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Scaffolding Models in a Project-Based Learning Course- A Case Study

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Abstract— **The study investigates the impact of establishing the different scaffolding models toward better percolation of knowledge and skills required to build a functional prototype in a first-year engineering Project Based Learning course. To facilitate students to design and build a mechatronics system, scaffolding students at various project phases is crucial. To cater to the need, scaffolding by the teacher all the time for all the project phases for a large classroom of students was challenging. Thus, there was a need to establish multiple scaffolding models to effectively scaffold students without burdening the teacher. This motivated the authors to establish the five scaffolding models. Data was collected from students and teachers involved in the course to measure the effectiveness of scaffolding models. Student data was collected through focus group discussion, while an interview was carried out with faculty to capture the data. The results reveal that designing multiple scaffolding models helped students to get just in time help to complete the projects and resulted in better design skills. The paper's outcomes help educators design scaffolding models for the PBL course in engineering for a large classroom.**

***Keywords*— Design Problems; Engineering Design Process; First-Year Engineering; Project-Based Learning (PBL); Prototyping skills; Scaffolding.**

***JEET Category*—Research**

I. INTRODUCTION

PROJECT Based Learning (PBL) is one of the accepted pedagogies (Guerra, 2021) in the field of design education in engineering. The gold standard PBL framework (https://www.pblworks.org) describes seven project design elements and seven teaching practices to be considered to use PBL as a pedagogy in the course. The seven design elements include a challenging problem, sustained inquiry, authenticity, student voice and choice, reflection, critique and revision, and public product, while seven associated teaching practices (enablers) include designing, planning, aligning to standards, building the culture, managing the activities, scaffolding students learning, assessing student learning, engaging and coaching. Scaffolding students is one such prominent enabler in the list. Scaffolding the students becomes much more significant in the context of the course (considered for the study) since the projects in the course are design-based and interdisciplinary; further projects are done by first-year engineering students. The performance of the student and the quality of the project artifact in the PBL course depends on how well the students are scaffolded at various phases of the project.

Although PBL is a successful pedagogy, it is at the cost of the teacher's tremendous efforts, and the scaffolding becomes much more difficult in the case of large classrooms. The challenge is, furthermore, in the context of design-based courses and first-year engineering.

This motivated the authors to establish multiple scaffolding models such that the knowledge and skills required by students at various project phases are taken care of.

Through this research, the authors investigate the following: "To what extent did the established scaffolding support prove effective for students across various project stages in a first-year engineering project-based learning course?"

The paper's organization is as follows. Section II introduces the context of the course to justify the need for multiple scaffolding models. Section III introduces the related theories of scaffolding, while the further section of the paper focuses on the data collection, methodology, and qualitative analysis of the data obtained from the faculty interview and students' focus group discussion towards analyzing the effectiveness of the scaffolding models.

II. COURSE DESCRIPTION

Engineering Exploration (Baligar, 2018) is a three-credit course designed for first-year engineering students and offered by the Centre for Engineering Education Research (CEER) at a private state University. This course adopts Activity Based and Project Based Learning (PBL) pedagogy (Kaushik, 2020) (Mallibhat, 2022) with an expected deliverable of a functional prototype for the identified problem. Students work in a team toward the project deliverables.

A. Course design

The course began in 2015 in collaboration with Virginia Tech University (McDonald, 2017). It was indigenized in the upcoming years (Baligar, 2018) to cater to the needs of the stakeholders of the University.

The course started with an enduring outcome of design experience for the first-year students. The course content, delivery, and assessment were anchored to the enduring

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outcome. The course content included an introduction to engineering, project management, engineering design, mechanisms, platform-based development, sustainability, and engineering ethics modules. The content of the course was tailored to equip the students to acquire the knowledge and skills required to convert the formulated problem statement into a mechatronic functional prototype. Each module in the course has Topic Learning Outcomes (TLOs), which are further mapped to course outcomes and further with the Graduate Attributes (Program Outcomes). The course organically matured to the current version. After every semester, a course re-design workshop was organized to arrive at the action items /revisions for the upcoming semester regarding pedagogy, activities, and project need statements. The inputs to the course re-design workshop are reflections from Focus Group Discussions (FGD) with students, faculty experience, and reflections on delivering the content, activities, pedagogies, assessment, and the quality of project deliverables.

