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Circular Economy in Engineering Education: Enhancing Quality through Project-Based Learning and Assessment

Ghada A. El Gamal[*a], Ahmed M.Gomaa[b,c] and Mohamed Daowd[d]

[a]*Mechatronics Engineering Department, Faculty of Engineering and Technology, Egyptian Chinese University, Cairo, Egypt*
[b]*Construction and Building Engineering Department, Faculty of Engineering and Technology, Egyptian Chinese University, Cairo, Egypt*
[c]*Department of Civil Engineering, The Higher Institute of Engineering and Technology Fifth Settlement, Cairo, Egypt.*
[d]*Electrical Power and Machine Engineering Department, Faculty of Eengineering, Helwan University, Cairo, Egypt.*

[*]*ghada.a.elgamal@gmail.com*

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A B S T R A C T

This study was planned to investigate an approach to involve sustainability in the engineering education process. An approach based on experiments on a group of students has been performed to assess the effect of including a project-based learning (PBL) strategy in a former theoretical engineering course titled "Material Science". The study focuses on the Sustainable Development Goals (SDGs) set by the United Nations (UN): Quality Education, gender equality, reasonable consumption, and production. A survey was carried out to evaluate the process in three sorts (Pre-, Mid, and After-course assessments) for 10 working diverse groups with a capacity of two to four students each. The comparison of three survey results showed that the PBL method and Circular economy (CE) concept is successful in engineering education. The diverse composition of student groups, the range of selected products, and the systematic approaches to assessment and feedback collectively enhance the richness and inclusivity of the learning experience. These elements foster a deeper comprehension of circular economy principles among students and support the SDGs' overarching goals by encouraging collaboration, inclusivity, and responsible practices. Moving forward, efforts should focus on pinpointing critical strategies for embedding circular economic concepts into foundational educational frameworks.

1. Introduction

Project-Based Learning (PBL) is a teaching method that focuses on a process-oriented, time-bound, problem-focused, and meaningful learning experience by integrating multiple domains of knowledge, disciplines, and collaborative learning activities [1]–[6]. In its implementation, teachers take on the role of facilitators, guiding students in designing and solving problems related to the subject matter to provide them with practical experience and promote deeper learning[3], [4], [7]–[11].

During the implementation of Problem-Based Learning (PBL), instructors provide problem sheets to students in the form of activities. The students then engage in these activities to address the problems while being supervised by the instructors. After the completion of the activities, a student representative from each group presents the discussion results to the entire group and facilitates a question-and-answer session among the students. The ensuing class discussion is led by the instructor [9], [12]–[15]. Buckles (2018) characterized traditional education as being rooted in the New Social Imaginary, which is similar to a new worldview [16]. This education approach has perpetuated the notion that the inherent world is quantifiable, manageable, expected, and susceptible to human strategy, which, in turn, has contributed to wicked problems. Therefore, a distinct education approach is required to address these issues [17]–[23].

Jones & Akura, proposition posits that the current world is becoming more intricate and interdependent, with the pressing threat of climate change being a tangible existential concern [24]. As a result, there is an escalating need for education that surpasses the conventional acquisition of knowledge and skills for employment purposes. Education has emerged as a pivotal instrument for advancing sustainable development. It's clear that traditional teaching and learning methods need to change to help individuals develop the skills and mindset required to become agents of change and promote sustainable development initiatives [24], [25]. Education for Sustainable Development (ESD) holds significant potential for tackling complex and persistent challenges by leveraging its specialized pedagogical strategies and the development of key competencies [26], [27]. These components encompass, among others, systems thinking, problem-solving abilities, and experiential, real-world learning. By incorporating these critical elements, (ESD) can effectively tackle complex, "wicked" problems and promote sustainable development [26], [27].

