduate engineering curriculum, providing time-bound achievements. It offers flexibility for online and offline use and is scalable for large groups of undergraduate students.

Keywords: Research-based learning (RBL); Undergraduate research (UR); Research outcomes; Publications; Problem-solving skills

1 Introduction

Research-based learning (RBL) represents a transformative approach to quality education that incorporates knowledge creation and innovation in learning. RBL complements learning through active engagement of students for research, fostering critical thinking, and problem-solving skills, offering new dimensions to understand the academic content. The involvement of students in the research activities empowers them to explore complex issues, create new insights, and develop the 21st-century skills necessary for lifelong learning and professional success. This educational approach not only enhances academic rigor but also cultivates a sense of intellectual curiosity and independence, preparing students to tackle real-world challenges with confidence. Thus, integrating Research-based learning into the curriculum serves as a catalyst for intellectual growth and contributions to society.

In response to the evolving demands of industries, the survival of engineering graduates is dependent on the deeper knowledge of the core subjects with the exploration of real-time problems and finding their possible solutions. Traditional classroom teaching emphasizes more on lower levels of Bloom's taxonomy [(1)]. Whereas, RBL facilitates the achievement of higher levels of Bloom's taxonomy. RBL is defined as a process of conducting systematic research-oriented activities for participants to achieve desired research outcomes. This study proposes a framework for RBL to motivate and empower undergraduate students and faculty for collaborative research based on projects undertaken during the undergraduate course.

Typically, every educational institution engages in R&D activities, but these initiatives are often driven by the interests of students or faculty members and may serve as part of their professional development. The traditional research approach often involves a student working under the guidance of a supervisor or mentor [(2)]. This model is predominant in academic programs, such as master's or doctoral studies. Adopting undergraduate research (UR) across disciplines is a highly effective pedagogical strategy. UR involves systematic inquiry or creative work that contributes to knowledge in a student's field, fostering critical thinking and enhancing learning. It prepares students for advanced studies and careers by facilitating close collaboration with faculty mentors and industry experts. However, introducing research at the undergraduate level presents challenges, including the need for time-bound contributions. Successful implementation requires careful planning, training, mentoring, and ongoing support.

This paper presents a novel approach focusing on undergraduate research of multiple disciplines under one umbrella. The use of the framework to implement the RBL curriculum as one of the components of holistic student development (HSD) activity in a private engineering college is a unique attempt in India [(3)]. RBL is not considered a core engineering subject but rather a distinct component of the curriculum. It fosters essential 21st-century skills among students while actively engaging them in the course.

This study suggests a framework that helps to streamline R&D activities involving undergraduate students and faculty by providing a platform for interaction and engagement. Academic institutions offering undergraduate courses can adapt the framework by customizing its implementation according to their available resources and specific R&D needs. This framework facilitates the conduct of research activities using appropriate processes producing time-bound research outcomes. Research and Development (R&D) are crucial for the sustainability and growth of an institution. Meeting specific targets and documenting achievements in R&D is essential to comply with the requirements of various accreditation and ranking bodies in India. Participation of students in undergraduate research has the following benefits: 1) Personal and professional growth of student and faculty. 2) Inculcating problem-solving and critical thinking skills. 3) Preparation of a career for higher education. 4) Enhancing technical and relatable skills. 5) Clarification for educational goals. All these benefits can be availed by students through high-quality mentoring by faculty [(2)].

Before discussing the framework, the background of RBL in the context of India, and other countries across the world is presented here: Sengupta and Blessinger emphasize that including undergraduate students in research is beneficial for faculty and students. Unfortunately, collaborating with students for project implementation and measuring their outcomes is difficult in most of the countries. Their study analyses the undergraduate research experience of faculty in three countries namely, India, Malaysia, and the Kurdistan region of Iraq. They discuss the results of a survey of faculty members teaching undergraduate students. The findings of the survey suggest that undergraduate research programs in these countries were limited due to financial constraints and a lack of support staff [(4)].

The book compiled by Hegde S and Karunasagar I describes case studies and research findings of the experience of authors in different universities all over the world. Case studies and research models have been shared based on their experience. Various aspects of their research have been highlighted including: 1) types of undergraduate research, 2) challenges and opportunities for undergraduate research, 3) preparing students to be employable through developing graduate attributes, 4) strategy for integrating undergraduate research practices into both the curriculum and co-curriculum, 5) summative assessment of the undergraduate program or as a means of training young researchers, 6) the investment made by the government in research in undergraduate courses, 7) professional development opportunities for faculty supervising undergraduate research, 8)

promotion of research skills by government, 9) best practices for instilling scientific integrity, and 10) recommendations to support undergraduate research [5].

Available open literature is systematically reviewed and summarized in Table 1. Table 1 summarizes case studies implementing RBL concepts concerning authors, discipline of students, learning models, research integration, timeline, and research focus. The learning model here refers to whether the activities are student-centric or teacher-driven. Research integration means whether research is carried out as part of an academic subject or is considered a separate component in the curriculum and carries credits. Research-based learning activities are planned and implemented for Biology students, as stated by Hegde S. & Karunasagar I. and Daryanes F. & et al.; Social Science students by Rohani R. et al.; and diverse disciplines by Hall E. et al. [2,5–7]. Engineering students are involved in research by only two papers, namely Noguez J. et al. and Seifan M. et al. [8,9]. In the paper authored by Seifan M & et al. RBL is considered a capstone project as a part of a subject [9].

Table 1. Comparative Analysis of Literature Based on Case Studies

Reference	Discipline of students	Learning Model	Research Integration	Timeline	Research Focus
[5]	Final year students of Biology.	Faculty-driven	As a part of the curriculum (4 hours per week forproject work)	Degree course	Learning through a research-based **pedagogy** program.
[6]	Prospective teacher students specializing in Biology Education	A student-centric approach	Research is carried out as part of the curriculum in the Learning Media course.	Over a semester	**Problem-solving** and developing students' **critical thinking skills.**
[7]	28 Social Sciences students	Faculty- driven	The research subjects were part of the Seminar Geography Course	Not known	To measure **critical thinking** and **problem-solving abilities** using RBL.
[2]	Undergraduate students of Diverse disciplines	A blend of both student-centric and faculty-driven approaches.	Integrated into the curriculum as part of a structured 9-week mentored experience.	9-weeks	The program emphasizes both the **research process** and **problem-solving**. There is a strong focus on developing research methods and processes to adapt virtual environments.
[8]	Computational Engineering students	Faculty driven	A research-based model is implemented for the topics of Data Science.	One semester (16 weeks)	Framework for undergraduate research is used and RBL **competencies** are used and measured.
[9]	51 Undergraduate students of the School of Science and Engineering	Student-centered to promoteproblem-solving skills	Engineering capstone research project	Not known	UR can be an efficient tool for **teaching andlearning process**.

In the papers authored by Noguez J & et al., Hegde S, Karunasagar I & et al., Rohani R & et al. the research is driven by Faculty, whereas Seifan M & et al. and Daryanes F & et al. use student-centric approaches for research [6–9]. Hall E & et al. use a blended learning model based on both student-centric and faculty-driven approaches [2]. Students are encouraged to take ownership of their projects and faculty mentors provide guidance and support. Most of the studies state that RBL is integrated into the curriculum but united into the subject teaching.

The proposed framework follows a blended learning model that considers RBL as a separate course that is mandatory for all students. Most of the literature indicates that RBL activities are typically conducted for one semester or less. The suggested RBL framework is developed and tested for 4 Semesters of 15 weeks each. All literature referred focuses mostly on the development of research skills, critical thinking abilities, and problem-solving skills. Hegde S, Karunasagar I, and Seifan M & et al. consider RBL as a teaching-learning pedagogy [5,9]. The proposed approach uses RBL not only as a pedagogy but also as a mechanism to assess and improve the skills of students. They have learned not only from the process but also excelled in the area of their interest.

All the case studies presented in the literature as per Table 1 focus on problem-solving, critical thinking, and research skills. There is a need to have a generic framework for undergraduates that can incorporate all skills required for their career growth.

The suggested framework helps to develop problem-solving, research paper writing, and communication skills, which can prepare them for higher studies or employment.

