Educational Administration: Theory and Practice
2023, 29(4), 864 - 870
ISSN: 2148-2403
https://kuey.net/
Research Article

Open Ended Projects (OEPs): A Tool to Improve Experimental Skills Among Undergraduate Students of Chemical Engineering

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Citation: B. R. Sudani, (2023) Open Ended Projects (OEPs): A Tool to Improve Experimental Skills Among Undergraduate Students of Chemical Engineering, *Educational Administration: Theory and Practice*, 29(4), 864 - 870
Doi: 10.53555/kuey.v29i4.5929

ARTICLE INFO

ABSTRACT

Practical classes are a crucial component of undergraduate Chemical Engineering programs, as they offer opportunities to reinforce theoretical concepts of individual unit processes and operations taught in almost all parts of the course. An open-ended project (OEP) is a type of assignment that does not have a predetermined outcome or a fixed set of instructions. Such OEPs were used as an alternative to the traditional 'Experimental Style' or 'Do as Directed' method of laboratory teaching learning process. The overall aim was to improve the student experience in practical classes of chemistry laboratory. To facilitate this, all third semester chemical engineering students were divided into small groups of two or three. Then each group of students was assigned a unique OEP title and given ample time to complete their projects while adhering to experimental protocols. At the end of the semester, students were assessed for changes in their learning behavior in relation to the curriculum and course outcomes. The results clearly indicated that this teaching method more accurately reflected real-life problem-solving techniques. This means that students were more regularly attending classes and exhibited a more positive and engaged attitude compared to past cohorts. This increased motivation and interest in the coursework, resulting in better attendance and a more positive classroom environment.

Keywords: Open Ended Projects, OEP, Experimental chemistry skills

Introduction:

Today's students will become the inventors, innovators, and leaders of the future. Well-educated and trained engineers are essential for solving many of humanity's challenges, driving the global economy, and enhancing every aspect of our lives. They are also going to be responsible for designing, defining, and meticulously documenting nearly everything in our surrounding environment.

The aim of this study:

One of the main aims of this work was to encourage student independence and 'ownership' of project works. Supervisor gave the groups an outline of the project objective. Groups had to identify what work, literature survey or experiments they would need to do to complete the OEP task.
The overall aim for research in chemical education is to gather knowledge and understanding that can be used to improve chemistry teaching and learning process. By doing this work author wants to identify the better teaching methodology for teaching chemistry practical work to the chemical engineering students.

Open Ended Projects (OEPs):

Open Ended Projects (OEPs) are a concept often used in various fields, including engineering education, software development, research, and creative endeavors. Essentially, an OEP is a project that is intentionally left open-ended in terms of its goals, outcomes, or scope. Instead of having a predefined endpoint or a specific set of deliverables, OEPs encourage exploration, experimentation, and continuous improvement. Its pedagogy can also be can be incredibly beneficial for fostering critical thinking, creativity, and independent learning skills among students

In the past years, numbers of educators have been advocating approaches to science and engineering teaching and learning involving projects either mini or major (e.g., Joseph L. Polman, 2000). Open-ended projects promote deeper understanding and engagement by allowing students to explore topics of interest, collaborate, and apply their knowledge in real-world contexts (Barron, B., & Darling-Hammond, L., 2008). A group of researchers highlighted the benefits of problem-based learning, a method closely related to open-ended projects, showing that it enhances critical thinking, problem-solving skills, and self-directed learning (Hmelo-Silver, C. E., 2004).

One of articles showed that how open-ended projects in the form of Learning by Desig help students develop inquiry skills, deepen their understanding, and increase their motivation. (Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., & Ryan, M., 2003). Savery provides a comprehensive overview of problem-based learning, arguing that open-ended projects are effective in promoting active learning, critical thinking, and the ability to transfer knowledge to new situations (Savery, 2006).

Project-based learning approaches are touted as a means of promoting students' active engagement with science in ways that are recommended by situated (e.g., Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). As Dewey put it long ago, "... science has been taught too much as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking, an attitude of mind, after the pattern of which mental habits are to be transformed" (Dewey, 1910/1964, p. 183).

