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PAPER

Creating Sustainable Competencies in Engineering Through Biomimetics Courses

Patricia Vázquez-Villegas[1], Elsy Geny Molina-Solis[2], Luis Alberto Mejía-Manzano[1], Javier Romo-Molina[2], Jorge Membrillo-Hernández[1,2](✉)

[1]Tecnologico de Monterrey, Institute for the Future of Education, Monterrey, Mexico

[2]Tecnologico de Monterrey, School of Engineering and Sciences, Monterrey, Mexico

jmembrillo@tec.mx

ABSTRACT

The United Nations 2030 plan establishes the incorporation of the Sustainable Development Goals (SDGs) as a multidisciplinary focus for training new specialized human resources. In engineering, the SDGs have been integrated into the curriculum as optional subjects. In this report, we present an investigation into implementing the SDGs in a Biomimicry and Sustainability course offered during the spring and fall semesters of 2022, with 194 students divided into six groups. Using challenge-based learning, students proposed utilizing wind or solar resources to generate electricity in a selected region. They were asked to conduct extensive research and precise engineering calculations to ensure the viability of their alternative energy sources. Additionally, each group had to select three or more SDGs that best aligned with their proposal, justifying their choices. The evaluation of the reports was based on rubrics and checklists that assessed the integrity of their argumentation and the adequacy of the report components. Most students chose SDGs 7, 11, and 13. In an anonymous survey, students expressed that incorporating the SDGs into the assignment significantly enhanced the importance of their learning experience. We recommend that other educators follow suit and incorporate the SDGs into their students' projects or proposals, irrespective of whether their institution has a sustainability plan, aiming to transform sustainability into a competency rather than a fixed concept.

KEYWORDS

educational innovation, higher education, STEM, education for sustainability, challenge-based learning

1 INTRODUCTION

In 2015, the United Nations, as a part of the 2030 Agenda for Sustainable Development, adopted 17 global goals as Sustainable Development Goals (SDGs). The SDGs aim to promote sustainable development by addressing the root causes of poverty, inequality, and environmental degradation. They also aim to foster economic growth, social inclusion, and environmental sustainability in a balanced and

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integrated manner [1]. Incorporating the SDGs into education can help educators guide students in developing an understanding of the intricate interconnections among social, economic, and environmental systems. This understanding can illuminate how these systems interact to influence the future of our planet [2], [3]. The SDGs can also inspire and motivate students to take action to address sustainability challenges in their own lives and communities, empowering them to become agents of positive change in the world [4].

1.1 Education for sustainable development

Education for Sustainable Development (ESD) is an approach to teaching and learning that promotes the values, knowledge, and skills needed to create a more sustainable and equitable world [5], [6]. ESD can take many forms, including formal and informal education, experiential learning, community engagement, and interdisciplinary research [7–11]. ESD is a key instrument for achieving the SDGs [12]. The SDGs are crucial for ESD because they offer a globally recognized framework for tackling the most urgent sustainability challenges on our planet [13], [14]. They provide a common language and a set of goals for stakeholders across various sectors and regions [15]. The SDGs are an essential and valuable tool for ESD, offering a compelling vision for building a more sustainable, equitable, and resilient world for all. In this line, it has been proven that including SDGs in university courses is part of higher education institutions' (HEIs) strategies for achieving sustainability with positive outcomes [16], even though it is a crucial step for engaging in sustainability rankings [17].

Teaching has the greatest potential for incorporating ESD into HEIs [18]. It is considered one of the main areas contributing to the achievement of the SDGs. It has been reported that teachers must share their experiences of curriculum redesign and incorporating the SDGs into curricula with their colleagues. Of course, incorporating the SDGs is not easy, and each institution presents different challenges. In the study [19] on the integration of the SDGs for the fulfillment of the 2030 agenda in public universities in Colombia, a stronger institutional commitment to sustainable development is observed in universities with high-quality accreditation. Organizational structure and resource allocation were identified as the primary barriers to the process. Other barriers identified included a lack of awareness and knowledge of the subject, as well as a deficiency in practical orientation and theoretical foundation for its implementation. However, the absence of official accreditation for professors in the subject does not preclude them from sharing knowledge and concerns about sustainability issues with students [20]. In this way, teachers and students can reflect on and learn about this issue that concerns everyone.

