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Engaging undergraduate students to analyze the results of published research articles

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***Abstract*—**Engineering institutions offer technical education by designing curriculum based on expected graduate attributes. The ability of undergraduate students (UG) to analyze complex engineering problems is one of the attributes and it is addressed by enabling students to work on certain projects or problems. The research experience during undergraduate studies can enhance the overall educational experience of students. But implementing research activities for undergraduate students can be challenging. To engage UG students, researchers have tried different strategies to enhance the research experience of students. This paper presents a case study in which, third-year students of Electrical Engineering were engaged to analyze the results of the combined economic emission dispatch problem (CEED) reported in past literature. As a part of in-semester-examination (ISE) for the course Power System Operation and Control, the students were given different research papers published in reputed international journals and associated with the CEED problem. The students were asked to identify the main equations, collect supporting data from literature and develop a computer program in MATLAB to analyze results in the research article under study. Each student presented findings on the assigned paper, the computer program developed, with explanations and conclusions. The research findings of all students were appropriately consolidated to prepare the manuscript as a review article for submission to a suitable international journal. The proposed methodology can be easily implemented in other courses by properly defining the scope of research work expected from students. The research experience of students (experimental group) was measured by conducting a test and the results were compared with other students (control group). The results show that students under experiment performed better than other students.

***Keywords*— Analysis; CEED; in-semester-examination; MATLAB; undergraduate research.**

***JEET Category*— Research**

I. INTRODUCTION

THE research activity at the undergraduate level (UG) can have a significant impact on the educational experience of students.

The required graduate attributes for undergraduate students are covered in different components of the curriculum (Lang et al., 1999; Lindsay & Morgan, 2021). These components primarily include theory courses, laboratory sessions, Tutorials, seminar presentations, internships, and a capstone project. Most engineering programs span over 4 years and the introduction of undergraduate research projects (UR) can be a very good opportunity for the students to develop research aptitude (Carpi et al., 2017). It can enhance the domain knowledge, the ability of students to think critically while solving complex problems, understanding of the process, and an ability to do research (Faber et al., 2020; Gonzalez-Espada & LaDue, 2006). This is very important because it helps prepare students for the right career and is also necessary for helping them work confidently in their professional careers (Stößlein & Kanet, 2016; Taber et al., 2011). However, engaging UG students for activities leading to research may be challenging since the courses introduced during the early stage are generally cover the basics of the engineering discipline (A.Sabatini, 1997). Previous studies have shown that the instructors have tried different strategies (Ball et al., 2020) to enhance the research experience of undergraduate students by designing suitable research assignments as a course project. Moreover, a survey of old literature reveals that the undergraduate research activities undertaken are through summer internship projects (Houser & Lemmons, 2018), course project/term projects (Amekudzi et al., 2010; Ford & Newmark, 2011; Ponce et al., 2021), or some kind of special research program organized involving undergraduate students. For example, the study reported by(Morley et al., 1998) is an evaluation of junior-level undergraduate students mentored by a graduate student during an eight-week program summer internship program. (Zydney et al., 2002) presents a survey on the impact of undergraduate research experience in engineering. It shows that students who participated in research activities could explain scientific discoveries, conduct literature reviews, and suggest that these undergraduate students were able to better clear about goals than alumni with no research experience during their undergraduate studies. The two summer programs at Western Michigan University (Abudayyeh, 2003) and the University of Alabama, Birmingham (Delatte, 2004) associated, respectively, with construction Engineering and structural engineering, as part of a research project for undergraduate students (UG), reveals that the UR can improve the ability of students to deal with complex problems. There is. A comparative study, by evaluating the impact of the National Weather Center REU Program involving undergraduates with other undergraduate students, is presented by (Gonzalez-Espada & LaDue, 2006). Most institutions offer degree programs in engineering and technology with major and minor degrees. The students studying for minor degrees learn courses offered by departments other than their department. The studies reported by (Acosta et al., 2007; Aktas, 2015; Gimenez & Thondhlana, 2012) demonstrate that by introducing undergraduate students of different backgrounds and perspectives to the research project, it is possible to provide helpful practical experience. Moreover, such interdisciplinary projects can help undergraduate students to grasp the full picture of the problem under study which can lead to better sustainable solutions. A case of honors research project taken by undergraduate Mechanical Engineering students at the University of Western Australia is reported by (Stappenbelt, 2009). This study finds that the deeper approach to enhance student learning supported by action learning can address some of the concerns of industry-relevant projects. The research work reported by (Wallen & Pandit, 2009) reveals that project-based learning that emphasizes developing research and critical inquiry skills among undergraduate students by forming a team of UG, postgraduate and post-doctoral students can help develop better research competencies. Certain mathematical courses such as Numerical Analysis, statistics, optimization, etc are included at the junior undergraduate level to lay down a strong foundation so that students can apply knowledge of such courses to other domain-related courses. The study presented by (Bishay, 2018; Hydorn, 2018) shows that the knowledge of such mathematical tools can be used by undergraduate students to analyze results in assigned specific research articles which they can compare with results in other similar research articles.

