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Role of Undergraduate Research Projects in Learning Skills of Chemical Engineering Students: A Brief Review

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The undergraduate research project (URP) is a valued co-curricular activity involving students and faculty members to improve skills through Constructivism Learning. Students benefit from the opportunity to broaden their knowledge and abilities, improve their sense of self-worth, accelerate their learning, and apply what they learn in the classroom to real-world situations. This work describes the developments of undergraduate research programs and different strategies involved in student learning skills. The roles of undergraduate research projects are discussed to achieve Sustainable Development Goals (SDG) such as hydrogen production to achieve a low-carbon economy. The students who took part in the program reported improvements in the form of increased learning experiences, technical skills, and greater resilience in the face of challenges. It was concluded that the implementation of undergraduate research projects had a positive impact on academic achievement. Participating in research projects benefits students' conceptual development.

1. Introduction

Since more than 900 years ago, when colleges were first established, lecturing has been the standard method of instruction. There are ideas that emphasize the necessity to modify this strategy so that students can advance their knowledge and skills. The new teaching/learning program, which is student-centred has a strong emphasis on active learning, which is defined as an educational strategy that involves students in the learning process. Performance in the STEM (Science, Technology, Engineering, and Mathematics) fields improves with active learning. Active learning is not a new concept; numerous formats are available such as Interactive Engagement, Student-Centered Activities, and Technology Enabled Active Learning (TEAL) (Rodríguez et al. 2018).
In view of enhancing students' learning skills, participating in undergraduate research projects (URP) is crucial. URP in engineering benefits students, faculty, and institutions (Mahecha-Botero et al. 2011). Participation in these projects increases the likelihood of students pursuing careers in different fields and provides opportunities to enhance the training and dedication of the future generation of scientists. Chemical Engineering (ChE), one of the many engineering specialties, is growing in importance in science and technology since it is closely related to the industrial sector and has the ability to alter and improve processes through new discoveries.
Currently, there is a demand for sustainable development goals (SGDs) including satisfying expanding energy demands (cleaner energy), sustainability, environment, entrepreneurship, and integration of conventional chemical processes with new technology (Voronov et al. 2017). The SDGs set by the United Nation provides strategies to tackle climate change and extreme weather conditions due to the excessive release of carbon dioxide (Tahir et al. 2021). The CO_2 concentration can be mitigated through its conversion to various valuable chemicals and fuels (Tahir et al. 2021). Besides, H_2 production as a clean and sustainable fuel has attracted consideration as an alternative approach to resolving energy and environmental issues (Baamran et al. 2021).
Here, the recent developments in undergraduate projects and strategies involved in students' learning skills are discussed. More specifically, the strategies to achieve SGDs through undergraduate research projects are disclosed. The outcomes of undergraduate research projects to produce cleaner hydrogen for a low-carbon economy are discussed. The importance of research projects and innovative approaches to get maximum benefits for both the students and mentors are disclosed.

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2. Recent Advances in Learning Theories

2.1 Different Learning Levels

The new teaching/learning paradigm, which is student-centred, appears to place a strong emphasis on active learning, which is viewed as an instructional strategy that involves students in the learning process (Rodríguez et al. 2018). Different levels of learning are depicted in Figure 1 (a) based on organizational structure and many more are included in Figure 1 (b). Oral communication skills, problem-solving abilities, critical thinking, and different group-working skills are stressed in higher education as crucial general skills that must be acquired during university courses (Ngereja et al. 2020).