1.2 The potential of biomimicry as a framework for sustainable development

Biomimicry has been defined as the process of learning from and emulating nature to solve problems, more commonly engineering problems [21]. It has been employed in various fields such as construction, aerospace, chemistry, materials science, engineering science, technology, physics, computer science, polymer science, biochemistry, molecular biology, and social sciences, impacting the global community [22–26]. Biomimicry is an innovative approach to sustainable development that seeks inspiration from nature to solve human problems [27]. This approach involves emulating nature's patterns and strategies to develop sustainable solutions to social, economic, and environmental issues [28], [29].

The concept of biomimicry as a sustainable framework is not new, but it has been recently utilized to develop various sustainable competencies. [30] examined how biomimicry, which mimics nature to solve human problems, can contribute to sustainability. They explored different types of biomimicry and the basic ideas about sustainability, nature, and imitation (mimesis) to show how biomimicry holds promise for addressing environmental challenges.They also suggested a possible direction for further theorizing its application to sustainability challenges. It consists of a quadrant with two axes. The horizontal axes categorize the biomimicry actions based on their objectives, such as innovation, net zero optimization, societal transformation, or biosynergy. The vertical axis categorizes actions based on whether they are fixed or flexible. This is whether nature plays a passive or active role, respectively. However, an educational approach is not discussed.

Studies have indicated the importance of researching biomimicry pilot projects that can bridge the gap between academia and industry [31]. These projects can help identify potential opportunities and applications for implementing and testing biomimicry concepts in infrastructure assets and networks at various levels, including form, process, and system. In this regard, the applications could range from infrastructure to social well-being [32].

Here, we introduce the SDGs into the biomimicry for sustainability framework, as depicted in Figure 1, following the research of [33–35].

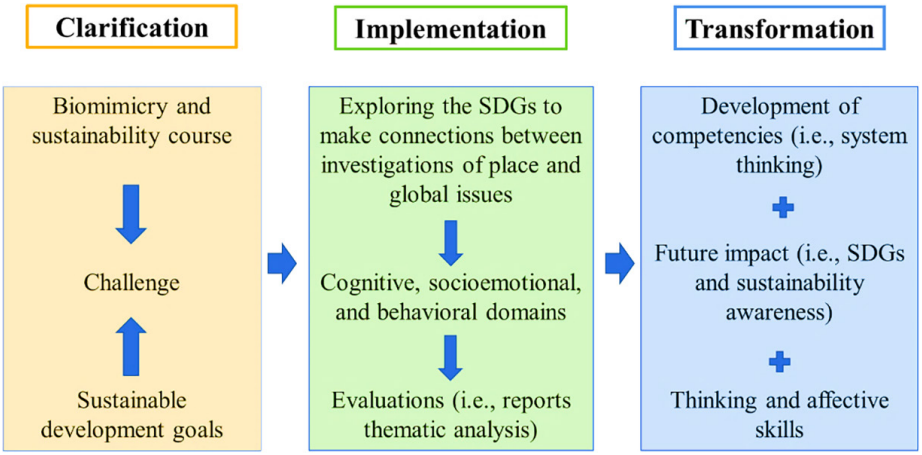

Fig. 1. The scheme of the use of biomimicry as a framework for sustainable development was implemented in this study [33–35]

As a framework designed for the educational sector, specifically for higher education courses, this approach begins with identifying a problem and incorporating biomimicry and SDG content. The subsequent step involves implementing the activity and evaluating it based on the domains related to the SDGs, which include knowledge and actions. We hope this method will transform students by developing cognitive and affective skills, competencies, and a deep understanding of the SDGs and sustainability principles, which they can implement in their future endeavors.