Classroom and laboratory experiences in any undergraduate engineering program should play complementary roles, working together to provide a comprehensive education. It is essential for students earning a certified degree in chemical engineering to be well-versed in both chemical concepts and laboratory practices. However, to become effective and productive engineers, students must also develop a range of skills that extend beyond the standard curriculum. The chemistry laboratory offers a distinctive environment where students can collaborate in small groups to investigate various phenomena, providing a unique mode of instruction and learning.

In this study, we present an innovative approach to chemistry laboratory education, where instructors adopt a facilitative stance, guiding students through the formulation of significant inquiries, the organization of substantial tasks, and the nurturing of both academic and interpersonal competencies. This method also involves meticulous evaluation of the students' learning outcomes. Proponents of this open-ended, project-based pedagogy argue that it equips students with the critical thinking and teamwork abilities that are essential in today's professional environment.

The Skills:

In Order to enhance their employability, students in any chemical science and engineering course or curriculum should acquire specific skills.

Here some of these skills are mentioned below in Table-1. It may not be possible to demonstrate all of these skills through a single course, but students should be able to develop them through other areas of their lives (Scott, 1994).

Table 1: Skills for better employability

Skill	Special ability due to skill
Problem-Solving Skills	The ability to design, plan and execute practical investigations, from the problems recognition stage through to the evaluation and appraisal of results and findings, selecting appropriate techniques and procedures.
Health and Safety Skills	The ability to adhere to specified health and safety procedure, especially when working within laboratory conditions.
Chemical Literature Skills	The ability to collect, record, interpret, store and retrieve of complex qualitative and quantitative data.
Communication Skills	The ability to communicate effectively both verbally, by giving presentations in writing too for instance in the production of technical reports.
Team Work Skills	Collaboration within disciplinary or multidisciplinary teams is essential for solving scientific problems in both industry and academia. Teamwork helps students appreciate the benefits of diverse expertise. Peer- and self-assessment are effective methods for evaluating student contributions to group activities.
Soft Skills	Soft skills are personal attributes that are outside one's professional qualifications and work experience. These attributes govern how one interacts, leads, and communicates with others and are essential for any successful career.
Creativity & Innovation	The ability to think creatively around a specific problem and to identify new approaches in order to achieve a specific goal, or to gain a deeper insight into an issue within the field of chemistry e.g. through the completion of a dissertation.
Technical skills	The ability to use complex equipment both safely and accurately, following technical manuals if necessary.
Ethics	Chemistry, like any field, has a social framework dictating acceptable behaviors. Progress in chemistry relies on integrity, transparency, trustworthiness, and reproducible results.

	Students must maintain high personal standards, act responsibly, and stay informed about current issues in chemistry.

Laboratory teaching is particularly valuable, as it provides first-hand experience in observing and manipulating scientific materials, which is more effective than other methods for fostering understanding and appreciation. Additionally, laboratory training is essential for developing the skills needed for advanced study or research.

Pedagogical possibilities of Open-Ended Project:

An open-ended project allows students the freedom to design their own experiments rather than simply following predetermined instructions from a lab manual. To create this open-ended environment, the teacher provides the students with a project goal or objective but not a specific procedure. Students must then develop their own experiments to support the theory or achieve the project's purpose.

For instance, the teacher might ask students to test the material properties of various household products. The students would then select the products they want to examine and design their own testing experiments. In this scenario, the teacher acts as a supportive guide, available to answer questions and assist with project concepts, while allowing students the freedom to explore their creativity. Some of the possible pedagogical benefits of this approach are given as follows.