The course, Power System Operation, and Control (PSOC) are offered to third-year students of Electrical Engineering in many universities and autonomous institutes. In this course, students are introduced to the concept of economic and emission dispatch (CEED) which is essentially a multi-objective optimization problem (Wollenberg, 2017). This problem assumes that all the power plants which generate electricity to supply power to customers are thermal power plants. This assumption is not difficult to accept since most of the electricity in the world is generated by burning coal or utilizing other similar energy resources. This problem is solved to find out the best combination of power to be generated by different power plants located at different places such that electricity generation will be at minimum cost with minimum emission pollution. This problem is solved by simple mathematical methods (Ievgen et al., 2018) as well as by applying advanced optimization methods (Carrasco et al., 2020) In this topic, the research part is to solve CEED based problems by some new method to find the best compromising solution (BCS), best fuel cost (BFC) and best emission value (EC). Since the course under discussion is offered to undergraduate students of Electrical Engineering, it is expected that the students should be able to solve the CEED problem for specific standard benchmark systems in the literature using the simple Lagrange multiplier method. This paper presents a case study to demonstrate that undergraduate students can be engaged in research activity by formulating small research work as a part of their course project (in-semester-examination). The students were asked to read assigned research papers that present solutions to CEED problems, identify concerned equations, collect supporting data from other research articles (if required), develop a computer program that utilizes the results in the assigned paper, equations, and collects data to reproduce the reported results. The results primarily consist of an evaluation of the best compromising solution (BCS), best fuel cost (FC), and best emission value (EC). Finally, the students were asked to calculate errors between results reported in the assigned paper and results found by students, to draw a suitable conclusion to be included in the report, and in the final presentation. This results analysis carried out by students for all 140 research articles was consolidated appropriately to prepare a manuscript for submission to an international journal that accepts review papers. This theme of student-driven research activity was chosen since it is one of the course instructor's domains of research; however, other course instructors can identify research articles, in their areas of research, in which the results can be verified or close form of solution exists. The outcome of research efforts can be analyzed by comparing the feedback of participants in the experimental and control groups.

II. Power System Operation And Control Course

The course, Power system operation and control is commonly offered to third-year Electrical Engineering undergraduate students in almost all universities around the world. This course comprises topics like an introduction to the economics of power generation, forecasting hourly, daily, monthly, and yearly electrical power requirements of electricity customers, scheduling power generation from power plants, power plant technical constraints to generate electricity at minimum cost, and with minimum pollution, etc. The evaluation scheme consists of an in-semester-examination (ISE) of 20 marks, a mid-semester examination of 30 marks, and an end semester examination of 50 marks. The ISE component is generally designed as a course project to evaluate the analytical, programming, or reasoning skills of students.