1.3 The biomimicry and sustainability (B&S) course

The B&S interdisciplinary course at Tecnológico de Monterrey explores how natural principles can be applied to design sustainable solutions to environmental problems [36]. The course typically integrates concepts from biology, ecology,

engineering, and design and encourages students to utilize a systems-thinking approach to problem-solving. It aims to prepare students to become innovative and responsible leaders who can contribute to a more sustainable future by using nature as a guide for design and problem-solving. B&S is a basic-level exploratory course where students will learn about the functional mechanisms and processes that biological systems implement in nature. The course focuses on identifying strategies that enable innovation and technological development, with an emphasis on sustainability. The fundamental principles of science, mathematics, physics, chemistry, and biology are essential for understanding and developing theoretical models that explain the behavior and functioning of chemical and biological systems.

As a result of learning, students must demonstrate their understanding of the principles of sustainability by solving problems and identifying the dimensions of sustainable development, as well as recognizing the indicators and principles of sustainability. The course is 16 weeks long, and the competency assessment is conducted using rubrics and checklists. At the end of the course, students must achieve the following sub-competencies:

- Solve problems and answer questions about reality using objective, valid, and reliable methodologies.
- Create communicative discourses utilizing various codes (visual, auditory, architectural, spatial, graphic, etc.) that take into account geopolitical and sociocultural contexts.
- Utilizes digital technologies, employing deliberate strategies to create value in different spheres for professional and personal engagement in the networked society.
- Explain the functioning of chemical and biological systems through structured and coherent arguments based on concepts, theories, and principles of the natural sciences, mathematics, and computing.
- Apply sustainability principles to solve bioengineering problems and chemical processes, ensuring the well-being of future generations.

The integration of the SDGs into the course content of a B&S course can be an opportunity to encourage students to think critically about how B&S design can contribute to achieving these goals [12].

1.4 Justification of this work

In April 2021, Tecnológico de Monterrey launched the 2025 Sustainability and Climate Change Plan [37]. With this plan, Tecnológico de Monterrey aims to enhance the culture of sustainability, encouraging everyone in the community to commit to contributing to institutional goals and embodying this culture in various aspects of our lives. The plan comprises six strategies: culture, mitigation, adaptation, education, research, and linkage. Each axis has a mission and one or more objectives for 2025 [37]. The mission of the education strategy is to train leaders who are dedicated to creating a sustainable future. The objective is to integrate climate change and sustainable development education into the upcoming professional curricula.

This work aims to share the strategies employed to incorporate the SDGs into the B&S course and address the research question: How does integrating the SDGs enrich the B&S course? This work aims to accelerate and enhance locally relevant ESD by providing examples of successes and failures that could strengthen the professional development of educators worldwide [38].

To move beyond merely describing the case study, we attempted to analyze the practice [39] by comparing the outcomes of the pedagogical approach used with the cognitive, socio-emotional, and behavioral aspects of the SDGs learning objectives [12]:

Cognitive: knowledge and thinking skills necessary to better understand the SDG and the challenges in achieving it.

- Socio-emotional skills encompass the ability to collaborate, negotiate, and communicate to advance the SDGs. Additionally, they include self-reflection skills, values, attitudes, and motivations that support learners in their personal development.
- Behavioral: actions and competencies.

2 METHODOLOGY

2.1 Pedagogical strategy

The present study was conducted as a case study, as this methodology has been deemed appropriate in studies of ESD in higher education [39]. The pedagogical approach used in this work was a derivative of the challenge-based learning approach called "Judge Better or Best," where students evaluate two or more options to determine which best meets the identified criteria [40]. The teaching style accompanying the pedagogical strategy was active learning, fostering critical thinking, creativity, and transformative learning [40].

The activity known as "energy harvesting" is conducted on this subject. In this project, the student must propose the use of wind or solar resources to generate electricity in a specific locality and various buildings. In this case, the biomimetic element was designed to harness wind and solar energies, but this framework can also accommodate other activities. The proposal is individual, corresponds to one of the two pieces of evidence for evaluating sub-competences, and accounts for 26% of the final score. In the proposal, students must provide technical information about the selected site and the availability of solar and wind resources. They must justify why their proposal leverages a specific resource by explaining the technical aspects of the resource to be utilized and its positive and negative impacts on the three dimensions of sustainable development (economic, social, and environmental). Students must select three SDGs and their respective targets that most align with their proposal and justify their choice.