B. Course delivery

The enduring outcomes of the course demand a unique way of course delivery. The content of the course focuses on the knowledge component and skill components. The course content includes knowledge components, including facts, concepts, procedures, and skill components, including design and prototyping.

The content of the course is delivered in studios (classrooms designed for students to work in teams) where the student learns the concepts through activities, thereby applying the learned concepts and skills to their respective project in a workshop-based environment (named 'Thinkering Lab').

Every student gets engaged for six hours weekly in the studio or Thinkering lab to acquire skills or knowledge. Every class has four teachers who play multiple roles, including as an instructor for the content delivery and as a mentor to scaffold the students learning through the activities and projects. Teachers play a significant role in the context of the PBL environment. The selection of teachers and training for teachers becomes crucial, especially in design-based and interdisciplinary projects. The study related to the process of inducting a teacher into the course and training the recruited teachers to equip them to mentor first-year undergraduate students for interdisciplinary design projects resulted in another study. It was discussed in detail (Koppikar, 2023).

In addition to the classroom sessions, each teacher spends at least 30-60 minutes per project team reviewing the project progress, debugging and scaffolding students through the design process, and building prototypes following agile practices (Gadad, 2022)

C. Assessment

Each class has a strength of 60-65 students handled by four faculties. The faculty team for each class is constituted by considering the disciplinary background of the teachers. Though all four faculty are actively involved in the content delivery and project reviews, only one faculty who becomes their project mentor is involved in the assessment.

Formative (assessment for learning) and summative (assessment of learning) assessments help the instructor evaluate the students' performance. Formative assessments are spread across the semester, while summative assessment is designed to be at the end of the semester.

The objective of the formative assessment is to evaluate the understanding of concepts and application of concepts or skills to the project, while the aim of summative evaluation is to assess the ability of the student to integrate and use the learned skills and concepts to build the solution to the given problem through the functional prototype. Both formative and summative assessments use rubrics for the evaluation. The assessment parameters are set to encourage students to work towards excellence.

Assessment in the course emphasizes technical and professional competencies and aligns with the Graduate Attributes (GA) defined by the Accreditation Board for Engineering and Technology (ABET).

D. Design Process

The five steps of the Engineering design process (Dym, 2005) are adopted in the course. The steps include

Problem definition phase: Carving out a problem definition from a given need statement by gathering pertinent information and client interaction.

Conceptual design phase: Ideating the diverse concepts (system level- black box) to solve the formulated problem and selecting the best idea using concept evaluation techniques like the Pugh chart.

Preliminary design: This phase includes sub-system level design, including circuitry, flow chart, CAD models

Detailed design: Includes fabricating sub-systems, integrating the systems, and performing system level and performance testing.

Design communication: This includes compiling all project details on the GitHub repository and casting a video showcasing the phases of the project and the final functional prototype.

E. Project workflow

In the course, the project begins with team formation and the selection of the need statement. Every team consisting of four students is allotted a mentor. The project follows five steps of the design process (Dym, 2005) to translate the identified need into a solution (functional prototype).

Studio sessions, activities, and LMS videos teach each design process step. The activities are designed such that students understand and apply the design concept for the given problem as a part of the studio activity. Later, students work in a team to use the design concepts for their project.

F. Agile methodology

Students follow agile methodology while they build the prototype. The entire system being designed is decomposed as a set of sub-systems, and demonstrating the functions of each of the sub-systems will be the sprint outputs. Each sprint output is tested and integrated with the previous sprint output. Functionality testing is done at the sprint level while performance testing is done at the system level. Fig.1 shows the agile methodology adopted in the course. A detailed study was carried out to find the effectiveness of the adopted agile methodology (Gadad, 2022) in a first-year PBL course (Kaushik, 2020). It was evident that adopting the agile method helped increase students' skill sets, thereby increasing the project's success rate.