This paper is structured as follows: It starts with an introduction to Research-Based Learning (RBL), including background information and insights from other authors on undergraduate research. Next, it presents the RBL framework's architecture, components, processes, and features. The results and discussion section highlights findings from applying the framework at TCET, evaluation criteria, and feedback analysis gathered through surveys. Finally, the conclusion summarizes the research contributions, outlines limitations, and offers suggestions for future work.

2 Methodology

The proposed RBL framework was introduced in Thakur College of Engineering and Technology (TCET), Mumbai from the academic year 2012-21 after conferring the autonomous status. RBL 1 has been an important component of the curriculum in the form of the Holistic Students Development (HSD) teaching scheme with one credit and 50 marks for teamwork including 25 marks for presentation and 25 marks for Report as shown in Figure 1. A similar structure is given for RBL 2, RBL 3, and RBL 4. Over 4,300 third-year and final-year engineering students participated in RBL activities between 2020 and 2024. Each semester, RBL outcomes are assessed using several key parameters, including the number of students involved, the number of in-house and out-house projects, patents filed, consultancy received, student participation in competitions, and publications. The analysis is done using the RBL activity reports submitted by each department's RBL coordinators of respective branches.

T.E. Semester –V (Computer Engineering)
Choice Based Credit Grading Scheme with Holistic Student Development(CBCGS- H 2019)
Approved by Board of Studies and Academic Council Under TCET Autonomy Scheme (w. e. f. A.Y. 2019-20)
(Meeting held on 10th and 20th July 2019 respectively)

Course Description			Teaching Scheme (Program Specific)					Examination scheme				
			Modes of Teaching / Learning / Weightage					Modes of Continuous Assessment / Evaluation				
Sr. No.	Course Code	Course Title	Hours Per Week				Credits	Theory (100)		Practical/Oral (25)	Term Work (25)	Total
			Theory	Tutorial	Practical	Contact Hours		IA(25)	ESE(75)	PR/OR	TW	
1	PCC-CS501	Theory of Computer Science	3	1	-	4	4	25	75	-	25	125
2	PCC-CS502	Introduction to Intelligent System	3	1	2	6	5	25	75	25	25	150
3	PCC-CS503	Software Engineering	3	-	2	5	4	25	75	-	25	125
4	ESC501	Microprocessor	3	-	2	5	4	25	75	25	25	150
5	PEC-CS501X	Professional Elective 1	3	-	2@	5	4	25	75	-	25	125
6	SI501	Seminar / Workshop*/Professional Training#	-	-	2	2	1	-	-	25	25	50
		Total	**15**	**2**	**8+2*=10**	**27**	**22**			**Total marks**		**725**
Course Description			**Non Credited Mandatory Course**									
1	MC501	Indian constitution	1	-	-	1	(Non-Credit)	Passing is mandatory for this course			25	
Course Description			**Teaching scheme (Holistic Student Development - HSD)**					**Assessment/Evaluation Scheme**				
								Presentation		**Report**		**Term Work (50)**
								AC		**AC**		
1	HSD-CSPS501	Professional Skill V(Industry / Research /Entrepreneurship)	1	-	2	3	2	25		25		50
2	HSD-CSPBL501	Project Based Learning - III	-	-	2	2	1	25		25		50
3	HSD-CSRBL501	Research Based Learning-I/Online/MOOCS	-	-	2	2	1	25		25		50
		Total	**1**	-	**6**	**7+1**	**4**			**Total marks**		**150**
		Total	**17**	**2**	**14+2*=16**	**33+2*=35**	**26**			**Grand Total marks:**		**875**

Fig 1. Teaching scheme snippet showing RBL 1 as a component of Holistic Student Development (Choice Based Credit Grading Scheme with Holistic Student Development under TCET Autonomy Syllabus in the Academic Year 2019-20)

Utilizing the RBL framework as a platform empowers both students and teachers to engage collaboratively in research endeavors within defined time constraints. The teacher will upgrade their domain knowledge and use it for teaching the related subjects. At the same time, students will benefit from career-building activities designed within the RBL framework. Through the collaborative efforts of students and faculty, the institute can showcase its research contributions and significantly enhance its global reputation. The framework will help to achieve the following research objectives:

1. To motivate faculty and undergraduate students for collaborative research.
2. To increase the higher-order thinking skills (HOTS) of students through RBL activities.
3. To provide a conducive environment for research and development.
4. To enhance the quality of the projects through RBL activities to make them useful for industry, government, and society.

It is challenging to keep all the objectives as targets at the same time, but setting personalized different targets for different academic years or branches/disciplines enables institutions to provide, effective, and outcome-oriented education that meets the diverse needs of students and fosters their academic success.

2.1 RBL Framework Architecture

Introducing research at an undergraduate level is challenging but it can be made productive with collaborative and systematic learning. The suggested RBL framework is an attempt to get research outcomes by planning, conducting, and analyzing research and development activities for students.

The inception of the framework is a result of a continual strengthening of research-oriented activities over a period of time. The R&D activities leading to the framework structure include several key initiatives. Initially, R&D activities were promoted by organizing technical seminars, conferences, and workshops to involve faculty and students in research. Additionally, some R&D activities were integrated into the free slots of the academic timetable as co-curricular activities to engage undergraduate engineering students. Later, a concrete structure of the framework was formulated after the formal introduction of RBL in HSD to ensure time-bound and target-based activities. Leveraging its autonomy, RBL was introduced into the curriculum, assigning appropriate credits. The framework is continually implemented, tested, and upgraded based on the mapping of expected outcomes and achieved results.

The proposed framework shown in Figure 2 comprises systematic RBL activities in 4 different semesters with 4 credits giving different outcomes at the end of each semester. These outcomes for all four RBLs are described below:

RBL 1: Project titles, validated ideas, and feasibility survey, Strength, weaknesses, Opportunities, and Challenges (SWOC) analysis (A sample outcome of RBL1 project title themes for 2022-23 are given in Table 2).

RBL 2: Blogs, LinkedIn profiles, prototypes, mathematical models, posters, and infographics (A sample poster is shown in Figure 3).

RBL 3: Potential projects for patents, and industry inputs to improve project quality.

RBL 4: Business Model Canvas, participation certificates of students in different competitions, products useful for industry and society, publications (A sample Business Model Canvas is shown in Figure 4).

Cumulative efforts done by faculty and students are reflected at the end of RBL4 in terms of outcomes.

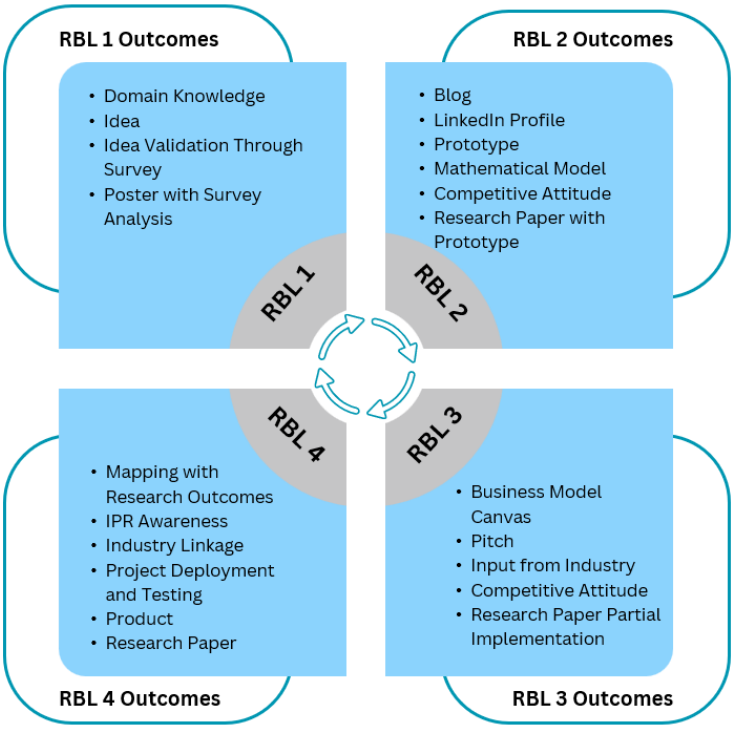

Fig 2. Framework Architecture

Table 2. Distribution of Project titles with Themes during the Academic Year 2022-23