III. Course Project

The first two topics of the course under discussion that present the theory behind electricity generation at minimum cost and with minimum emission without violating any technical constraints and yet satisfying the electricity demand of customers were considered to design the course project. This is a bi-objective optimization problem, which is commonly referred to, in research articles, as the Combined Economic Emission dispatch problem (CEED), and is handled by several methods. For undergraduate-level students, some simple methods such as Lagrange multiplier, Gradient, and Newton methods are included in the syllabus. The main idea behind this course project was to enable undergraduate students to analyze the results of CEED problems solved, by specific methods by past researchers and reported in research articles assigned, by developing suitable computer programs to check if any discrepancy in reported results and manually calculated results. All assigned research articles were from international journals affiliated to six reputed publishers namely Elsevier, Springer, IEEE, IET, Taylor & Francis, and Wiley. All research papers were collected using the Google Scholar search engine. For this purpose, the search was conducted using the advanced search option available on Google Scholar. To optimize the search process and to ensure that no research article in this field is missed, we used specific keywords and the Google Scholar search was conducted by Title option. The methodology used to engage undergraduate students, for the research activity discussed is stated below.

1. We identified 140 research articles associated with the CEED problem published from 1993 to 2021 and distributed them to all students (Experimental group).
2. Each student from the third-year Electrical Engineering class was assigned two research articles. (The total number of student participants was 70).
3. All students were asked to read assigned papers and identify methods used to solve CEED problems and benchmark test systems presented.
4. We helped students to collect supporting data required toevaluate the results in the assigned research articles.
5. After helping students to collect supporting data, all students were asked to develop a computer program using MATLAB codes to verify the results presented in the research articles assigned.
6. After evaluating assigned papers, students were asked to prepare results in tabulated form with results reported in assigned papers and results found by students.
7. Students were asked to calculate the error between results reported in assigned research papers and calculated manually based on results in articles.
8. Finally, students prepared a small scientific article with all details like Abstract, Introduction, Theoretical background, Methodology of analysis, Results, and Conclusion.
9. The final grades were awarded based on the quality of thereport (in terms of originality and grammar) and presentation.
10. The results submitted by all students have consolidated appropriately considering different case studies toprepare a review paper. The manuscript is submitted to an international journal for a review process.
11. To assess the research-related knowledge, all students (experimental group) were given a set of multiple-choicequestions. These questions were also circulated to students of the third year of Electrical Engineering in other Engineering institutes. These test questions aregiven in Table I and Table II.
12. The mean of responses received from experimental and control groups was compared using a nonparametric unpaired t-test (Brewer, 1972) to assess the impact of research activity on students learning experience.

IV. Assessment of Students Performance

To assess the confidence level about research-related knowledge and skill, both the experimental and control groups were asked to submit information on a 5-point Likert scale ranging from 1 representing Extremely Unconfident to 5 representing Extremely Confident (Mastronardi et al., 2021). To find out, in what ways did this project work affected students' way of thinking and the possibility that the student may opt for Master's or Doctoral studies in the future, another survey was conducted and details of this survey are presented in Table II. The values presented in Table I and Table II indicate the average score for a particular question. The number of samples used for the experimental group was 70 while the number of samples used for the control group was 104. After conducting an independent t-test considering 95% confidence level, we found that there is a significant impact ($p \leq 0.0042$) on research-related knowledge and skills acquired by students under the experimental group compared to the control group for different parameters given in Table I. Table II gives the analysis of the survey conducted using some open-ended questions shared with students of the experimental group as well as a control group. From this survey, we found that majority of students reported that the research activity, as part of in-

TABLE I
RESEARCH-RELATED KNOWLEDGE AND SKILL

Questions	EG[A]	CG[B]
Can you understand scientific journal articles?	4.27	3.94
Can you design research question?	3.4	3
Can you collect data for research problem?	4.29	4.01
Can analyze results of research articles?	4.57	3.97
Can you present results of research article?	4.34	3.99
Can you correlate theory and results of article?	4.44	3.91
Can you explain relevance of research topic with real world?	4.61	4.03
Can you write scientific reports?	4.65	4.08
Do you know statistical tools to analyze data/results?	4.7	3.4

[A] Experimental group, [B] Control group,

TABLE II
DECISION TO APPLY TO HIGHER STUDIES

Questions	EG[A]	CG[B]
Do you think that you can confidently work on research projects?	4.36	3.88
Do you think that one should engage in research	4.44	3.91
studies for better career	4.51	3.79
Do you think that you enjoy while working on research activity	4.03	3.1
Would you like to register for PG/PhD studies after		

[A] Experimental group, [B] Control group, semester-examination, they will opt for higher studies to work on research projects after completing undergraduate studies ($p \leq 0.0047$). Hence, we conclude that the undergraduate research activity has developed enough confidence among students and they believe that these kinds of activities need to be included at the UG level. One of the students shared his feedback which is stated below,

"Through this experience, I am very satisfied with the idea of this research activity. I am confident that I can read a research article and identify gaps. I would like to continue working in this field in the future too."