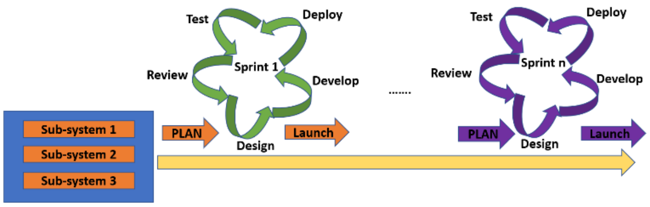

Fig. 1. Agile methodology adopted in the course

G. Design problems

Identifying a set of new problems every semester with the required amount of complexity and excitement is a challenging task for the faculty. So, the faculty team at the University developed a set of guidelines and framework (Baligar, 2022) (Baligar, 2020) that helps to craft design problems for first-year engineering students.

H. Project Exhibition

An essential element described in the gold standard PBL framework is 'public product' (Kaushik, 2020) (Mallibhat, 2021). Public product refers to providing ample opportunities for students to exhibit and show their project work. In the course engineering exploration, the element 'public product' of PBL is considered through a project exhibition (Mallibhat, 2021), and the project exhibition is titled 'Prayog.' At the end of every semester, a project exhibition is organized, where every team presents their functional prototype. The project exhibition aims to encourage peer learning and celebrate students' success. Faculty across the country, delegates from industry, entrepreneurs, parents, higher-semester students, and students from neighboring colleges participate in the exhibition.

In the backdrop of the course, scaffolding students at every phase of the project is crucial. Hence, the authors considered establishing the scaffolding models towards better percolation of knowledge and skills required to build a functional prototype in a first-year engineering Project Based Learning course.

III. Related Works

Scaffolding refers to a strategy or tool that helps students improve their skills or competencies by engaging them through authentic experiences and ill-structured problems (Belland, 2017) (MacLeod, 2020) (Koedinger & Aleven, 2007). Literature connects the scaffolding with the theories, including activity theory, Adaptive Character of Thought-Rational (ACT-R) (Anderson,1996), and knowledge integration (Linn, 2000). The literature further adds that the definition of scaffolding needs to be standardized but aims to fill the gaps in knowledge and skills so that students can complete the given task. Some of the critical characteristics of scaffolding that differentiate between scaffolding and instructional methods (Belland, 2014; Wang, 2021) include

1. Providing just-in-time help to the students to perform the given task and the support can be withdrawn upon the student/student team's ability to complete the task.
2. Scaffolding should aim at equipping the students to become independent to carry out similar tasks in the future.
3. Scaffolding should help students perform the task easily rather than not be of the type of offering the services/ outsourcing the task.

Three types of scaffolding defined in the literature are one-to-one, peer, and computer-based (Belland, 2017). On the other hand, authors (Ertmer, 2019) categorize scaffolding as hard and soft scaffolds. Hard scaffolds are in the form of helping students through some instructional materials or artifacts, while soft scaffolds are dynamic.

However, there is a gap in the literature on designing effective scaffolding models that suit a design-based course that uses PBL as a pedagogy for large classrooms. This motivated the authors to design multiple scaffolding models so students are handheld through the various project phases.