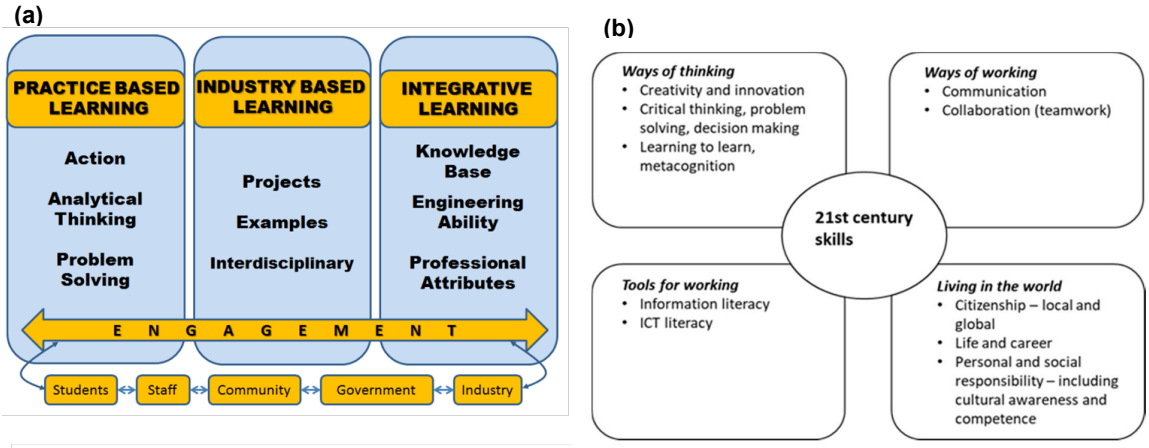

Figure 1: (a) Different level of learning; (b) 21 century learning skills (Väisänen et al. 2020).

Undergraduate research projects (URPs) have been more popular at universities all around the world in recent years(Mahecha-Botero et al. 2011). The research activities are defined by the URP as inquiries or investigations carried out by undergraduate students that contribute anything new or innovative to the field (Long et al. 2019). Participation in URP includes advantages for advisors who mentor undergraduate students and also advantages for student achievement (Lenihan et al. 2020). URPs have been acknowledged as a high impact practice in undergraduate education in order to facilitate deep learning and the requirements of high-quality education(Webber et al. 2012). However, many colleges find it difficult to combine demands for productive research and scholarly teaching with inquiry-based learning, and other factors (Wolf 2018).

Numerous studies demonstrate the value of undergraduate research projects for active learning, improving problem-solving skills, cognitive growth, determining whether to continue postgraduate study or professional professions, and making career decisions (Ahmed et al. 2021). According to a study on the advantages of research projects that was done in this light, 91 % of students benefited from their research projects (Seymour et al. 2004). Similarly, in another work, assessment on undergraduate research project was conducted at California State University and observed Underrepresented Student Success (O'Donnell et al. 2015).

It is well known that learning is the ultimate purpose of education, yet this begs the question of how to determine whether learning has actually occurred (Ngereja et al. 2020). The motivation to mentor students in undergraduate research projects is also very important to consider (Morales et al. 2017). Students, faculty advisors and the university all benefit from developing and maintaining undergraduate research programs. By combining a research component with a strong academic foundation, students can develop independent critical thinking abilities as well as oral and writing communication skills. While student and supervisor engagement in URP is expanding, there is little study on the engagements of student participation, outcomes of research projects and strategies to enhance students learning skills according to constructivism learning theory.

2.2 Constructivism Learning Theory

Constructivism is an important learning theory, which is based on the idea that students construct by themselves based on their own knowledge. It helps to improve the learning skills of the students. In essence, students know based on what they have discovered for themselves based on their prior knowledge as a foundation (Gunduz et al. 2015). The concept of learning through doing themselves has been adopted for engineering students for many years. Constructivist learning style of engineering students has been discussed in detail previously. It has been reported that most engineering students are visual, inductive, sensing and active. Most engineering education is abstract, auditory, deductive, sequential and passive. These discrepancies led to professorial frustration, poor student performance and a big loss to the society of many excellent engineers (Moons et al.