Department	DEPT 1	DEPT 2	DEPT 3	DEPT 4	DEPT 5	DEPT 6	DEPT 7	DEPT 8	DEPT 9	TOTAL	Percentage
TV-2035	7	3	11	1	10	11	0	0	0	**43**	14.78
SIH 2022	12	16	26	3	4	5	7	6	7	**86**	29.55
Faculty Own Ideas	17	18	5	8	8	11	0	5	2	**74**	25.43
Student Own Ideas	20	5	5	9	12	0	16	12	2	**81**	27.84
Sustainable Development Goals	0	0	0	0	0	4	0	0	0	**4**	1.37
NEP	0	0	0	0	0	3	0	0	0	**3**	1.03
Total	**56**	**42**	**47**	**21**	**34**	**34**	**23**	**23**	**11**	**291**	

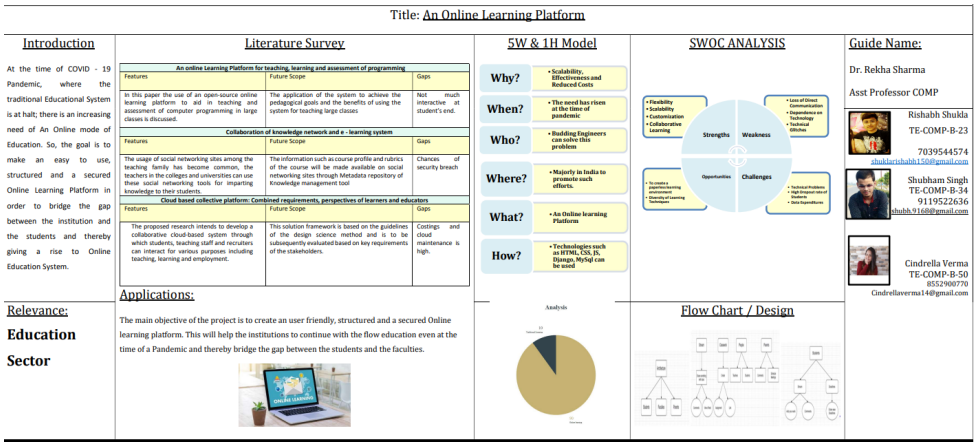

Fig 3. A sample poster prepared by students for the project Title "An Online Learning Platform"

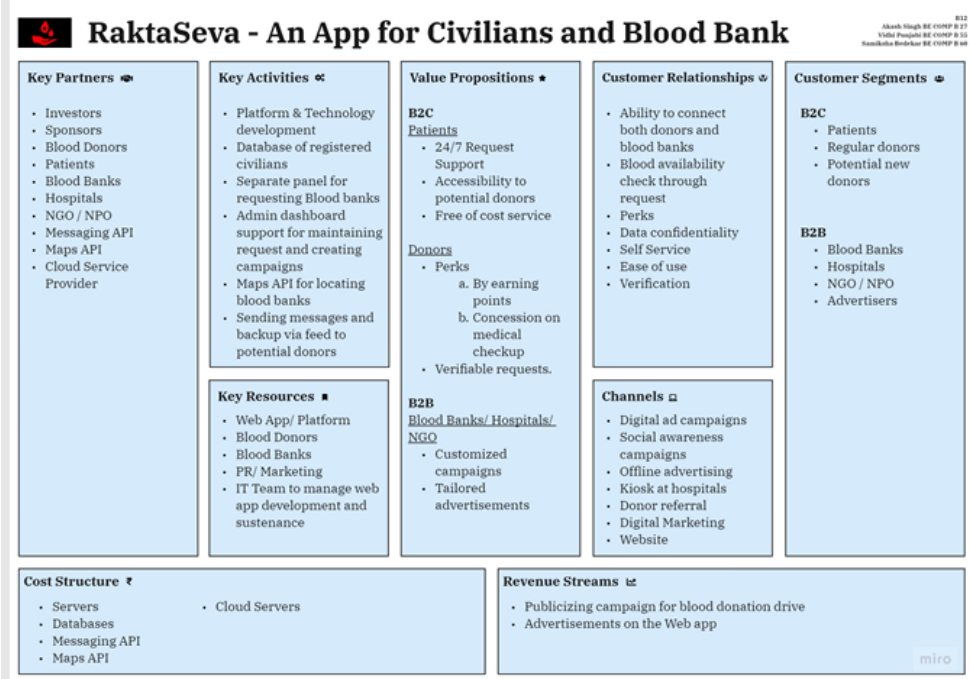

Fig 4. A sample of the Business model Canvas

2.1.1 Framework Components

RBL framework consists of the following major components:

1) Curriculum

It sets the foundation for planning RBL activities by taking inputs from subject experts. RBL syllabus drives the participants to carry out time-bound activities and gives credits to the course. RBL objectives for various activities are set in alignment with the course objectives described in the curriculum.

2) RBL activities

There is a predefined and linked set of R&D activities for RBL as per the curriculum. RBL activities are strategically organized and conducted, tailored to either online or offline modes, utilizing the institute's resource availability and aligning closely with needs and expectations. Every activity is assessed by designed rubrics common for all branches of engineering.

3) Processes

RBL activities should be designed with all potential research outcomes in mind, as the project idea may lead to unexpected results that cannot be predicted in advance.

4) Emerging Tools and Technologies

Tools and technologies are an inherent part of project development and research. Participants may be trained in emerging tools by conducting seminars and workshops like Figma for prototyping, Grammarly, Lit-maps, Ref-n-Write, etc. for research paper writing.

5) Project Development

The project development process includes initiating the project by setting objectives, feasibility assessment, planning and scheduling, resource acquisition, task execution, monitoring progress to manage changes, and closing the project by evaluating results, and documentation. This approach ensures the project is completed on time and meets quality standards.

6) Research Outcomes

Research outcomes are the ultimate entities desired by participants for the benefit of the institute, industry, and society as a whole. Research outcomes of the framework can be given as follows: 1) Knowledge base for faculty and students, 2) skills acquired by students, 3) Research Publications, 4) Startups, 5) Academia-Industry Collaborations, 6) Patents, 7) Consultancy, 8) Technology transfer, 9) Products Useful for Industry, 10) In house or Industry Products, 11) Research grant, 12) Recognition in terms of awards.

7) Feedback

Regular qualitative and quantitative feedback is taken every semester from stakeholders and planning, design, and implementation are updated in the next cycle accordingly**.**

Additionally, participants in RBL activity, mentors, and infrastructure are an inherent part of the framework.

8) Participants

Students and faculty, coming from diversified cultural backgrounds, work together as a team to conduct RBL activities. Subject experts from industries and funding organizations give inputs and provide resources for the successful completion of projects.

9) Mentors

Mentors play an important role in the conduct of RBL activities. Their expertise, regular guidance, involvement, coordination, and availability are suggested for the implementation of projects.

10) Infrastructure and Resources

It includes classrooms, laboratories, hardware, software, and other resources provided by the institute and R&D organizations which are required for creating a platform for interactions and creating an environment for research.

2.1.2 RBL Activity Processes

Every project starts with an idea and problem statement formation. At the initial stage, research outcomes cannot be figured out. When a certain level of implementation and prototype is completed, it can be aligned with a specific outcome. After the identification of expected outcomes, a different process is to be followed for every type of project. Describing the process for each research outcome is beyond the scope of this study. As an example, let us consider research paper writing activity for the outcome of research publication. A research paper consists of various sections like title, abstract, keywords, introduction, literature survey, methodology, results and discussions, conclusion, future work, and references. Guidance is provided to the students for writing a technical paper based on their project and publishing it in journals or conferences. As an example, the set of steps given to write an abstract of a research paper is shown in Table 3.