IV. Implementation

This section of the paper describes five categories and a total of thirteen scaffolding models implemented in the engineering exploration course that adopts PBL pedagogy. The five categories and their subcategories are shown in fig. 2, and

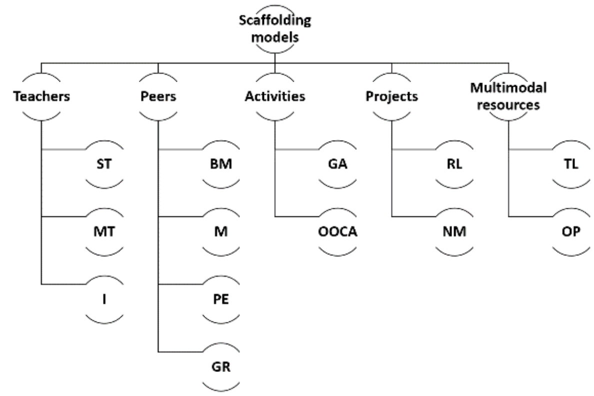

Fig. 2. Five Scaffolding models implemented in the course

ST- Scaffolding through Single Teacher
MT- Scaffolding through Multiple Teachers
I- Scaffolding through Instructors
BM- Scaffolding through Batch mates
M- Scaffolding through MITRAs
PE- Scaffolding through Project Exhibition
GR- Scaffolding through GIT Repositories
OOCA- Scaffolding through Out-of-Class Activities
GA- Scaffolding through Group Activities
RL-Scaffolding through Reinforcement Learning
NM- Scaffolding through Novel Metrics of Learning
OP- Scaffolding through Online Platform
TL- Scaffolding through Thinkering Lab

further section of the paper describes the deployment of scaffolding models in detail.

A. Scaffolding through Teachers

One primary source and the conventional way of transferring knowledge is through teachers. A PBL course demands deeper engagement between a teacher and a student. A faculty development model caters to preparing a teacher to handle the interdisciplinary project (Koppikar, 2023).
was designed and implemented.

The objective of the faculty development model was to prepare the faculty for building interdisciplinary knowledge,
interpersonal and intra-personal skills, and mentoring capabilities. Each of the faculty is allotted two divisions of classes. Every class division consists of seventy students, four teachers, one instructor, and a helper. Indeed, effective course delivery is the outcome of teamwork exhibited by teachers, instructors, and helpers. The teacher team for each class is composed by considering the disciplinary background of the teachers. Typically, the teacher team consists of one teacher from a mechanical engineering background, one from a circuitry engineering background such as electronics and communication engineering, an electrical or robotics engineering background, and one or two from a programming background.

All four teachers deliver the course through co-teaching methods where the information or skills teachers share complement each other.

The course outcomes demand multiple competencies and skills among the students, and the pedagogy adopted includes PBL and Activity Based Learning (ABL). The nature of the course and the pedagogy adopted are demanding, and students require scaffolding continuously.

1) Scaffolding through a Single Teacher

Students work in a team of four to carry out a project for which a teacher is allotted as a mentor, and that implies that every teacher has four or five student teams (16-20 students) under them as a mentee team. The role of the teacher is significant in the PBL environment, and the teacher's influence extends beyond the classroom. During the class, the mentor handholds the student to complete the activities, reflect upon the activities, and help towards debugging the circuitry or program. The teacher is responsible for instilling design skills, project management skills (time management, resource management, teamwork), documentation skills, and conflict resolution.

In addition to the class delivery time, the teacher provides weekly office hours to scaffold the students, review the project progress, and monitor fabrication processes, sub-systems, and integrated system testing.

2) Scaffolding through Multiple Teachers

The primary outcome of the course focuses on designing a functional prototype of a mechatronics system. This mandates the teachers to possess interdisciplinary skills. Though the basic interdisciplinary skills among the teachers are ensured through the faculty development model to give students access to expertise, the course is co-taught by multiple teachers. The role of multiple teachers for a PBL course is essential to cater to the students' need for 'Just in Time' help at various project phases.

3) Scaffolding through Instructors

Instructors refer to people who maintain laboratory equipment, machinery, and services. In the PBL ecosystem, instructors also played an important role.

Another essential skill to be developed among the students is translating the design into a prototype. While fabricating the prototype, the students use several tools, from a simple screwdriver to machine operating, including laser cutting machines and 3D printers. They helped students choose the materials, decide upon the dimensions of the prototype, decide on the components to build the prototypes and provide service by guiding the operations of the machines.