Table 2: Benefits of OEP based pedagogy

Sr. No.	Benefit	Description
1	Fostering Creativity and Innovation	Encourages students to think creatively and develop innovative solutions without predetermined outcomes.
2	Enhancing Problem-Solving Skills	Promotes critical thinking by allowing students to tackle real-world problems and devise effective solutions.
3	Developing Research Skills	Provides opportunities for independent research, data gathering, analysis, and drawing meaningful conclusions.
4	Promoting Interdisciplinary Learning	Integrates knowledge from various fields, fostering a comprehensive understanding of the intersection between chemistry and other disciplines.
5	Improving Teamwork and Collaboration	Enhances the ability to work effectively in teams, communicate ideas, and share responsibilities.
6	Building Practical Skills	Offers hands-on experience with laboratory techniques, instrumentation, and experimental design, essential for professional competence.
7	Encouraging Lifelong Learning	Instills curiosity and a desire for continuous learning and self-improvement beyond formal education.
8	Understanding Ethical and Societal Implications	Raises awareness of the ethical, environmental, and societal impacts of chemical research and engineering practices.
9	Enhancing Communication Skills	Improves the ability to present findings clearly and persuasively through written reports, presentations, and discussions.
10	Preparing for Professional Careers	Equips students with the skills and experience necessary to succeed in professional roles within academia, industry, or research institutions.

Method:

The open-ended projects were introduced into second year Organic Chemistry and Unit Processes (2130501) of B.E. Chemical engineering of Gujarat Technological University (GTU). According to course curriculum of GTU for 2130501 minimum 5 practicals to be performed and remaining Open-ended Projects / Study Reports / Latest outcomes in technology study should be given to students. In the beginning of the academic term, faculties will have to allot their students at least one Open-ended Projects / Study Reports / Latest outcome in technology. These can be done in a group containing maximum three students in each. Faculties should cultivate problem-based project to enhance the basic mental and technical level of students. Evaluation should be done on approach of the student on his/her efforts (not on completion) to study the design module of given task.

For the present study one group only post test research design has been selected. Students of BE have been selected as sample. After the completion of the project questionnaire has been given to the students. Data gathered on the questionnaire has been analyzed. On the basis of results conclusion has been derived.

Participants (Sample for the Research): -

For the present study population was the students of B.E. Chemical. From the population student of B.E. 2nd year Semester 3 student of division one and two of Government Engineering College, Valsad have been selected as sample. Sample was selected by purposive sample selection technique.

- According to above guidelines all the students were divided in to groups of two to three students according to their previous results. We all know that heterogeneous grouping works, but sometimes homogenous grouping can be an effective way to differentiate in a project. This grouping was done intentionally so that each group can have similar brilliancy.

- After the grouping groups of students were assigned forty-eight different open ended project titles. Examples of the four titles from them are given in Table-2. All the students in this semester were asked to attempt an open-ended project at the end of some of the set experiments and they were asked to note down the experiences and leanings form the projects.
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Table-2: *Examples of open-ended project titles.*

Sr no.	Title	Topics covered
1	Prepare soap from any edible oil.	Colligative property, Saponification, TLC, extraction
2	Prepare an experimental set up for treatment of textile effluent.	Oxidation process, Effluent treatment, COD, BOD, TOC
3	Prepare any one heterocyclic compound from any ketone.	Organic Synthesis, TLC, FTIR, Reaction kinetics
4	Prepare a bio-plastic polymeric material on lab scale.	Bio-synthesis, reaction mechanism, acid base reactions

- Each of the open-ended projects was a practical problem that had to be solved using the laboratory techniques and chemistry underpinning the experiments. Normally no more than about five to six hours were required to complete the project.
- Students had to plan how they intend to solve the problem and to list the necessary apparatus and chemicals. All groups were required to devise a project plan, do a short literature review on the topic and carry out a chemical risk assessment on materials they would be using.
- Once the plan was completed it had to be shown to the faculty member who checked it for safety only before the student commenced the experimental investigation. After checking the students were asked to perform the experiments in the laboratory and demonstrate them to their peers and faculty.
- On successfully demonstration students were also recorded the observations and calculation from these they also derived the results and conclusions.

Assessment:

Students were asked to keep individual project diaries for the duration of the project, which were helped in the assessment of the project work. I looked for evidences that the students had kept records references and information they had collected from different sources, they had also kept detailed records of their work in the laboratory. Importantly I also looked for the evidences that the students used for experiences/results in the laboratory to modify or expand their experimental work. The time bound submission of the project plan was also one of the parameters to check the student involvement in the given project. On completion of the project each group was required to give a 10-minute PowerPoint presentation on their project or to explain their work with the help of poster presentation. As this was a group presentation, coherence of the presentation was evaluated. The project statement, a summary and reflection by the student of their project work, was awarded proportional grades.