2013). Constructivism theory works on several principles such as (i) Knowledge is constructed, (ii) Student learn to learn as they learn, (iii) learning is an active process, (iv) learning is a social activity, (v) learning is contextual, (vi) knowledge is personal, (vii) Learning exists in the mind and (viii) Motivation is key to learning. Thus, undergraduate research projects can be beneficial to enhance student skills in constructivist learning.

3. Undergraduate Research Projects at UAE University

The Summer Undergraduate Research Experience (SURE) Program initiated by UAE University encourages undergraduate students to participate in research activities and enables them to develop their knowledge and learning skills through exposing them to research work. It encourages them to participate in a variety of research opportunities at the undergraduate levels while working with other students from various disciplines under the supervision of knowledgeable faculty members. Recently, a project was supported by United Arab Emirates University under Summer Research Project for the duration of nine months. The project support students in terms of monthly allowance, advisor allowance and also provides funds for materials and consumables. In this project, five female students participated on research project recycling carbon fibers reinforced polymers (CFRP) to construct CFs-based composite for photocatalytic hydrogen production. In order to lessen the negative effects of CFRP trash and to produce green hydrogen for SDGs, this research was carried out with the support and internal funding from the UAE University. According to approved proposal, a comprehensive plan was given to students with a monthly detailed outline, scope of work and the anticipated takes and deliverables. The students' progress was monitored by the supervisors on weekly basis to achieve project objectives. The students were divided into two teams and detailed program for one year was given to complete their objectives and learning outcomes. The experimental plan was divided among the students which involves both the materials synthesis and their testing for photocatalytic hydrogen production. According to research plan, one supervisor was assigned to monitor students' progress on daily and weekly basis and help them to improve their learning and problem-solving skills. The students were trained on how to use laboratory equipment's, read safety manuals, and standard operating procedure (SOP). Conducting a lab orientation is a crucial learning step for new students participating in research for the first time since it provides the students with the necessary and vital information about the lab and hazardous materials.

The students worked on synthesis of composite materials, their characterizations and photoactivity test for green hydrogen production to achieve sustainable development goals (SGDs). The initial training was given to students with information and step by step explanation about the materials synthesis and their photocatalytic applications. The training was beneficial for students because of their first-time experience to conduct research and work independently in a research lab. Additionally, all of the materials, tools, techniques, and safety standards for handling composite materials and their testing were introduced to the students. The project consists of four phases, converting CFRPs int to pure CFs, composite materials synthesis, characterization using various instruments and their testing for photocatalytic water splitting to produce hydrogen. The students were trained on processing CFRP from scrap to get pure carbon fibers through pyrolysis. The CFRPS were first cut into small pieces and was heated in a furnace at temperature of 500 °C for 2 h. The final product obtained was grinded to get CFs that was further used to prepare two different composites by two research teams.

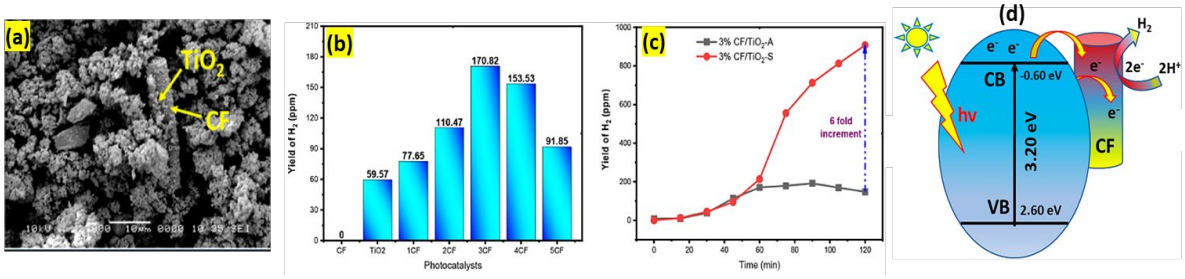

Figure 2: (a) SEM of CFs/TiO_2 composite; (b-c) Effect of CF-loading on TiO_2 for H_2 production, (d) Schematic illustration for photocatalytic hydrogen production (Tahir et al. 2023).