B. Scaffolding through Peers

Another channel through which student learns is from peers. The word 'peers' refers to their classmates and mentors in the Thinkering Lab (MITRA) (Gadad, 2021) (The term MITRA in the Indian language refers to a friend). Multiple occasions are designed to promote KD through peers, including project reviews (an opportunity is created to learn from other project teams), group activities designed at studios, out-of-class activities (activities designed to improve skills required for students towards prototyping), project exhibitions, and access to GitHub repositories of previous year students.

C. Scaffolding through Activities

To equip students to carry out the projects, upskilling the students with the appropriate knowledge and skills is essential. The course adopts activity-based learning pedagogy to upskill students with the required knowledge and skills. There are two types of activities: Out of Class Activities (OOCA) (Kavale, 2018) and Group Activities (GA) (In-class activities). The group activities intend to build teamwork, project management skills, design skills, circuit building, debugging skills, and an understanding of sustainability concepts and best ethical practices. In contrast, out-of-class activities intend to build fabrication and integration skills. The University supplied all the components and materials required to complete OOCA and GA.

D. Scaffolding through Projects

The Group Activities, OOCA, and project formative and summative assessment evaluations use novel metrics (rubrics). The rubrics are crafted in such a way that it encourages students to aim for higher grades. The rubrics help for fair evaluation and as a reinforcement learning strategy.

The reward is in the form of the best scores, and the punishment is the lower scores. However, in the formative assessment, a provision was made to improve the marks upon reiterating the work.

E. Scaffolding through Multimodal Resources

A research study was initiated to understand the learning styles of the newer generation (Kaushik, 2016), and it was observed that the skew is toward visual learners, sequential, and kinesthetic learners. Though the authors (Kirschner, 2017) argue that learning styles are a myth, the authors believe that scaffolding through multimodal resources is often beneficial to students. So, an additional scaffolding model was established, and an attempt was made to make videos on the course's conceptual, factual, and procedural contents. It was made available through Moodle-based Learning Management System (LMS). The conceptual content was distilled through an online platform, while the skills were distilled through thinkering lab activities like OOCA for kinesthetic learners.

V. Methods and Findings

The study investigated "To what extent did the established scaffolding support prove effective for students across various project stages in a first-year engineering project-based learning course?"

A. Site and Context of the Study

This research was done in the first-year engineering course "Engineering Exploration," developed by a multi-disciplinary team of faculty members.

Every year, the course gets delivered to 1300 students by 15 faculty, and 500+ functional prototypes are exhibited in the exhibition. This innovative course has been the platform for several research studies, from crafting a design problem to the final project exhibition. This paper presents a study with a focus on investigating the impact of establishing multiple scaffolding models in a PBL course.

B. Data Collection and Participants

The required data for the study was collected through three sources: the data from Focus Group Discussions (FGD) with students, semi-structured interviews with the teachers, and project artifacts (GitHub repositories and the course project videos (functional prototypes)) for artifact analysis. The data from the three sources helped the author triangulate and draw inferences. The participants considered for the study include ten faculty (three women and seven men), among which three of them were part of the design (since the inception of the course). The remaining seven of them were part of the delivery and had at least two years delivered the course. For FGD, fifteen students (six male and nine female) were chosen such that they represented their respective divisions. On the other hand, the author and team carried out the observational study approach for the project artifact analysis, and the observations were validated during the interview with the other faculty.

C. Data Analysis and Methodology

The data from FGD and semi-structured interviews were thematically analyzed (Braun, 2006) (Creswell, 2002) to unravel the significance of each scaffolding model and its influence on the quality of the projects. Table 1 presents the FGD interview snippets with their corresponding emerged codes and their connection with
scaffolding models. The standard protocol of semi-structured interview, member checking, and thematic analysis with the phases of getting familiarized with the data, generating initial codes, generating themes, refining them, and reporting them was carried out.

D. Findings

The findings are derived from the data through FGD, interviews, and artifact analysis by the authors.