Student evaluation:

At the end of the projects, students were provided with feedback forms to allow them to give their views and reflections on the project work they were assigned. This questionnaire asked students to list seven positives and seven negatives, rank what they felt were difficult aspects of the project from a given list and respond them in 'Yes/No' as Table-3.
To compare this OEP method with the common laboratory practice students were asked to grade on the scale 1–5 the extent to which they found a particular component of the project difficulty. The questionnaire given to students after completion of the project work was as Table-4.

Table-3: Positivity and negativity mapping questions

Sr. No.	Question	Answer in Yes or No
1	Was this experience joyful/good?	
2	Did you like team work?	
3	Was this OEP useful for understanding theory?	
4	Did this help increase your confidence in handling the instruments?	
5	Did your team members help you in your difficulty?	
6	Was the supervisor helpful?	
7	Do you fill that your presentation experience was good?	
8	Does it require a lot of time?	
9	Do you think that it was boring exercise?	
10	Do you think that it would be better if were given more time?	
11	Did you fill that computer knowledge would be help you better?	

12	Do you think that it was not interesting?	
13	Do you suggest that the title of the project should be of your own choice?	
14	Do you fill that selection of team members should be of your choice?	

Table-4: Difficulty level mapping questions

Select your answer for following questions from the below difficulty levels in 1-5 scale by putting tick in the box.		1	2	3	4	5
1	Difficulty level in project planning.					
2	Difficulty level in working in team.					
3	Difficulty level in experimental work demonstration.					
4	Difficulty level in literature survey/data collection.					
5	Difficulty level in presentation of work					

Results and discussions:

From the positive responses of above questions, it was found that the positive and negative aspects of the OEP in the opinion of the students are quite notable which is shown in the Figure-1. One of the most encouraging responses from students' feedback was that they (94%) found the open-ended projects 'joyful/good'. 89 % of the students liked the team work, similarly almost majority of the students found it was useful task for understanding the theory too. Helping hands from team members were also useful for students. In addition, Confidence level was also been found increased in the laboratory instruments handling.

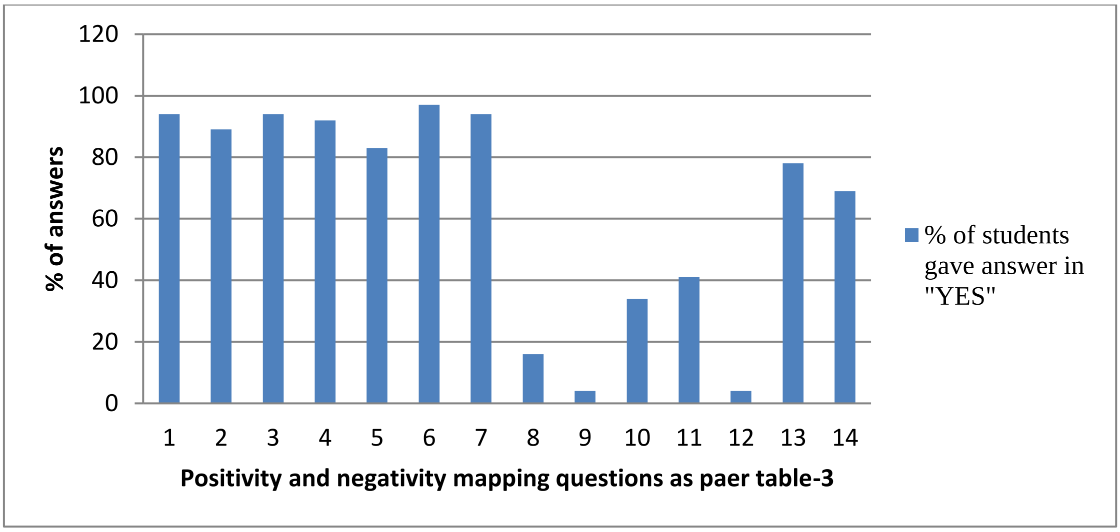

Fig.1: % of students gave answer in "YES"

Among the negatives, more students wanted to get the choice for both, in selecting group member and the topic or tilter of the OEP. According to students' team incompatibility proved to be a major issue for some students, but it reflects a common situation that must be overcome in the real-life work environment. Although from these answers we will plan to use teams of mixed ability in future projects. Only few students were thought that it was time consuming technique while majority of the students were in the favor of the OEP. One interesting answer I received was that the 41 % of the students were found difficulty in the computer literacy.