The above guidelines are given to the students for writing the abstract which is just one part of the research paper writing process for the research outcome as publication. Presentations are given by the coordinator or assigned resource person for

Table 3. Steps of Writing the Abstract of a Research Paper

Step 1	Start writing the abstract after writing of manuscript of a paper is completed.
Step 2	Select the major objectives/hypotheses and deductions from the introduction and conclusion sections of the research paper.
Step 3	Select key sentences and phrases from your methodology section.
Step 4	Identify the major results from your results section.
Step 5	Now, arrange the sentences selected in steps 2, 3, and 4 into a single paragraph in the following sequence: Introduction, Methods, Results, and Conclusions.
Step 6	Make sure that this paragraph does not contain new information that is not present in the paper, undefined abbreviations, a discussion of previous literature or reference citations, and unnecessary details about the methods used.
Step 7	Remove all extra information (refer to step 6) and then link your sentences to ensure smooth information flows, preferably in the following order: purpose; basic study design, methodology, and techniques used; major findings; summary of your interpretations, conclusions, and implications.
Step 8	Confirm that there is consistency between the information presented in the abstract and the paper.
Step 9	Ask a colleague to review the abstract and check if the purpose, methods, and conclusions of the study are clearly stated.
Step 10	Check if the final abstract meets the guidelines of the targeted journal (word limit, recommended subheadings) as every journal uses a different template for their research papers.

guidance about technical paper writing based on their own experience. Guidance is provided about writing title, abstract, introduction, methodology, results and discussions, conclusion, future work, and references. Students were given awareness of Indexing, type of journals, research methodologies, etc. Similarly, other processes are tailored for different types of research outcomes.

The framework is flexible, and scalable to accommodate different types of activities. It is an incremental model since the scope can be broadened to include different activities and adjust the number of credits for the course. The framework is an iterative model that gets maturity after upgrading knowledge in different cycles and students' batches. Expected outcomes and targets can be redefined in the next cycle. If there is a gap in the conduct of RBL for any semester, it can be filled in the next RBL. The RBL course design presently used in the institute is given in Table 4.

Table 4. RBL Course Design

Parameter	Value
Duration	4 semesters, 30 hours in each semester for instruction and evaluation
Participants	All TE (RBL1, RBL2) and BE (RBL3, RBL4) students of all branches
Credits	One credit in each semester - Total 4 credits
Evaluation	The same set of rubrics for all branches
Platform	Online and/or offline as per the need for activities or availability of resources
Mode of conduct	Individuals and Groups as per the activity requirements
Frequency of Meetings with Mentors	Weekly or more based on the needs and requirements for guidance.

2.2 Application of the Framework

The following set of steps describes how to use the RBL framework:

1. **Defining**: Define the RBL activities based on the curriculum of RBL 1, RBL 2, RBL 3, and RBL 4 in semesters V, VI, VII, and VIII respectively.
2. **Planning and scheduling**: Plan and schedule the activities based on inputs received from stakeholders (faculty and students).
3. **Training**: Conduct training programs for faculty mentors and coordinators before the commencement of a semester.
4. **Define Outcome and Targets**: Define the expected research outcomes and targets appropriate as per the discipline and institute R & D requirements.
5. **Conduct**: Focus on the project ideas and conduct the set of activities customized as per the different branches of engineering.
6. **Assessment**: Assess the research outcomes of different RBL activities every semester.
7. **Analysis**: Collate the findings of various research outcomes and compare them with the set targets.

8. **Review**: If the expectations are met, share the experience and good practices among other branches or streams and set new targets.

9. **Redefine**: Otherwise, analyze the gaps and redefine the activities for the next cycle or increase the effectiveness of activity conduction.

10. **Refinement**: Steps 1 to 9 are repeated every semester based on feedback and achieved outcomes.

A diagrammatic representation of the above steps is given in Figure 5. A few activities like the creation of a LinkedIn profile and participation in various coding competitions are evaluated individually for each student, whereas project demonstrations and presentations are assessed for teams of 2 to 4 students.

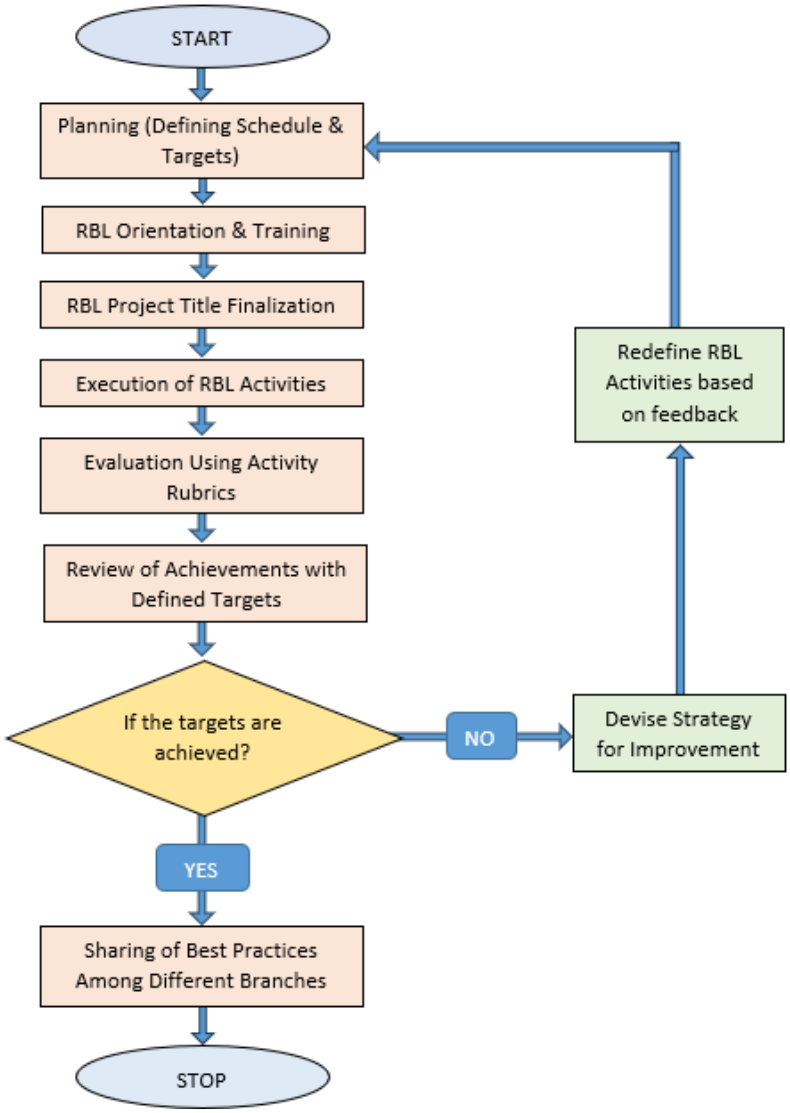

Fig 5. Flowchart for using RBL framework

2.3 Features of the Framework

The framework activities are refined based on its application and learning experience. The framework has the following features:

1. It is an iterative model that works as a guiding force for R&D activities.
2. It has the flexibility to update or enhance activities or processes to achieve desired outcomes based on time constraints.
3. The activity conduct can be customized based on online and offline modes.

4. The outcomes are assured based on the effort and sincerity of participants involved in the process and the high level of mentor guidance [2].

5. The use of the framework enhances various skills among students like, problem-solving, research analytical, creative thinking, etc.

6. It tries to balance student-centric and teacher-centric problem definitions or research problems (A ratio of 70:30 is targeted). This allows a blended mode of learning as suggested by Hall E & et al [2].

7. It is inclusive to allow the participation of all students. A student can work as a presenter, team leader or member, and learner for different types of activities.

8. It allows to work all researchers together on a single platform.

9. Continuous feedback taken from various stakeholders improves the conduct of activities.

Table 5 represents a comparative analysis of the referenced literature focusing on the methodology adopted for RBL. It explores different researchmethodologies, highlights prevalent gaps or challenges in the existing literature, and discusses features of the proposed RBL framework addressing the challenges.

The papers by Hegde S & Karunasagar I suggest a six-step pedagogy to conduct the experiment involving 44 students, 10 teachers, and 10 scientists, which was validated by collecting qualitative and quantitative feedback from students [5]. Their major dissatisfaction was related to a lack of available time, supervisor competency, technical support, and funding. The RBL framework proposed in this paper is used for 4311 engineering students by providing a slot of 2 hours per week for interaction between teachers and students. Their mentors are given training by resource persons with suitable expertise in the subject. The institute provides technical support and other resources as per the needs and project requirements through the R & D cell, and institute-level or department-level funding. The effectiveness is tested through feedback taken from students and faculty.