1) Findings from FGD and Interview

The inferences drawn after the analysis from FGD and interviews are presented as shown in Table 1.

1. Multiple scaffolding models ensure an excellent project success rate as they supplement and complement resources at every project stage.
2. Establishing multiple scaffolding models catered to the needs of students with different learning styles as, by nature, scaffolding models were multimodal.
3. ‘RL’ model helped to make students responsible for their learning.
4. Faculty handling the PBL course should not only possess technical skills, but interpersonal skills are also necessary.
5. Every scaffolding model has significance and is vital in certain project phases. Ex: 'I' and 'TL' played a significant role during the building phases of the project while less critical during the initial phases. Scaffolding models like 'GR' and 'P' were essential during the project's conceptual design phase.
6. The scaffolding model 'GA' has a direct influence on the project. However, there can be a bias/ design fixation made among the students. This further requires investigation through another research study.

2) Findings from artifact analysis and personal observations

The first distinct observation was that all scaffolding models were not effective at all points of time. Since the course adopts PBL pedagogy and the main focus is the project deliverables, the project phases are considered as the baseline for the analysis to understand the effectiveness of scaffolding models at different phases of the project. The data for the artifact analysis was derived from GitHub repositories, project videos, assessment sheets, FGD, and Interview data. Table 2 shows the various sources of data considered for the analysis.

Fig 3. shows the significance of the various scaffolding models for different project phases. The five project phases are on the x-axis, while a score between 0 and 5 determining the usefulness of each scaffolding model is plotted on the y-axis. The rating was captured during faculty interviews, and the average was considered and plotted in Fig 3. The key observations include

1. The ST model was essential during all the project phases.
2. The role of the MT model was significant during problem definition, conceptual design, and detailed design phases, while the role of the ‘I’ model was significant during detailed design (during project building in the Thinkering lab).
3. BM and M models influenced the project's later phases.
4. GitHub repositories and Group Activities models were helpful during most project phases and scaffolded students through the projects.
5. The OOCA model was significant and influenced the conceptual design and detailed design phases of the project.

TABLE I
SNIPPETS VS. EMERGED CODES FROM FGD AND INTERVIEW DATA.

Snippet	Emerged code	Related scaffolding model
Source of data: FGD		
Other faculty helped us debug the program since our mentor was from a non-programming background.	Multiple teachers played a significant role.	MT
At one point in time, we lost hope and gave up. But our guide motivated and supported us technically and morally and built confidence.	The teacher requires not only technical skills but also interpersonal skills.	ST
In case of the unavailability of guides, the other teachers helped us a lot.	Multiple teachers played a significant role	MT
Even teachers from other divisions were quite helpful in providing Justin with time help.	Multiple teachers played a significant role	MT
A whole new idea for fabrication was given by instructors in the Thinkering lab.	Instructors played a role during fabrication.	I
Material handling was a difficult task during fabrication. Instructors in the lab helped us a lot.	Instructors played a role during fabrication.	I
Instructors taught us to use a lathe machine, a LASER cutting machine, a polishing machine, and 3D printers. We enjoyed learning them.	Instructors played a role during fabrication.	I
I did not realize at all that drilling was to be done clockwise	Instructors played a role during fabrication.	I
We learned to use a soldering gun and glue gun with the help of my other division students.	Learning skills from peers	P
Our seniors helped us a lot during coding and debugging	Learning skills from MITRAS	M
Seniors helped me come up with an altogether new concept	Learning skills from MITRAS	M
It was a proud moment to showcase our project to all the visitors	Celebrate success	PE
Source of data: Semi-structured interviews with Teachers		
I spent a lot of time resolving team conflicts, ensuring individual contributions, and motivating them.	The teacher requires not only technical skills but also interpersonal skills.	ST
The credit for the success of the project is the ecosystem built to provide just-in-time help.	Impact of ecosystem	TL, DI, M, A
Most mechanisms in the project replicated the standard mechanisms that were part of OOCA.	Impact of OOCA and GA	OOCA
Every time I get an opportunity to learn from my colleagues, this also helps me.	Multiple teachers played a significant role	MT
The newly recruited faculty for the course requires some guidance from experienced faculty.	Multiple teachers played a significant role	MT