One team of two students work on synthesizing CFs/TiO_2 composite for photocatalytic hydrogen production and their results are presented in Fig. 2. CFs/TiO_2 composite was synthesized using physical mixing and sol-gel methods, whereas, good interface interaction of TiO_2 with CFs was obtained as shown in Fig. 2 (a). The composite was beneficial for higher visible light absorbance and efficient charges separation. The composite was further tested for photocatalytic hydrogen production and found promising to maximize hydrogen production as shown in Fig. 2 (b-c). The highest hydrogen was obtained using 3% CFs-loaded with TiO_2 due to efficient charge carrier separation (Tahir et al. 2021). It was observed that sol-gel method is more efficient, in which 6-fold higher hydrogen production was obtained under the same operating conditions. The schematic illustration

about the charge separation and hydrogen production is presented in Fig. 2 (d). The students get detailed information and knowledge about the materials synthesis with various compositions, their characterizations, activity test for hydrogen production and detailed results and discussion, enabling them to publish their work. The detailed information about the project, materials synthesis and their applications can be found in our recently published paper (Tahir et al., 2023) . In this project, students learn about the safety of the laboratory, how to handle equipment's, time managements between research and courses, self-confidence, decision making, scientific learning skills and ultimately contribute to community for low carbon economy and to achieve SDGs.

4. Strategies on Engaging Students in Research Projects

Undergraduate research has emerged as a high-impact strategy for increasing student engagement and enriching student learning experiences. Such experiences frequently impart motivation in the students who participate. URP are available at the majority of colleges and universities. Long-term URP participants frequently pick up new methodological skills, gather their own data, analyze results, and develop fresh research topics. The scalability of URP is constrained by the time and resources. (Gutierrez-Bucheli et al. 2022).

4.1 Involvement of Students in Research Activities

Students can experience varying levels of participation in higher education research as they gain more control over the research process. Five levels of student participation in research are important and they discussed as follows:

4.1.1 Students are assigned not informed

The purpose of the research and the tasks allocated to the students are explained. Students perform normal research assignments using recognized techniques at this level, which is frequently used as an introduction to laboratory-based sciences. The first level is crucial for understanding and applying a discipline's practices. While level 1 activities allow for reflection and improvement by the student, staff members continue to hold ownership of the assignment. The staff member also has influence over the dissemination of the research's scope.

4.1.2 Students are consulted and informed

Students are updated on the study and are consulted about it. As an illustration, as part of a summer scholarship program, students could participate in an ongoing staff research study. The results of this kind of advisor-directed study occasionally lead to co-authored papers, enabling students to participate in research teams. Students may be able to shape the study and contribute to its dissemination even though it is tightly guided.

4.1.3 Staff initiated; decisions shared with students

Students play a significantly larger part in decision-making when it comes to designing techniques, reframing, deciding on courses of action, and taking ownership of the results and distribution than advisor do in the initial framing of the inquiry. An example would be a module where the teacher arranges for groups of students to work on a number of consulting projects with local community contacts.

4.1.4 Student initiated and directed:

Level 4 could represent an exceptional situation. Here, decisions are all made by students without input from advisors. Unconventional students occasionally opt to complete their final project or dissertation independently. This paradigm can be more fruitful outcomes if the learner had gotten feedback throughout the process.

4.1.5 Student initiated; decisions shared with university staff

Students are responsible for starting the investigation, formulating the question, and carrying it out, but they do so in coordination with faculty members at a level set by the student. This enables the student to connect with a university mentor or supervisor and receive continuing feedback as needed. The outcomes of this effort, which is often done for individual final-year research, can change depending on the situation. While a dissertation or thesis may be required of students, the study may also be presented in other ways, such as through research papers or undergraduate research conferences.