During the class sessions, students were provided with the necessary information to create the proposal. Additional advice was available upon request, and students had three weeks to prepare it. They were provided with a format to present all their research information in a complete and orderly manner. The objective of providing the format is to emphasize important aspects such as selecting the SDGs and targets that align best with the proposal, as well as justifying this selection, without being distracted by the presentation of the information.

To incorporate the SDGs, students must engage in a deliberate process that necessitates a comprehensive understanding of the goals and their relevance to the project content [41]. First, resources were provided for students to learn more about the SDGs, including links to relevant websites and discussions about the SDGs and their relevance to the course content. Students had to review the 17 goals and their targets to understand their objectives and interrelationships. After this, students had to identify at least three SDGs most relevant to the project content, considering the local context and the most relevant SDGs to the chosen region. Once the relevant SDGs were identified, the next step was to incorporate them into the project outcomes and integrate how the project could address a specific SDG into the final report.

2.2 Sample

B&S is a general course offered by the School of Engineering and Sciences. Students from the first to the fifth semesters can take the class. This report is based on the implementation of IT during the Spring and Fall terms of 2022. Three courses were taught in the spring term, and three were taught in the fall term. A total of 196 students participated in these B&S courses.

2.3 Data collection

The data was obtained from the students' reports. We collected demographic information such as career field, technological proficiency, gender, academic level, group affiliation, the SDGs selected by the student, and the scores obtained in the report.

We also wanted to investigate how the SDGs influenced student engagement and learning outcomes, whether the SDGs enhanced students' motivation to learn, and whether the SDGs improved students' comprehension of sustainability issues. For this study, we observed students engaging with course materials related to the SDGs and participating in an anonymous and optional survey. We inquire about the following from students: 1) their experiences with the course materials related to the SDGs; 2) how the SDGs have influenced their learning; and 3) whether they have experienced an increase in motivation to learn. The Google Forms platform provided an open-ended, anonymous, and optional survey.

2.4 Data analysis

Through content analysis, we assessed the scope of project coverage related to the SDGs, identified the SDGs that receive the most extensive coverage, and determined which SDGs are not covered at all [42]. The assignments were analyzed by developing a coding scheme to investigate the extent to which SDGs were covered in the projects.

With qualitative analysis, we identified themes and patterns related to the impact of SDG inclusion on student engagement and learning outcomes [43]. Participant observation and feedback provided valuable insights into student behavior, interactions, and engagement [44]. We calculated the frequency with which each SDG was covered, comparing the extent of coverage across different SDGs and identifying any data patterns or trends. A statistical analysis was performed to determine any correlations among the data. By using a combination of methods, we could gain a comprehensive understanding of how SDG inclusion is impacting student engagement and learning outcomes.

From the collected data, contingency tables were constructed considering the categorical variables (avenue, technology, gender, academic level, group, SDG option #1, SDG option #2, SDG option #3) and the discrete variable: scores. For this last variable, the values were grouped into the following four categories: incipient ($scores < 70$, $70 \leq scores < 80$, $80 \leq scores < 90$, $90 \leq scores \leq 100$). A chi-square test for association examined the relationship between variables using a significance level of 5% [45]. As a null hypothesis, it was stated that the two variables were independent, while the alternative hypothesis was that the variables were associated. A simple correspondence analysis was performed using the software Minitab® 21.1 [46] to explore the relationship between the pair of variables showing association.

Regarding the Google Forms survey, students' answers were coded using an inductive approach to identify themes from the data [47]. Code analysis was conducted manually [48].

3 RESULTS AND DISCUSSION

Higher education plays a crucial role in achieving the SDGs. It is considered that none of the SDGs can be met without the intervention of the education sector. Therefore, it is necessary to equip students with sufficient knowledge, skills, and motivation to understand and address these goals. Additionally, provide academic experience to implement solutions to achieve the SDGs [49]. This requires universities to integrate sustainability into all aspects of the educational institution [50]. It includes rethinking curricula, campus functions, organizational culture, student engagement, leadership and management, community relations, and research [51], [52]. This aligns with the 2025 Sustainability and Climate Change Plan, in which Tecnológico assumed the following commitment: to achieve carbon neutrality by 2040 [37].