Rohani R & et al. discuss three models as described in Table 5 for the implementation of research-based projects as part of their academic course, social science. Their focus is increasing student engagement in research [7]. The proposed framework and its activities are mandatory for students of all branches of engineering as part of Holistic Student Development in the curriculum. The focus is measuring the research outcomes after the implementation.

Table 5. Methodology-based Comparative Analysis of Literature

Ref. No.	Methodology	Gaps and Challenges	Features of Proposed Framework
[5]	A six-step pedagogy is suggested comprised of **inspiring, ideating, action, refining, reporting, and rewarding**. Qualitative and quantitative student feedback was collected.	Students expressed dissatisfaction mainly due to limited time, supervisor competency, technical support, and funding, with input collected from 44 students, 10 teachers, and 10 scientists.	The framework is applied to more than 4300 engineering students using 10 step process described in section 2.2. 83 teachers and 605 students were involved in the Feedback.
[7]	Discusses 3 models: 1) Allow the students to select the research problem, content, or process. 2) Suggests eight 8 different approaches for continual refinement 3) Provides independence based on the level of maturity.	RBL was part of the academic course (social science). The focus is on increasing student engagement in research.	RBL was implemented as a mandatory course as a part of HSD in the curriculum. The focus is more on measuring research outcomes.
[8]	This paper describes 4 phases: 1) Diagnosis of RBL competencies of students 2) Presentation on research methodology by the teacher 3) Design of a monograph by the students and 4) Preparation of a research project by the students.	RBL is experimented with for one specific topic of data science. Student's skills are analysed and trained to make them competent for scientific paper writing.	The proposed generic framework and its application process covers the activities as mentioned in Figure 2.
[10]	The primary goal of undergraduate research is to teach students for research and to develop **necessary skills** that can be applied outside of the academic setting.	The challenges facing healthcare students' involvement in research are identified as lack of knowledge, skills, training, interest, and resources.	The mentors are trained for RBL activities. The proposed framework supports all 8 recommendations given in the paper [10].

Continued on next page

Table 5 continued

(11)	A framework for challenge-based learning (CBL) is suggested. It focuses on open-ended, real-life problems thereby leading to self-learning.	Outcomes are measured by interviewing 8 interested teachers who were experimenting with CBL. Additionally, direct outcomes are partially discussed.	Students receive mentorship through a systematic process that measures tangible outcomes and evaluates effectiveness based on feedback from both students and faculty.
(2)	Focused on mentorship models that can be used in a virtual environment involving different teachers and alumni.	Virtual mode of learning may not be effective for all branches (such as Civil and Mechanical).	The suggested framework uses blended mode of learning.
(12)	The CRAFTS framework presents an evidence-based approach to encourage learner-generated content. The application of the framework supports students' academic performance through interaction and engagement.	The CRAFTS framework is tested for a 5-year tertiary course in health science and medicine subject. This framework embeds the activities to the individual learner.	The framework is applied for engineering students focusing on research skills, and problem-solving. It provides platforms for Student-teacher interaction and improves their performance.

Noguez J. & et al. describe four phases of research project implementation for a specific topic of data science. Students are trained for scientific paper writing and their RBL competencies are measured through evaluation rubrics[8]. The proposed framework is generic and adaptable which follows a similar approach covering more sets of activities as described in Figure 2. Research paper writing is one part of it. It also uses the evaluation using rubrics as shown in Table 6.

Table 6. Rubrics for Research Paper Writing

Evaluation parameters / Marks	Excellent 20 Marks	Very Good 15 Marks	Good 10 Marks	Average 5 Marks
Identification of the problem and its analysis	Selected the latest problem most relevant to society	Selected latest problem	Selected matured problem	The selected problem is very old
Design /Algorithm Feasibility study	Algorithm/design is innovative and uses software tools for designing /drawing Feasibility studies cover all aspects Plagiarism less than 10%	The algorithm/design is copied from the reference paper Feasibility study covers the majority of aspects Plagiarism 11% to 30%	Traditional design /algorithm minimum usage of new tools for drawing A feasibility study is restricted to one parameter only Plagiarism 31% to 50%	Traditional design /algorithm. A feasibility study is absent Plagiarism more than 50%
Teamwork	Diverse talents are present in teams with different skill sets which can contribute to the holistic development of idea	The team is concentrated on only one type of skill set	Team members are not contributing much to the multifaceted development of the idea	Team members are passive only one person makes some efforts
Presentation and quality of paper	Use of multimedia tools for presentation/writing Use of professional language in writing technical articles/papers/short papers etc.	Use of multimedia tools for presentation. Use of error-free language	The paper has moderate corrections of grammar and language	Lots of errors in the writing
Quality of reference to support the idea	Sufficient Use of standard references (More than 25)	Moderate use of References (In between 15 to 24)	Less number of references (Less than 15	No standard reference

Adebisi Y A focuses on the development of necessary skills for undergraduate healthcare students that can be applied outside of academic settings. It suggests eight recommendations to involve students in research[10]. Helker K & et al. suggest a framework for Challenge Based Learning (CBL) which focuses on self-learning and development of disciplinary and trans-disciplinary skills among students. Outcomes are measured by collecting feedback from 8 teachers who were interested in the research experiment and experimenting with CBL[11]. Student's point of view is equally important as they are the ones who will be affected by experiments. The suggested framework attempts to guide the students throughout the design and development of the project and provides a platform suitable for interaction.

Hall E & et al. focus on mentorship models that can be used in a virtual environment involving different teachers and alumni. Virtual mode of learning may not be effective for all branches of engineering. The proposed framework is used for a blended mode of learning, online and offline, both modes are tried and tested. However, a higher level of mentoring by teachers and alumni will help in achieving target outcomes[2].

Moro, C. & et al. present the CRAFTS (**C**reate, **R**elevant, **A**ccessible, **F**un, **T**ailored and **S**cholarly activities) framework for health science students which is an evidence-based approach for individual learners[12]. The proposed framework focuses on building research skills in engineering students both at the individual level as well as team activities.

The comparisons drawn highlight that the proposed RBL framework not only incorporates the ideas from related literature but also provides new dimensions to research in terms of a variety of time-bound activities and scalability, adding to its novelty.

3 Results and Discussion

The framework proposed in the paper is effectively implemented at TCET from 2020-21 to 2023-24 for 4 years in 3 student batches as shown in Table 7. A procedure to use the framework is given by a flowchart as shown in Figure 5. Various activities were planned for RBL as suggested in the framework architecture shown in Figure 2. Implementation steps followed to test the framework are given below:

1. Initially RBL activities planned were prepared for offline delivery but due to the COVID-19 pandemic, they were implemented in online mode[5]. All activities can be carried out online, offline, or in a hybrid mode.

2. Project ideas from emerging trends aligned with TV2035, NEP 2020, SIH, and other national initiatives are selected by faculty and students.

3. The framework is applied initially for 6 different branches of TCET namely Computer Engineering, Information Technology, Electronics and Telecommunication Engineering, Electronics Engineering, Mechanical Engineering, and Civil Engineering. Later the usage of the framework was extended to Artificial Intelligence & Data Science, Artificial Intelligence & Machine learning, and Internet of Things branches.

4. Systematic planning and orientations were given before starting a new semester by preparing the schedule and assigning faculty responsibilities.

5. Activities are fairly assessed based on rubrics prepared to evaluate every activity. For example, research paper writing was assessed based on 5 parameters for evaluation as shown in Table 6. The parameter used for evaluation is a) Organization of Content, b) Grammar and Format, c) Design and Implementation, d) Presentation and Team Work, e) Quality of Publication.