4.2 Motivating Students to Conduct Publishable Research

Active learning is a tactics that enables students to be co-authors of their own learning process. Professors have a significant role as process mediators using this methodology. Students must be encouraged to comprehend basic concepts and relationships of a specific theory and learn to apply them to solve problems. One of the biggest challenges is to help students develop their own in-depth knowledge through undergraduate research projects rather than giving them that knowledge already. Students gained "recognition as a researcher" as a result of the event's real-world environment, their acceptance to speak at a conference, and their effective

participation. A conference has the potential to raise educational attainment and able to incorporate new ideas into their thinking (Adams 2019).

Motivating students to perform publishable research can be difficult, but the benefits to both students and the academic community can be substantial. There are several successful undergraduate projects in which students were able to publish their work in a journal. For example, undergraduate research work was conducted by Fahad et al (Sarwar et al. 2022) at University Technology Malaysia (UTM), Malaysia. The project was completed in one year and student worked on the synthesis of Ni-Ag loaded g-C_3N_4 for photocatalytic hydrogen production. The student was given clear roadmap and plan of conducting publishable research. The student was guided on a daily basis, whereas, research outcomes were discussed on a weekly basis. The student was able to get enough knowledge and experience to build CV, enabling him to secure scholarship from the reputed University of Canada. The following are some techniques for motivating students to undertake publishable research:

a) Offer opportunities for students to undertake research: Giving students the opportunity to conduct research increases their motivation to do so. This can be accomplished by including research internships, research assistantships, or research projects in the curriculum.
b) Have clear expectations for students: It is critical to establish clear expectations for students regarding the research project. This contains the study topic, methods, expected results, and timeline. Clear expectations assist students in concentrating on the topic at hand and being motivated throughout the research process.
c) Emphasize the value of research: Students must grasp the value of research and how it benefits the academic community. This can be accomplished by explaining the importance of research in class, introducing guest lecturers who are experts in their field, and highlighting prior students' research accomplishments.
d) Make incentives available: Rewards can be utilized to encourage students to perform research. Offering research funds, scholarships, or awards for great research is one example. Offering opportunity to present findings at conferences or publish in scholarly journals is another example.
e) Ultimately, inspiring students to do publishable research necessitates a combination of encouragement, direction, and rewards.

5. Recommendations

Undergraduate research experiences demand a sizeable time, financial, and student commitment. It is important to comprehend the costs and benefits of research experiences for enhancing educational outcomes, expanding employment diversity, creating human capital, and helping students. URP encourage students to participate in research activities and enables them to develop their knowledge and learning skills through expose them to research work. However, for a successful project, some recommendations are as follows:

a) With the students, a thorough research strategy, including goals and publication plans is required. At the beginning of research projects, students should know and have sufficient motivation to conduct research with high accuracy and data can be publishable.
b) Students should be supervised on a daily basis, and specific tasks should be given and feedback should be discussed on weekly basis. In this stage, students need motivation and encouragement to achieve their objectives and tasks in a specific timeline of the project.
c) Students should be encouraging to participate in research seminars and workshops and other variety of research opportunities to strengthen their knowledge and skills. The data analysis, discussion of data and paper writing strategies should be discussed with students.
d) Interdisciplinary research at the undergraduate levels to work with other students from various disciplines under the supervision of knowledgeable faculty members will be more beneficial.
e) It is important to provide financial support to both the students and advisors to comprehend the project with significant learning outcomes.

6. Conclusions

This study is unique since it is the first of its kind on research done by undergraduate students as a requirement for their education and provide directions on how to plan research to improve knowledge and publish their work. In conclusion, research can boost self-efficacy and professional goals by giving individuals with useful knowledge, skills, and competence in their field of study. Applying the constructivism learning theory is crucial to ensuring shared authority, shared knowledge, and teachers acting as mentors or facilitators between teachers and students. Research experience can boost job market competitiveness, provide access to career prospects and promotion, and provide a pleasant and gratifying experience.

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