ESD is recognized as a broader framework than environmental education because it includes socio-political and socio-cultural aspects, such as poverty, equity, alleviation, democracy, and quality of life. [28]. This broader perspective allows ESD to offer a comprehensive and holistic approach to sustainable development, addressing social and political dimensions alongside environmental concerns. It recognizes sustainable development as a multifaceted and multidimensional concept requiring an integrated approach to address its interconnected components. The discourse on sustainability began to take shape in the 1980s and 1990s, driven by key global initiatives and publications like the World Commission on Environment and Development, the World Conservation Strategy, and the United Nations Conference on Environment and Development (UNCED).[19], [29]. During this period, the pivotal role of education in fostering sustainability became more widely recognized and emphasized. This shift highlighted the necessity for strategies to cultivate awareness, perspectives, values and skills, empowering individuals to pursue sustainable livelihoods, actively participate in democratic societies, and embrace sustainable lifestyles. [19], [30]. ESD is a pedagogical framework designed to equip learners with the skills, knowledge, and values necessary to make informed decisions and take responsible actions. Its focus is on promoting environmental sustainability, social equity, and economic resilience for both current and future generations. Cultural diversity is emphasized and recognized as a crucial element of quality, lifelong education. [14], [26]–[28]. ESD adopts a holistic and transformative approach by integrating curriculum content, pedagogy, and the learning environment. This framework underscores the importance of shifting societal values, attitudes, and behaviors, recognizing education as a catalyst for such transformation. By fostering a comprehensive understanding of the interconnections among environmental, social, and economic dimensions, ESD seeks to empower individuals to engage in meaningful actions that advance sustainable development. [7], [11].

The SDGs, established by the United Nations General Assembly in 2015, encompass 17 goals and 169 targets aimed at addressing critical global challenges such as climate change, poverty, environmental degradation, and inequality. Central to the United Nations' 2030 Agenda for Sustainable Development, these goals form a comprehensive action plan to foster global peace and prosperity while safeguarding the planet. Although the development of the SDGs was a collective effort of the United Nations, UNESCO, as a specialized UN agency, supports their achievement. [4], [11], [31]–[33]. Hume and Barry believe that ESD should be interdisciplinary, holistic and action-oriented, integrating both cognitive and affective dimensions while also involving political and ethical analysis. [1]. ESD has gained considerable momentum through initiatives such as the Decade of ESD, The Global Action Programme (GAP) on ESD and the Sustainable Development Goals, especially SDG 4 and Target 4.7, highlight the growing importance of ESD in addressing complex, 'wicked' problems. As these challenges become more prevalent, the role of ESD in tackling them across all levels of education has become increasingly evident. [8], [19], [27], [30], [34].

Within this framework, this paper examines Project-Based Learning (PBL) and its potential to support Education for Sustainable Development (ESD) by cultivating the competencies necessary to address complex, "wicked" problems. It presents two seemingly distinct case studies: one from Jamaica, focusing on graduate-level teacher training, and another from Bulgaria, highlighting student learning facilitated through an online platform.
Heliopolis University (HU) is actively promoting the integration of the UN SDGs into its educational programs. One approach involves transforming traditional classroom teaching methods into a primarily PBL methodology. However, this paper focuses on PBL in competencies to support topics such as circular engineering, zero waste management, and green energy through a range of small-scale projects suitable for student engagement in finding solutions to engineering challenges within a sustainability framework.

2. Theoretical Background

2.1. ESD competencies

The UN Economic Commission for Europe (UNECE) has developed a framework to incorporate sustainability education into learning systems. This initiative aims to empower individuals to actively contribute to the creation of sustainable societies. This initiative is designed to promote Education for Sustainable Development (ESD) across member states, with a primary objective of strengthening the education sector's capacity to implement ESD. In alignment with this goal, significant progress has been made in identifying and categorizing sustainability competencies [35]. The term 'competencies' is interpreted differently across various sectors and contexts. According to Lambrechts et al., competencies are often equated with the knowledge, skills, and attitudes related to ESD. [36]. In contrast, Leicht et al. define competencies as the ability or disposition to address complex challenges. [37]. Similarly, Wiek et al. describe competencies as an integrated set of knowledge, skills, and attitudes that are functionally interlinked, enabling individuals to perform tasks effectively and solve problems successfully. [19].

Various definitions of competencies emphasize essential components for addressing sustainability challenges. Multiple frameworks have been developed to identify these critical elements, such as the Curriculum, Sustainable Development, Competences, Teacher Training (CSCT) framework, which outlines five competence domains, and the UNECE framework for teacher education, which organizes competencies into four clusters. [35]. Building on the work of various scholars, Wiek et al. proposed a framework consisting of six core competencies, supplemented by specific learning outcomes to facilitate their application across educational levels. This operationalization addresses a gap identified in existing literature. While different models exhibit variation, they share several common features. [19].