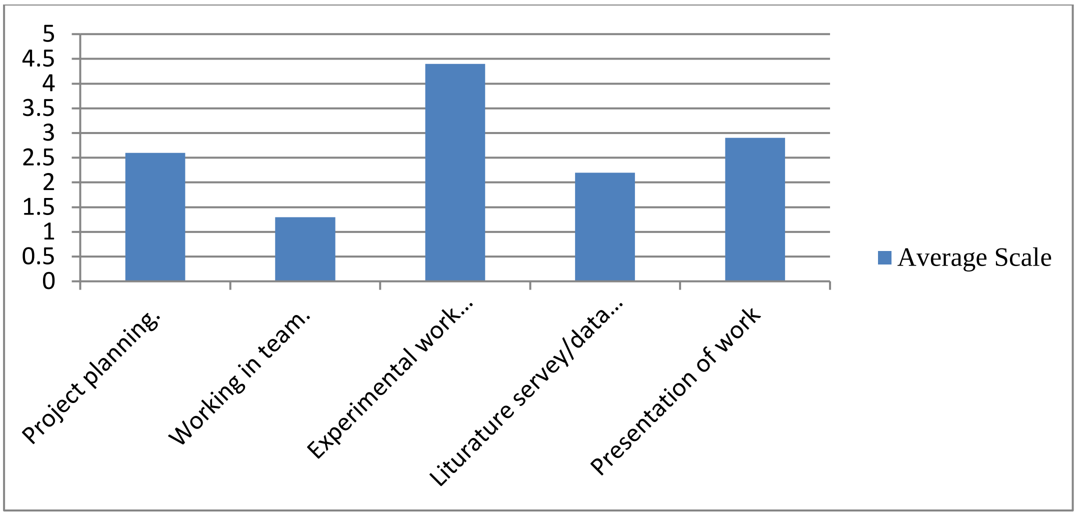

Fig.2: Average relative difficulty levels in the 1-5 rating scale

In the relative difficulties' question, (Figure 2) students were asked to give answer about a particular component of the open-ended project to which they found difficult in the scale 1–5. From the analysis of the responses, it was been clear that most of the students were found difficulty in the experimental work demonstration. And the least difficult task was to work in team.
Similar to project planning, this area has a moderate rating of difficulty levels. The moderate confidence suggests that participants are reasonably capable in gathering and analyzing literature and data, but there is potential for further development to achieve higher proficiency.

Faculty Experiences:

After assigning the titles during the lab hours the average students' presence in the laboratory hours and theory hours were found increased. The overall attentiveness of students was also dramatically increased. From the result of the external examinations, it was surprisingly observed that most of students who were having back logs in previous semester were passed in this semester with better performance.

Conclusion:

In order to improve OEP as effective teaching technique the involvement of all the students is required. The faculty should develop proper problem-solving culture in the classroom as well as in the laboratory. There may have some constraints that prevent this approach from being applied to non-chemistry students, particularly at institutions with large enrollments. OEP is the method at the chemistry laboratory, which place students in the center of learning. This method encourages students asking more questions, inquiring and researching, promoting suggestion of solution methods and enabling them to take the responsibility of their own learning through designing an experiment. This method of learning chemistry can be used to improve problem solving skills as well as scientific aptitude among the students. After using this in practically the students can participate effectively and creatively in the society and in their work environment.

Acknowledgment:

The author wishes to express his gratitude to the HOD, Chemical Engineering department and The Principal Government Engineering College, Valsad, for inspiration and guidance. All colleagues and subject teachers teaching and non-teaching staff for helping in the work as well the students of the department for their active participation.

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