6. Assignments are given in the form of quizzes, presentations, and reports using Google Classroom.

Table 7. Execution of RBL course for 4 years considering 3 batches of students from 2020-21 to 2023-24

Academic Year	**2020-21**		**2021-22**		**2022-23**		**2023-24**	
Semester	odd	even	odd	even	odd	even	odd	even
Student Batch 1	RBL 1	RBL 2 (TE)	RBL 3	RBL 4 (BE)				
Student Batch 2			RBL 1	RBL 2 (TE)	RBL 3	RBL 4 (BE)		
Student Batch 3					RBL 1	RBL 2 (TE)	RBL 3	RBL 4 (BE)

This framework is used to conduct RBL activities for a total of 4311 students of TCET from the academic year 2020-21 to 2023-24 as shown in Figure 6 using the process described in Figure 5. On a sample basis, one department's outcomes are analyzed as follows: In the first batch of RBL 1, for DEPT1, apart from the project ideas from faculty and students, industry problems, problem definitions of National-level project competitions like Smart India Hackathon (SIH), etc. were selected to experience a competitive environment. This strategy continued in subsequent years. The first batch participation analysis for DEPT 1 in the third year (RBL 1 and RBL2) and final year (RBL3 and RBL4) of engineering are given in Figure 7. It indicates that the total number of students ranged from 154 to 156, with projects assigned varying between 49 and 52. There is a variation in the number of students in one class since some students get a drop due to ATKT and some students of the previous batch get added to the class. Every group was given 1 mentor as a faculty. In RBL 4, a total of 20 faculty were assigned 2 to 3 projects for mentoring.

RBL outcomes for batch 2020-21 for DEPT1 were measured in terms of industry-collaborated projects, publications, consultancy, and students' participation in in-house and out-house competitions. Efforts by faculty and the application of

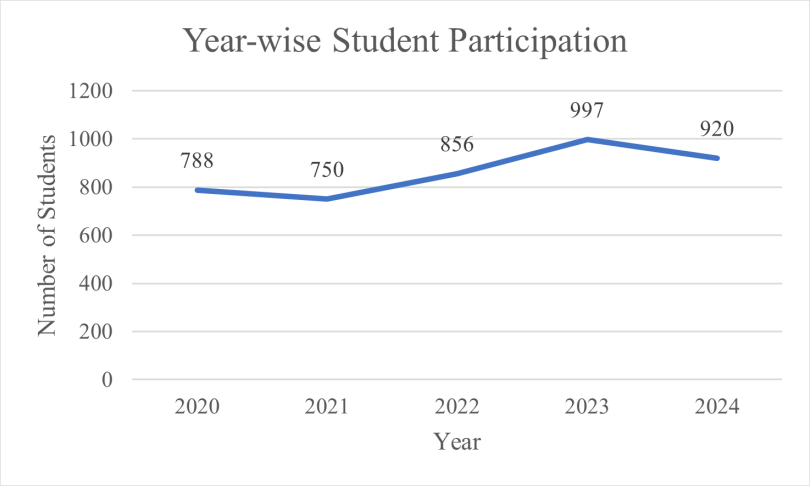

Fig 6. Student's participation in RBL activities in TCET from year 2020 to 2024

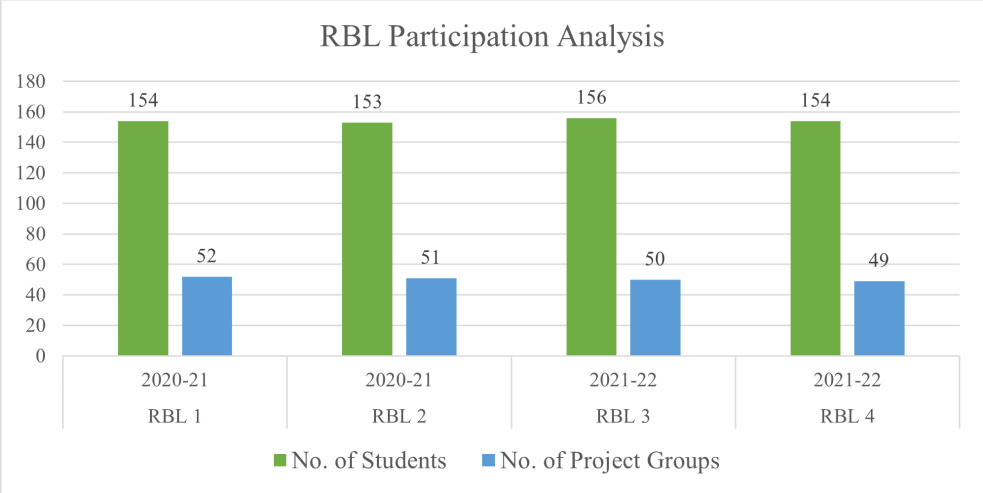

Fig 7. RBL participation Analysis for DEPT 1

acquired knowledge by students during RBL1, RBL2, and RBL3 have a cumulative effect after RBL4. Outcomes at the end of RBL 4 (year 2021-22) for 154 students doing 49 projects were as follows: There was one outhouse project, one project having received a consultancy of Rs.1 lakh from Industry. Two projects were used by the training and placement cell of the institute itself (in-house project). Three project groups were winners at the department-level project competition and three project groups were winners, at the institute level. 36 Groups have shown the outcome in terms of in-house publications. The remaining 3 project groups could not achieve satisfactory outcomes. A total of 93.87 percent (46 out of 49) have demonstrated significant outcomes for the first batch. In addition to internal participation in various competitions, more than 21 students participated individually or as a team in various outhouse project competitions, paper presentations, project exhibitions, coding challenges, and domain activities. All these outcomes were possible since they got a chance to present themselves on various platforms. Additionally, the input received from faculty, industry experts, and academicians helped them to improve the quality of their projects.

Although patent awareness seminars are conducted for each batch of students, the results have been underwhelming. In 2022, a single German patent was granted, credited to a faculty member from DEPT1 and three students. This indicates a need for more significant efforts to boost innovation and patent generation. As an outcome of industry linkage activity, some project groups worked on Industry-driven problem statements. Table 8 shows that the number of out-house projects increased from 8 in 2021-22 to 29 in 2023-24. Students worked on industry-based real-life projects.

Table 8. Out-house Projects of DEPT1

Year	Out-house projects	Total Projects	Percentage of Out-house Projects
2021-22	8	56	14.28 %
2022-23	21	70	30 %
2023-24	29	63	46 %

Analyzing the outcomes of all branches, one of the major outcomes across different departments was research paper publications in in-house conferences as shown in Figure 8. Three departments were established in the academic year 2021-22, and their first batch of BE passed out in 2024. Therefore, their previous data is not available for comparison. For DEPT 1, the number of publications increases in the academic year 2022-23 from 36 to 58 due to the addition of one more division consisting of 60 students. Change in the number of publications in the academic year 2022-23 and 2023-24 is marginal. DEPT5 and DEPT6 have a lesser number of projects in the academic year 2023-24 as compared to the academic year 2022-23. One important factor affecting this count is groups per project. Publications are group-wise and each group may have 2, 3, or 4 students groups per project. The no of publications increased from 133 to 274 from 2022 to 2024 as shown in Figure 9. Before the implementation of RBL, the publication counts were lower in the years preceding 2019 since only a few interested students published their papers.