Rieckmann et al. synthesized these frameworks, incorporating the six competencies defined by Wiek et al.—systems thinking, anticipatory thinking (futures thinking), normative thinking (values-based reasoning), strategic thinking (action-oriented problem-solving), collaboration (interpersonal skills), and integrated problem-solving. They also included additional competencies such as critical thinking, self-awareness, and communication skills, which they considered essential for advancing sustainable development. [27]. Additionally, ESD competencies are defined by futures thinking, interdisciplinary approaches, and personal engagement, which includes reflection, empathy, self-motivation, and inspiring others. They also place a strong emphasis on values and ethical considerations. [38]. Collectively, these competencies provide a robust foundation for addressing sustainability challenges.

2.2. PBL in Engineering Education

PBL in the context of ESD focuses on engaging learners with the intricate content associated with "wicked problems," defined by their inherent complexity. A critical aspect of ESD is understanding how the necessary competencies can be developed to address such real-world challenges effectively. Lambrechts et al. [38] identified three categories of teaching and learning approaches suitable for ESD: research-oriented methods (e.g., problem analysis and values clarification), interactive and participatory methods (e.g., group discussions and peer assessments), and action-oriented methods (e.g., addressing real-world community issues). The action-oriented approach, in particular, aligns well with Problem-Based Learning (PBL). [36], [39], [40].

The Buck Institute of Education defines Project-Based Learning (PBL) as “a pedagogical approach that engages students in acquiring knowledge and skills through an extended inquiry process focused on complex, real-life questions” [41]. This methodology also includes the development of carefully crafted products and tasks. Bell et al. highlight PBL as a vital strategy for promoting independent thinking and learning, as it involves students tackling real-world problems by designing their inquiries, using diverse strategies and organizing research, [42]. These definitions suggest that students are at the heart of PBL, actively managing their own learning and forging connections with their communities [41], [43]. A specific model of Project-Based Learning (PBL) outlines essential components, including a central, open-ended, and complex question; student autonomy in selecting topics and resources for inquiry; opportunities to develop 21st-century skills such as collaboration, communication, creativity, critical thinking, and technological proficiency; and a final presentation of findings to a public audience, including community members, peers, and parents. [44].

The benefits of PBL include improved understanding of specific subjects, heightened motivation, the cultivation of independent thinking, responsibility, collaboration, communication, and problem-solving skills [42], [45], [46]. However, challenges in implementing PBL must be acknowledged, such as limited resources and administrative support, the time required to transition to a facilitative teaching approach, and the necessity to balance curriculum demands within exam-focused educational systems [25], [42], [46], [47].

The characteristics of PBL closely match the competencies of Education for Sustainable Development (ESD). These include strategic skills for planning and action, collaborative skills for problem-solving and peer learning, critical thinking for questioning norms, and integrated problem-solving for tackling complex issues. Both PBL and ESD competencies are based on social constructivism, where learners build knowledge through hands-on experiences, reflection, and peer interaction. [48].

Furthermore, both PBL and the cultivation of sustainability competencies align with experiential learning theory, which emphasizes the application of various skills to real-world situations [7]. This theory, influenced by scholars such as John Dewey and Jean Piaget, posits that learning occurs through active engagement and participation, with immersion in relevant issues and subsequent reflection fostering the acquisition of new skills and actions. Additional research is necessary to investigate pedagogical methods that support the development of ESD competencies [26]. This paper aims to address the existing research gap by proposing the integration of three primary components: ESD, Circular Product concepts, and responsible consumption within engineering education. PBL will serve as the framework for this integration, which will be examined in the contexts of a higher education institution and an online platform.

3. Methodology

This study investigates the effectiveness of Project-Based Learning (PBL) in promoting education for sustainable development. Given the urgent need for sustainable practices and the integration of environmental, social, and economic considerations into education, PBL has significant potential to engage students in real-world problem-solving and empower them as active participants in sustainability efforts. This section details the research design, data collection methods, and analytical approaches used to evaluate the outcomes and impacts of PBL initiatives in the context of sustainable education. By employing a rigorous methodology, this study aims to contribute to the growing body of knowledge on effective educational strategies that promote sustainable development and empower students to become environmentally conscious and socially responsible citizens.