V. Discussion

One byproduct of research efforts was the classification of all research papers into different categories. Through this student-driven research activity, we were able to identify three different methodologies, used by the past researcher, to solve the CEED problem. These three methodologies are the weighted sum method (Kaddani et al., 2017), ε -Constraint method (Tabrizi & Razmi, 2013), and Pareto optimal method (Deb et al., 2000). Moreover, with the help of the collective effort of undergraduate research activity we could list down different types of benchmark test systems (IEEE Test Systems) studied by past researchers for solving CEED problems. We were also able to identify the research articles which claimed the best results, for a particular test system for some kind of methodology used, with violation of technical constraints. Furthermore, since CEED is a bi-objective optimization problem with conflicting objectives, we came to know that, the past researchers proposed the best compromising solutions, using their proposed method, but without any supporting reasons. This issue was a concern for some groups of students who came out with the idea of using a multi-criteria decision-making (MCDM) approach (Baumann et al., 2019) to identify the best compromising results among several results in research articles. So after trying different MCDM methods we could able to identify the best compromising solution for the CEED problem for all test systems referred by past researchers in literature. Such type of analysis ofCEED problems for different test scenarios is not reported in any past research articles and hence we decided to consolidate all such results into a single document to prepare a review article. Accordingly, we prepared a manuscript mentioning research motivation, research gaps, research contribution, and analysis carried out by all undergraduate students. This manuscript is under review in a refereed international journal. The sample result analysis carried out by all students involved in this research activity is presented in Appendix section Table III.

VI. Conclusion

The course, Power System Operation & Control is offered to third-year students of Electrical Engineering in most of the Universities. This course mostly includes one of the important topics i.e.an an economic emission dispatch which is found to be suitable for introducing research activity to undergraduate students through the proposed approach. In this paper, we have presented a methodology to engage students of the above class in simple research activity in which each student was given two research articles published in international journals affiliated to reputed publishers such as IEEE, IET, Elsevier, Wiley, Taylor & Francis, and Springer. We explained the concept in research papers and connect it with the course content so that they can apply the theory studied in the class to analyze the assigned research papers. The students were asked to regenerate the results given in assigned research papers by writing computer programs, thus applying the knowledge they have learned in this course. We found that all students were able to read assigned technical articles carefully to comprehend the main idea, structure, and contribution of the research article in terms of novelty and originality. Also, they were able to identify research articles other than assigned to collect data to be used to analyze the results of assigned research articles, develop computer codes to verify the results, write the Technical report of work done, and present it to instructors. This activity also contributes to addressing program outcomes. The methodology proposed to engage UG students in the research activity does not require higher-end hardware resources and laboratories or instrumentation systems compared to other methods proposed in the past research articles. The questionnaire survey results give enough evidence about the effectiveness of the proposed method as well as the importance of mentoring to help students in code writing to analyze the first research paper. The result analysis submitted by all students was compiled to write a review article and the same is under review in an international journal. We recommend that the course instructors can identify a suitable topic in the course dealing with and develop suitable research activity for students to analyze the past research papers in a particular area. Such analysis done by students, which may represent in-semester- examination, can be translated into a suitable review article.

APPENDIX

TABLE III
BCS for 6-unit test system with losses

Methods	ACS[1]	BB-MOPSO [27]
Fuel Cost Given in Paper($/h)	614.571	605.9817
Emission Given in paper (t/h)	0.2015	0.22019
Losses are given in the paper (pu)	0.0254	0.0255
Manually Calculated Losses (pu)	0.025689817	0.025623968
Difference in Losses (pu)	0.000289817	0.000123968
Fuel Cost calculated manually ($/h)	614.502483	605.9761076
Emission Calculated manually (t/h)	0.201601584	0.220190465
Fuel Cost Difference ($/h)	-0.068517	-0.0055924
Emission Difference (t/h)	0.000101584	0.000000465

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