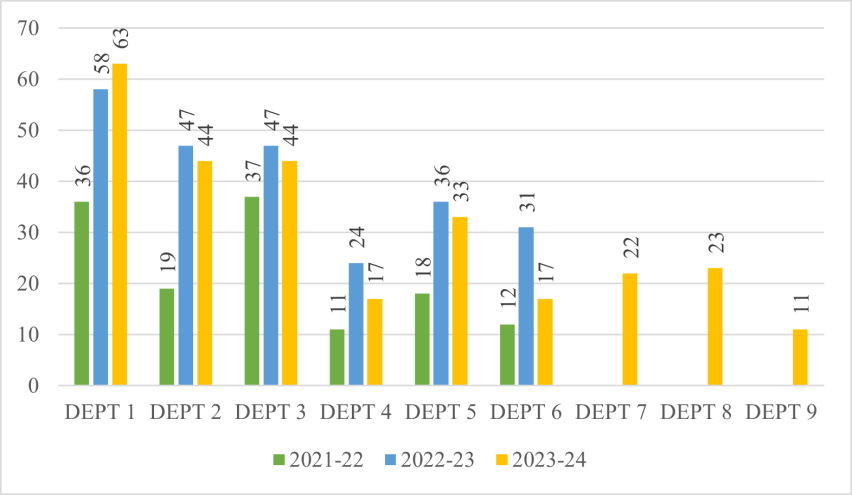

Fig 8. Department-wise Count of Publications

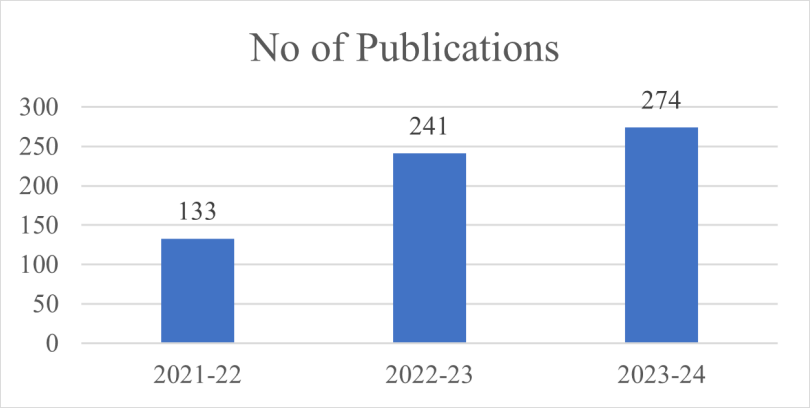

Fig 9. Total Count of Publications in TCET

Students of all branches in various teams have participated at different institute levels, state, national, and international levels. Compilation of data of all students is difficult. A few students have received appreciation in the form of prize money. Statistics of students' selection in project competitions and their prize money received are visually represented in Figure 10. The total grant received is Rupees 9.44 lakhs from 2019 to 2023. It can be observed from Table 2 that project title themes based on SIH 2022 are 29.55% which is the maximum. Although, the problem statements were different from their RBL projects. They were encouraged to participate in competitions by their mentors by giving marks as per their level of participation. The institute also supported them by providing the necessary resources.

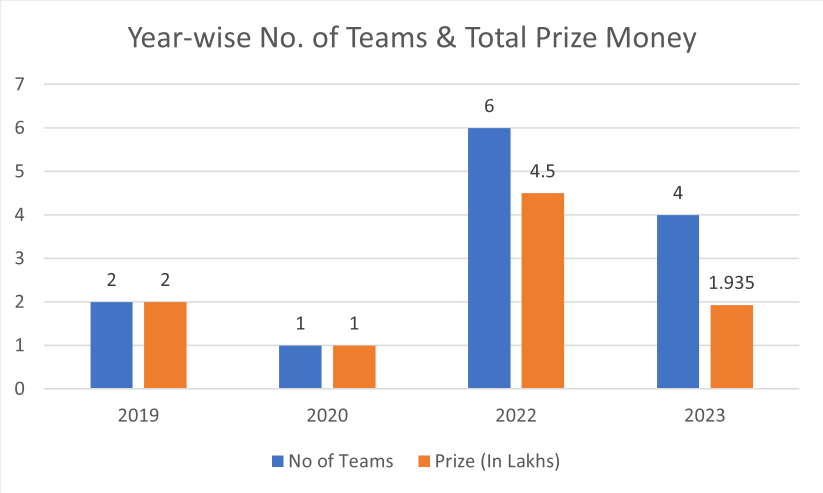

Fig 10. Year-wise Prize Money from Project Competitions at the State and National Level

One of the important components of the framework is the regular feedback from various stakeholders which plays an important role in planning the activities in the next cycle. It has been taken by conducting online surveys. Feedback is taken from stakeholders including Faculty and students. The purpose of the surveys was to assess the acceptance of the RBL framework among students and teachers. The following questionnaire is used to assess the acceptance of the RBL framework among faculty:

Q1. Do you think Research activities can be initiated at the UG level?
Q2. Do you think Research activities are to be done along with the subject teaching or as part of holistic student development?
Q3. Do you think RBL activities help engage students in research?
Q4. Do you think RBL activities are helpful for student's participation in outside competitions?
Q5. Do you think RBL activities are helpful for the students going for higher studies?
Q6. Do you think RBL activities Rubrics are appropriate and helpful for Evaluations?
Q7. Do you think RBL activities are helpful for research collaborations?
Q8. Suggest activities to improve the student-faculty Publications in good quality Journals and conferences.
Q9. What activities can be added for the improvement of RBL activities?
Q10. Any suggestions for improvement in the conduct of RBL activities?

A total of 83 faculty responded to the feedback survey consisting of 9 close-ended questions and one open-ended question. Out of these, one adjunct professor, three professors, nine associate professors, and seventy assistant professors responded for feedback. 72 faculty were RBL guides and 11 of them were not RBL guides out of 83 faculties. 23 faculty were RBL coordinators 60 were not RBL coordinators, but they were mentors. A comprehensive analysis of the respondents is as follows:

- 94% supported conducting research activities at the undergraduate level.
- 49.4% favored integrating research into subject teaching, 42.2% preferred separate holistic student development activities and 8.4% opposed both options.
- 94% supported RBL activities for student engagement in research.
- 95.2% believed RBL activities aid participation in external competitions.
- 91.6% felt RBL activities benefit students pursuing higher studies.
- 96.4% agreed that the suggested rubrics were helpful for evaluations.
- 90% thought RBL activities promote research collaborations.

In conclusion, the response from the faculty is positive as positive responses were in the range of 90% to 96.4 % with some suggestions for improvement. Faculty suggestions for improving RBL activities include 1) Organization of competitions, 2) Activities for industry interaction, and collaborations, 3) Recognition and incentives, 4) Technology Integration, 5) Sessions by industry experts, and 6) Research collaborations. Faculty also suggested improvements in terms of structured faculty guidance, improved interaction between students and faculty, interdisciplinary research projects, funding support, etc.

Meanwhile, to check the acceptance of the RBL framework among students, a survey consisting of 5 questions was conducted in which 605 students of all 9 branches participated. Their responses are given in Table 9. Results demonstrate that positive responses were 90% or above except for question 4. Question 4 was about the need for a dedicated slot for one-to-one interaction or evaluation in the academic timetable for RBL to which 73.6% of students responded positively.

Table 9. Survey questionnaire for students' feedback and their responses

Questions	Positive Responses
Q1. Do you think the activities conducted under RBL were helpful in the development of the project?	92.1%
Q2. Do you think RBL is useful to improve your Publications in Conference/ Journal	93.4%
Q3. Do you think the activities conducted will help you in the future when you join the industry?	89.6%
Q4. RBL in this semester was conducted in the first week, and evaluations were taken during the semester. Do you think there is requirement of a slot in the time table to improve the productivity?	73.6%
Q5. Do you think RBL activities are helpful in the improvement of verbal and written communication skills?	90.1%

RBL framework nurtures students' intellectual growth. Students are being assessed based on their participation levels, categorized as institute level, university level, state level, national level, and international level. A team of students of DEPT1 from the 2020-23 batch selected a problem statement in collaboration with an organization dealing with IoT (Internet Of Things) technologies. Students participated in a project competition based on their RBL project entitled "Asset Monitoring System using Battery Operated and Wi-Fi Enabled Temperature and Humidity Sensor". The student team was honored with a bronze medal at the university-level project competition-17th Aavishkar Research Convention organized by the University of Mumbai, and a gold medal and certificate at the state level. In the same year, TCET received the Trophy for the Zonal Championship and overall Championship in the Engineering and Technology category. Students' journey from the inception of an idea to the delivery of a product has made them learn a lot and improve their research skills. Students from various branches have many such achievements every year. This complements the effort made towards the planning and conduct of RBL activities.

Overall, the RBL framework and its activities have significantly enhanced undergraduate research, leading to a higher number of publications and improved student research skills. These skills include presentation and communication skills, design thinking, problem-solving, and analytical skills. This has resulted in high-quality projects that benefit students, teachers, the institute, industry, and society as a whole.

This study aimed to assess the following outcomes as per defined objectives:

- Collaborative efforts involving more than 4,300 students and their mentors can be visualized by their total publications of 648 papers as shown in Figure 9.
- RBL activities given in the framework involve teamwork and contribute to the development of higher-order thinking skills such as problem-solving skills which are difficult to achieve through academic subjects.
- Conducting seminars, workshops, internal conferences, and institute infrastructure and support contribute to a conducive environment for learning and research.
- Enhancement of the quality of projects can be visualized by getting the project outcomes as discussed in the result section in terms of industry collaborations, publications, and student participation in various competitions organized by industry and government.