3.1. Gathering Data

In order to assess the effectiveness of the Problem-Based Learning (PBL) method and its integration with the principles of circular economy in engineering education, a research study was conducted. The study focused on exploring the environmental dimension of this educational initiative within the context of ESD. The research was carried out with a sample of seventh-semester students enrolled in the Faculty of Engineering at HU in Cairo, Egypt. The participants were specifically enrolled in the material science course, which is a mandatory requirement for all students in the faculty.

To begin the study, the students were introduced to the topic of circular economy and the PBL approach. They were then assigned a task that involved analysing the life cycle of a specific product and devising potential solutions to enhance its circularity across different phases of its life cycle.

3.2. Analytical Assessment approaches

Prior to conducting the analysis, rigorous measures were taken to ensure the quality and reliability of the data collected. The questionnaire surveys administered underwent a thorough vetting process to identify and rectify any errors or inconsistencies. Follow-up procedures were implemented to address questionnaires that exhibited such issues. Furthermore, meticulous screening of the data was conducted to detect any missing variables, outliers, and multicollinearity. This meticulous screening process aimed to ensure that the factors derived from the data were suitable for the subsequent statistical procedures. The assessment of the Problem-Based Learning (PBL) teaching method was carried out using several techniques, as outlined below.

3.2.1 Questionnaire at the Beginning of the Semester

During the first week of the semester, students were required to complete a questionnaire. This questionnaire aimed to gather their opinions and background knowledge regarding circular economy principles. Additionally, students were asked about their perspectives on teamwork, course topics, and their expectations for the project.

3.2.2 Formation of Multidisciplinary Groups and Product Selection

Following an introductory session on circular economy concepts and circular product design, students were tasked with forming multidisciplinary groups consisting of four to five members. Each group was then required to select a product to study during the course.

3.2.3 Mid-Semester Progress Evaluation

At the 7th week of the semester, the progress of each group was assessed through a pre-designed follow-up report. This evaluation allowed for constructive feedback to be provided to the groups before the final project submission.

3.2.4 Final Project Submission, Presentation, and Prototypes:

The final project submissions, presentations, and prototypes were conducted amidst the challenges of the COVID-19 pandemic. As a result, submissions took place online, with two physical submissions, while prototypes were showcased in video format.

3.2.5 Grading Based on a Rubric

To ensure fair and consistent assessment, a Rubric form was employed to grade both individual contributions and group performances in the final project submissions.

3.2.6 Exit Survey

To gain insight into the students' experiences and reflections on the PBL method and the project as a whole, an exit survey was administered. This self-evaluation survey allowed students to express their thoughts and perspectives on the learning approach and the outcomes of the project. These assessment techniques provided a comprehensive evaluation of the effectiveness of the PBL teaching method and its integration with circular economy principles in engineering education. The data collected through these methods facilitated an informed understanding of the students' learning experiences and the impact of the project on their understanding of circular economy concepts and collaborative work in a multidisciplinary setting.

4. Results and Discussion/Analysis

This section presents the findings of the study and provides a comprehensive analysis and discussion of the collected data. This section aims to interpret and evaluate the results in relation to the research objectives, hypotheses, or research questions. It explores the significance, patterns, and relationships revealed by the data, providing insights, interpretations, and contextualization of the findings. Through critical analysis and synthesis, the section offers a deeper understanding of the study's outcomes and their implications for the field of research.

4.1. Course Information

The course under study is "***Material Science***" (3 credit hours) with the following contents:

- Bonding in materials: the crystal structure of metals and ceramics, mechanical properties of metals and alloys, introduction to defects in materials.

- Introduction to microstructural evolution: basic principles of phase diagrams and phase transformations, the effect of microstructure on the mechanical properties of metals and alloys.

- Mechanical properties: testing methods, strengthening mechanisms, and fracture mechanics.

The course teaching and learning methods recommended hybrid learning in course specifications in many different strategies like lectures, presentations, discussions, tutorials, problem-solving, self-learning, E-learning, cooperative education, and consultations with the instructor. The course is modified to include projects during the proposed research study.

4.2. Questionnaires analysis

4.2.1. Pre-course evaluation Questionnaire:

A pre-course evaluation format is used to break the ice and know the level of information about the circular products and the course in general and results showed that the 59 participants are multidisciplinary as they contain 44.1% mechatronics engineering students, 35.6% civil engineering students, 13.6% architecture engineering students, and 6.8% energy engineering students. 50.8% are from level 3 (Junior), 30.5% from level 5 (Senior-2), 15.3% from level 4 (Senior-1), and 3.4% from level 2 (Sophomore).