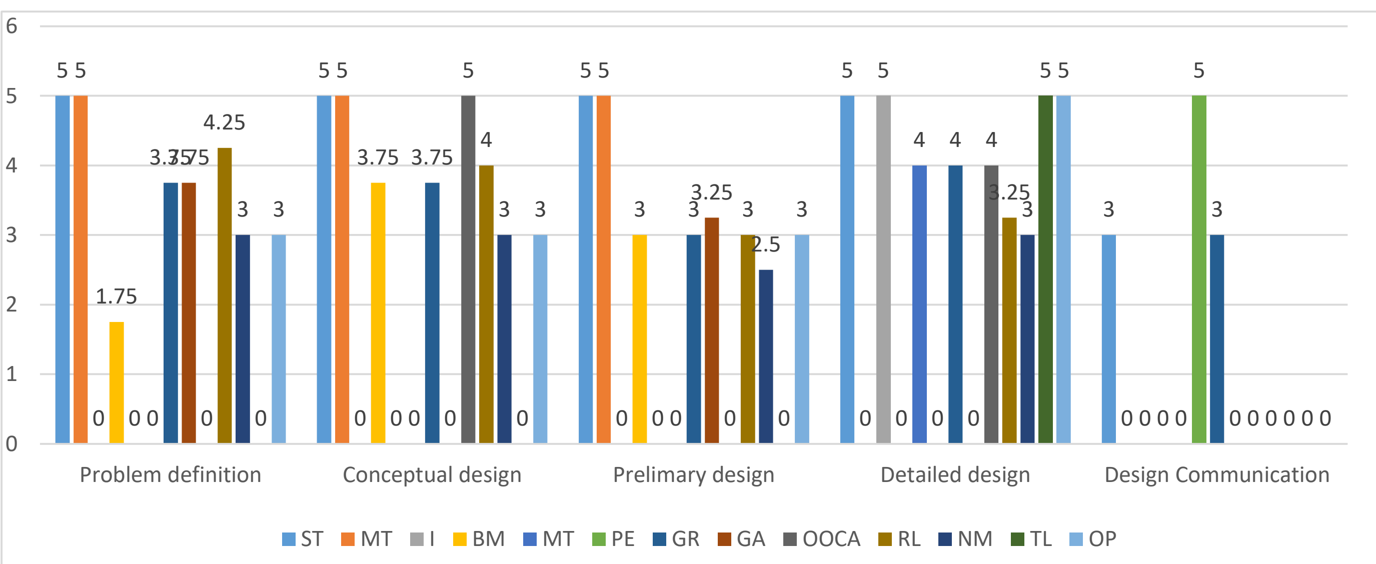

Fig. 3. Effectiveness of scaffolding models in five project phases

6. The NM model is significant and motivates the students.
7. The OP model was significant in the project's problem definition and conceptual design phases. However, the modules, including sustainability and engineering ethics, were helpful.
8. The TL model was significant only during the project's detailed design.

TABLE II
SOURCES OF DATA CONSIDERED FOR ANALYSIS

Project Phase	GitHub	Video	Assessment sheets	FGD data	Interview data
Problem Definition	✓		✓		✓
Conceptual Design	✓		✓	✓	✓
Preliminary Design	✓				
Detailed Design	✓	✓		✓	✓
Design Documentation	✓	✓			

VI. CONCLUSION

All thirteen scaffolding models were helpful for students at different phases of the project. However, the scaffolding through the Teacher model significantly impacted not only students learning (knowledge and skills) but also the quality of the projects. The authors further observed that hard and soft scaffolding methods are necessary in project-based learning, design problems, and first-year engineering courses. The paper's outcomes are intended to help educators design and deploy the described scaffolding models to effectively improve students' competencies and skills.

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