Acquiring research skills is a challenge at the undergraduate level. However, this has been effectively addressed through the application of the RBL framework, enabling the attainment of specific research outcomes. Students learn not just from achieving outcomes but also from engaging in the RBL process itself. RBL at the undergraduate level helps students in their higher studies and professional lives [8].

A significant increase in the number of publications is noted over the years. Figure 9 indicates that in-house publications increased from 133 in A.Y. 2021-22 to 241 in A.Y. 2022-23, further climbing to 274 in A.Y. 2023-24. Online surveys from students resulted in 87.76% positive responses and teachers' survey resulted in positive responses in the range of 90% to 96.4%. The positive responses of Student and Teacher feedback analysis show the acceptance of the RBL Framework among them. Students'

problem-solving abilities, communication skills, and research paper writing skills have improved as a result of participation in RBL activities.

Publications can be analyzed using a model similar to the adaptive learning framework as suggested in the review paper by Martin F et al.[13]. Further student's problem-solving skills and critical thinking skills can be measured with the help of instruments and critical thinking indicators like Pretest, Posttest, Gain, and N-Gain as suggested by Rohani R et al.[7]

Active participation of undergraduate students in research is important to develop skills that influence the growth of students directly or indirectly and focus on the research process rather than research content. The student's critical thinking abilities can be increased through the 'Student as researcher' strategy[6]. RBL is considered a multi-faced learning[14]. It concludes that RBL can be implemented properly in three ways, namely RBL as a method, RBL development, and integration of RBL in learning. Hensel and Blessinger recommend developing a community of practice that will allow professors to share their experiences and best practices. Knowledge creation and innovation are the key factors instrumental in the growth of the economy as per National Education Policy Guidelines -2019[15].

4 Conclusion

This study presents a Research-based Learning (RBL) framework covering RBL activities for undergraduate engineering students in the post-COVID-19 Indian scenario. Implementation for every batch is done for 4 semesters for five years from 2020-21 to 2023-24. The framework activities are refined based on experience and feedback. Rubrics are developed for the assessment of activities to achieve research outcomes. Regular feedback taken from various stakeholders is used to refine the framework activities. Results of the application of the framework demonstrate an improvement in various outcomes such as publications. The other research outcomes for students of all branches still needs an investigation.

The major research contributions of this paper are 1) Proposal of a comprehensive RBL framework to elevate undergraduate research. 2) Present a unique methodology to apply the framework integrating student-centric and teacher-driven problem statements implementing time-bound activities for effective execution. 3) Testable application of the framework for engineering undergraduate courses of different branches of Engineering. 4) Assessment of tangible research outcomes in the form of publications, consultancy, research grants, etc., and 5) Validation of acceptance of RBL framework through stakeholder feedback responses.

The limitations of this study are as follows: 1) All data presented in the paper is based on the RBL report submitted by RBL coordinators of each department. Apart from publications, the other outcomes still require further exploration. 2) Varying project group size per project makes the comparative analysis for publications difficult across different departments. 3) The feedback for RBL is collected from participants and mentors. However, responses from alumni could also be collected to better assess the course's impact on students' employability and satisfaction.

Results shown in this study are of in-house research paper publications as a direct assessment of RBL activities. Future studies may focus on the publication of papers in national and international journals and conferences. In the future, it will be possible to measure various research outcomes and the 21st-century skills developed by students through structured assessments. One effective method for evaluating the impact of research-based learning (RBL) activities on professional careers is to engage with alumni. This interaction can provide valuable insights into how these experiences of RBL activities have influenced their career trajectories.

Additionally, analyzing the benefits of undergraduate research and the effects of funding from industries and government sources will contribute to a deeper understanding of RBL's impact. While the current framework has been applied within a private engineering college, it can be adapted for degree and management programs by customizing the associated activities. The framework's scalability and iterative design allow for tailored implementations that meet the specific needs of various educational contexts.

Acknowledgments

The authors thank Dr. B.K. Mishra, Principal, Thakur College of Engineering and Technology, Mumbai for his unwavering support and encouragement. Also thankful to all faculty and students of Thakur College of Engineering and Technology who have supported this study by participating in RBL activities.

References

1) Lavania S, Giri A. PBL an Inductive Approach: Case study in India. *In2022 OPJU International Technology Conference on Emerging Technologies for Sustainable Development (OTCON) 2023 Feb*. 2023;8:1–6. Available from: https://doi.org/10.1109/OTCON56053.2023.10113982.

2) Hall E, Bailey E, Higgins S, Ketcham C, Nepocatych S, Wittstein M. Application of the salient practices framework for undergraduate research mentoring in virtual environments. *Journal of Microbiology & Biology Education*. 2021;22(1):10–128. Available from: https://doi.org/10.1128/jmbe.v22i1.2287.
3) Gupta S, Sedamkar RR. Re imaging of Engineering Education Model to re-invent Next Gen engineers. *Journal of Engineering Education Transformations*. 2021;35(3). Available from: https://dx.doi.org/10.16920/jeet/2022/v35is3/22132.
4) Sengupta E, Blessinger P. Undergraduate research from three Asian countries. *International Perspectives on Undergraduate Research: Policy and Practice*. 2020;p. 115–129. Available from: https://doi.org/10.1007/978-3-030-53559-9_7.
5) Hegde S, Karunasagar I. Building research competence in undergraduate students. *Resonance*. 2021;26(3):415–442. Available from: https://doi.org/10.1007/s12045-021-1139-7.
6) Daryanes F, Ririen D, Fikri K, Sayuti I. Improving Students' Critical Thinking Through the Learning Strategy "Students as Researchers": Research Based Learning. *Jurnal Penelitian Pendidikan IPA*. 2023;9(5). Available from: https://doi.org/10.29303/jppipa.v9i5.2345.
7) Rohani R, Delita F, Yuniastuti E, Rosni R, Arif M, Matondang M. Enhancing Critical Thinking and Problem Solving Ability Through the Implementation of the Research-based learning Model in Higher Education. In: Proceedings of the 3rd International Conference on Innovation in Education. North Sumatera Province. 2021. Available from: http://dx.doi.org/10.4108/eai.31-8-2021.2313755.
8) Noguez J, Neri L. Research based learning: a case study for engineering students. *International Journal on Interactive Design and Manufacturing (IJIDeM)*. 2019;13(4):1283–95. Available from: https://doi.org/10.1007/s12008-019-00570-x.
9) Seifan M, Lal N, Berenjian A. Effect of undergraduate research on students' learning and engagement. *International Journal of Mechanical Engineering Education*. 2022;50(2):326–374. Available from: https://doi.org/10.1177/0306419021988962.
10) Adebisi YA. Undergraduate students' involvement in research: Values, benefits, barriers and recommendations. . *Annals of medicine and surgery*. 2022;81:104384–104384. Available from: https://doi.org/10.1016/j.amsu.2022.104384.
11) Helker K, Bruns M, Reymen IM, Vermunt JD. A framework for capturing student learning in challenge-based learning. . *Active Learning in Higher Education*. 2024. Available from: https://doi.org/10.1177/14697874241230459.
12) Moro C, Mills KA, Phelps C. The CRAFTS learning framework: equipping learners to create relevant, accessible, fun, tailored and scholarly activities in higher education. . *Interactive Learning Environments*. 2024;3:1–2. Available from: https://doi.org/10.1080/10494820.2024.2308100.
13) Martin F, Chen Y, Moore RL, Westine CD. Systematic review of adaptive learning research designs, context, strategies , and technologies from 2009 to 2018. *Educational Technology Research and Development* . 2018;68:1903–1932. Available from: https://doi.org/10.1007/s11423-020-09793-2.
14) Arifin Z, Sukristyanto A, Widodo J, Rahman MR. Implementation, outcomes, and effectiveness of Research-based learning: a systematic literature review. *International Journal of Education and Literacy Studies*. 2022;10(4):153–63. Available from: https://doi.org/10.7575/aiac.ijels.v.10n.4p.153.
15) Blessinger P, Hensel NH. Undergraduate research as a high-impact educational practice. *International perspectives on undergraduate research: Policy and practice*;2020. Available from: https://doi.org/10.1007/978-3-030-53559-9_1.