4.2.2. End of the course Questionnaire:

The objectives of this course encompass gaining knowledge about material properties, acquiring in-depth understanding of material classification and selection, utilizing materials for the manufacturing of new products, exploring the life cycle of various materials in the production real life time and their practical applications, harnessing the benefits of recycling to preserve the environment, comprehending material structure and composition, and employing these materials effectively in real-life applications through practical processes. Additionally, the course aims to foster the development of materials science and engineering expertise to enhance the functionality and performance of technologies utilized in our daily lives.
The Questionnaire’s main question was How would you rate your understanding of the term “Circular Economy”? As shown in Fig. 1 the reflection of the students with 33.9% rated their understanding of circular economy by 80% (4-agree level) and this was the maximum rate expected, which concludes a good significance for relevant results.
When assessing the concept of collaborating within an interdisciplinary team, the findings indicated that 93.3% of the responses were favourable towards the notion of working with individuals from various disciplines, as illustrated in Fig.2

and finally asking about the expectations out of the project, the feedback was about Recycling and reusing multiple materials. It will be hard to find something to make the project, but we will learn many things. how to get introduced to different types of materials and their optimal uses, Learn how transfer from linear approach to circular approach, using internet in project, How can we obey circular economy in any project, knowing new material features, to know the Properties of material and different manufacturing techniques, To find new source of fuel, The concept of circular economy and end of life of the materials, Learning a new fundamental topic for my disciplines that will be very helpful in future production, fascinating area of research that is often at the cutting edge of science and engineering. It involves both developing new materials and improving on existing ones, how to work with the team and create a successful project and gaining more knowledge and experience, good teamwork, transformation from linear to circular economy, how to recycle tires.

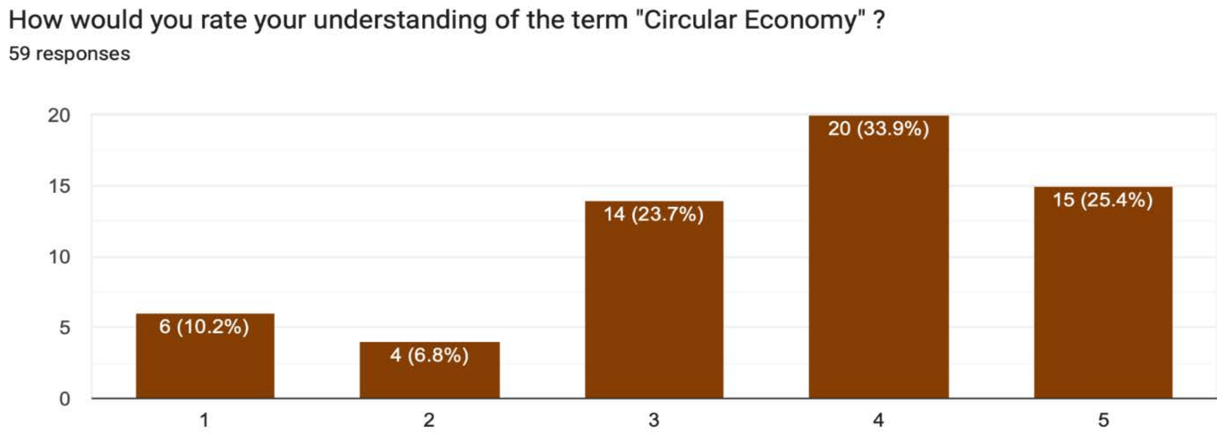

Fig.1 Understanding of circular economy.

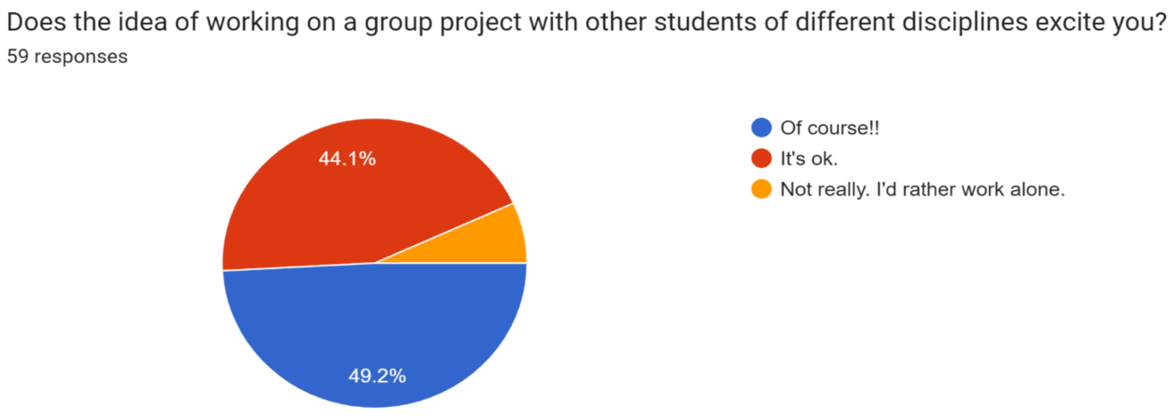

Fig.2 Interdisciplinary team opinion.

4.3. Statistical Analysis for Student Survey:

Following our discussions, it became evident that not all students were familiar with the concept of project-based education within the theoretical course. The initial survey indicated a lack of understanding regarding the principles of the circular economy. Additionally, there was a noticeable reluctance among students to engage in group work, particularly given their diverse disciplines, academic levels, and performance backgrounds.

After students were introduced to the concepts of the circular economy through an online lecture and tutorial groups, they formed groups of 1 to 4 students, each selecting a product for study. The results of the group formation and product selection are summarized in the accompanying table and figure.

4.3.1. Diversity of Student Groups

The composition of student groups reflects a significant diversity in terms of academic disciplines, gender representation, and team sizes. This diversity aligns with SDG 4: Quality Education, which emphasizes inclusive and equitable quality education and promotes lifelong learning opportunities for all. By bringing together students from various backgrounds, the groups are likely to benefit from a range of perspectives and expertise, enhancing their understanding of the circular economy.

4.3.2. Diversity of Products

The variety of products chosen for study illustrates the interdisciplinary approach to learning, reinforcing the importance of SDG 12: Responsible Consumption and Production. By examining different products, students can explore how circular economy principles can be applied across various sectors, fostering innovative thinking and problem-solving skills.

4.3.3. Follow-Up Sheets and Common Themes

To facilitate ongoing reflection and discussion, follow-up sheets were utilized. These sheets helped identify the most common themes, ideas, and problems encountered during the project. This structured feedback loop promotes continuous learning and improvement, aligning with the goals of SDG 4.

4.3.4. Final Presentation and Group Discussion

Students culminated their projects with a final presentation, allowing them to showcase their findings and insights. This presentation not only reinforces communication skills but also encourages engagement with peers through group discussions. The emphasis on peer-teaching fosters a collaborative learning environment, enhancing understanding and retention of circular economy concepts.

4.3.5. Assessment via Rubric

The assessment was conducted using a rubric that evaluated various aspects of the students' work, including collaboration, critical thinking, and application of circular economy principles. This structured assessment process ensures transparency and provides clear expectations for students, further supporting their educational journey.

4.3.6. Online Process

The entire process, including lectures, discussions, and presentations, was facilitated through an online platform, promoting accessibility and flexibility in learning. This approach aligns with the goals of SDG 4 by providing equitable access to education for all students, regardless of their circumstances.

4.3.7. Numerical data

The evaluation of course outcomes involved the administration of a questionnaire comprising distinct assessment queries, which garnered 53 responses from students, as per Table 1.

The questionnaire's questions can be grouped into Six groups; the group number 1 represents the Interest and Value in Circular Economy, the second group studies the Course Evaluation and Assessment, the third group about the Course Preferences and Mode of Assessment, the fourth group about the Skills Development, the fifth group asking about the Social Responsibility and Impact, and finally Six group seeking for the Instructor and Course Recommendation

First questionnaire's questions group "Interest and Value in Circular Economy"; initial query was analysed the interest of the circular economy, A notable 36% of respondents strongly endorsed this statement, while 43% expressed agreement. Collectively, a substantial 79% of students exhibited positive attitudes, either strongly agreeing or agreeing with the statement. This collective response indicates a statistically significant level of positive impact on students' interest in the subject matter. The second question was analysed the knowledge gaining about circular products. A significant 38% of respondents strongly agreed with this statement, while 40% indicated agreement. In total, an impressive 78% of students demonstrated positive attitudes, either strongly agreeing or agreeing, highlighting a statistically significant positive influence on their interest in the subject matter. The third question was examined the circular products benefits to the student study fields. Here, 36% strongly endorsed the statement, and 45% agreed, resulting in an overall positive attitude from 81% of students. This finding also indicates a statistically significant positive impact on their interest in the material. The fourth question the students learning evaluation fairly through various assignment methods, it revealed that 47% of respondents strongly endorsed this statement, while 43% agreed. Altogether, 90% of students expressed positive attitudes, thereby indicating a statistically significant positive effect on their engagement with the subject matter. The fifth question shows that the exams and assignments fairly reflect the student course material understanding, it showed that 38% of respondents strongly agreed, and 53% agreed. This amounts to 91% of students holding positive views, which suggests a statistically significant positive impact on their interest in the course.

Table 1. Students' responses on the project game affect achieving learning goals (n = 53).

The Project Game Increased My Ability to:	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	R^2	Median
1. This class has heightened my interest in the circular economy field.	36%	43%	11%	2%	8%	0.59	3.97
2. I believe that the knowledge I'm gaining in this course about circular products is valuable.	38%	40%	19%	2%	2%	0.72	4.13
3. I believe that the concepts I'm learning in this course about circular products will benefit me in my field of study.	36%	45%	11%	6%	2%	0.77	4.07
4. Student learning was evaluated fairly through various methods, such as quizzes, exams, projects, and other graded assignments.	47%	43%	2%	2%	6%	0.61	4.23
5. The exams and assignments were a fair reflection of my understanding of the course material.	38%	53%	6%	2%	2%	0.78	4.26
6. The examinations and projects effectively assessed my understanding of the course material.	34%	49%	11%	2%	4%	0.68	4.07
7. Regarding the course quizzes, which mode do you prefer?	70%	30%	0%	0%	0%	1.00	4.7
8. Which mode do you prefer for the course midterm?	47%	53%	0%	0%	0%	1.00	4.47
9. This course encouraged me to think critically.	34%	49%	11%	2%	4%	0.68	4.07
10. Circular economy, products, and design strategies understanding has increased.	43%	40%	15%	0%	2%	0.67	4.22
11. The course enhanced my communication and presentation skills.	23%	49%	21%	4%	4%	0.54	3.86
12. The course enlarged the ability to collaborate and teamwork.	36%	49%	8%	4%	4%	0.76	4.12
13. The course assisted to develop intellectual skills (e.g., critical/creative thinking, problem solving, quantitative reasoning, etc.).	34%	49%	11%	2%	4%	0.68	4.07
14. The course enhanced my awareness of social responsibility.	28%	47%	19%	2%	4%	0.58	3.93
15. I would like to participate in the concepts of circular design that I have learned into other courses in my discipline.	28%	53%	11%	4%	4%	0.67	3.97
16. I'm highly recommend the course Instructor to all students.	53%	34%	8%	4%	2%	0.92	4.35
17. I'm highly recommend the course Teaching assistant to all students.	58%	30%	9%	2%	0%	0.87	4.41
18. I'm highly recommend the course to all students.	32%	49%	11%	2%	6%	0.60	3.99
19. The course had great educational impact.	38%	40%	19%	2%	2%	0.72	4.13

Second questions group "Course Evaluation and Assessment"; The sixth question was analysed the examinations and projects assessed the student understanding with 34% of respondents strongly endorsing it and 49% agreeing. Collectively, 83% exhibited positive attitudes, indicating a statistically significant positive influence on their engagement. The seventh question asked about preferences for course quizzes, revealing that 70% preferred online quizzes, while 30% favoured in-class quizzes. This notable preference suggests a statistically significant positive impact on students' interest in online assessments. The eighth question regarding the midterm format indicated that 47% of respondents preferred an online midterm, while 53% preferred an in-class format, demonstrating a statistically significant positive impact on students' interest in the traditional assessment format.

Third questions group “Course Preferences and Mode of Assessment”; The ninth query about student thinking garnered a strong endorsement from 34% and agreement from 49% of respondents, resulting in 83% exhibiting positive attitudes. This response reflects a statistically significant positive impact on students' interest in the course content. The tenth question - circular economy, products, and design strategies understanding - was affirmed by 43% of respondents who strongly agreed and 40% who agreed, leading to 83% of students reporting a positive impact on their understanding.

Fourth questions group “Skills Development”; The eleventh question studies the student communication and presentation skills, it showed that 23% strongly agreed, 49% agreed, and 21% remained neutral. Overall, 72% of students expressed positive attitudes, indicating a statistically significant enhancement in their communication skills. The twelfth query analysis the student ability to collaborate and teamwork, revealed that 36% strongly endorsed it, while 49% agreed. Hence, 85% of students expressed positive attitudes, signifying a statistically significant improvement in teamwork skills. The thirteenth question demonstrates the develop in student intellectual skills, it was positively endorsed by 34% and agreed upon by 49% of respondents, resulting in 83% collectively indicating a statistically significant positive impact on intellectual skill development. The fourteenth query about the social responsibility awareness, found that 28% strongly endorsed it and 47% agreed, yielding a total of 75% of students with positive attitudes, indicating a significant increase in social responsibility awareness.

Fifth questions group “Social Responsibility and Impact”; The fifteenth question regarding the participation of the circular design concepts into other courses was supported by 28% of respondents who strongly agreed and 53% who agreed, leading to 81% expressing a positive inclination towards integration of these concepts. The sixteenth question about course Instructor recommendation to the other students showed that 53% strongly endorsed this statement and 34% agreed, resulting in 87% of students indicating a statistically significant positive view of the instructor.

Six questions group “Instructor and Course Recommendation”; The seventeenth question about course Teaching assistant recommendation the other students received strong endorsement from 58% and agreement from 30%, leading to 88% of students expressing a favourable opinion.

The eighteenth query represents the course recommendation to other students, it showed that 32% strongly agreed and 49% agreed, resulting in 81% of students affirming a positive recommendation for the course. Finally, the nineteenth question about the course educational impact revealed that 38% strongly endorsed it and 40% agreed, resulting in 78% of students demonstrating positive attitudes, indicating a statistically significant positive effect on their educational experience.

The survey results show that the course was highly effective in enhancing students' understanding of the circular economy and related concepts. Students particularly appreciated the fairness of assessments, with quizzes, exams, and projects receiving high ratings for their alignment with course material. The course also successfully encouraged intellectual engagement, critical thinking, and teamwork, as reflected in the high medians for items related to these areas. Teaching quality stood out, with both the instructor and teaching assistant receiving strong recommendations. However, there are areas for improvement. Students felt that the course had a relatively lower impact on improving their verbal communication and presentation skills, highlighting an opportunity to integrate more activities focused on these aspects. Additionally, while the course fostered a sense of social responsibility, this area could be further emphasized through practical applications of circular economy principles. Encouraging students to integrate circular design concepts into other disciplines could also enhance the course’s interdisciplinary relevance. Overall, the course achieved its objectives effectively, with opportunities to refine certain elements for an even greater impact.

5. Conclusions

The findings indicate that students possess limited prior knowledge of the circular economy, which varies with their academic year, as this concept is not commonly integrated into the curriculum. This gap can be attributed to insufficient exposure to these ideas in earlier coursework. However, it was noted that students value the acquisition of knowledge about the circular economy through collaborative projects positively. Those with greater prior knowledge demonstrate a heightened appreciation for the circular economy's significance in product development and future professional practices.

The circular economy is viewed as a complementary discipline and a transversal competency. Consequently, applying circular economy techniques in product design and development is essential for enhancing analytical abilities related to various circular economy strategies. This approach allows students to acquire knowledge in areas such as energy efficiency, reuse, and eco-design, enriching the solutions they generate.

Moreover, the results underscore the benefits of incorporating circular economy education throughout university curricula, thereby enhancing students' training in sustainability. This study highlights the relevance of the circular economy in students' foundational education and its critical role in product design and development. The ease with which students assimilate the fundamentals of the circular economy is significantly improved through collaborative projects focused on product engineering.

In summary, the diverse composition of student groups, the variety of products selected, and the structured assessment and feedback mechanisms contribute to a rich and inclusive learning experience. This not only deepens students' understanding of circular economy principles but also aligns with the broader objectives of the SDGs by promoting collaboration, inclusivity, and responsible practices.

Future efforts should concentrate on identifying key points for effectively integrating circular economy concepts into foundational training.

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