In this regard, we have been actively involved in developing pedagogical strategies to incorporate the SDGs into course curricula. This initiative aims to equip students with the necessary skills to become global citizens capable of contributing to the realization of a sustainable future. To address this issue, various approaches have been implemented, including conducting awareness and training sessions for faculty members, students, and other stakeholders about the SDGs and their significance in higher education [53]. In this work, we present the results of a pedagogical strategy designed to be implemented in the B&S course.

In this work, a total of 196 projects were completed by students enrolled in the B&S courses in 2022. Two students did not complete the assignment based on these works, and those incomplete assignments were not considered for further analysis. Thus, only 194 works will be considered from here. Table 1 displays the sample distribution based on several variables.

Table 1. Study population distribution

Variables	Frequency	(%)
Gender		
Female	86	44%
Male	108	56%
Term		
Spring	98	51%
Fall	96	49%
Group		
1	32	16%
2	35	18%
3	31	16%
4	31	16%
5	33	17%
6	32	16%

(Continued)

Table 1. Study population distribution *(Continued)*

Variables	Frequency	(%)
Career avenue		
Innovation and transformation	47	26%
Business	38	21%
Bioengineering and chemical processes	24	13%
Built environment	19	11%
Applied sciences	15	8%
Creative studies	14	8%
Computing and Information Technologies	14	8%
Law, Economics, and International Relations	14	8%
Health	9	5%
Academic level		
Year 1	91	47%
Year 2	72	37%
Year 3	31	16%

For the data analysis, we selected the initial technology chosen and the first three SDGs listed in the report, if applicable. From the documents delivered, 14.43% chose wind technology, and 85.57% chose solar technology. Figure 2 illustrates the distribution of regions chosen by students for the implementation of wind or solar technology based on the characteristics of the location.

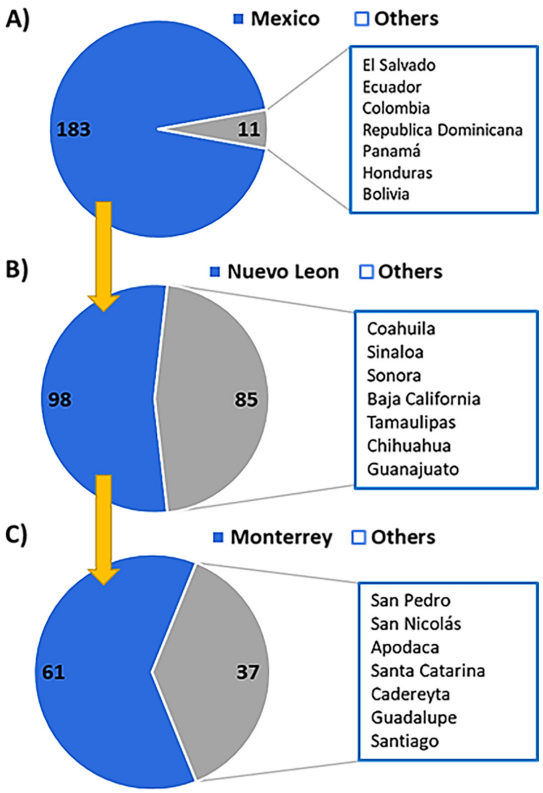

Fig. 2. Distribution of the regions selected in the "Energy Harvesting" project delivered by the students of the B&S course during 2022 to implement wind or solar technology, according to the place characteristics

As observed, only 31% of the total documents were considered by the students to be applicable in the city where they took the class (Monterrey, Nuevo León, Mexico). Nevertheless, the rest were distributed throughout the state, the country, and some in other Latin American countries.

In Figure 3, there is a list of the types of real state (RS) categories in which the selected buildings were classified. As observed, more than half of the students chose a single house or department to propose the implementation of the selected technology.

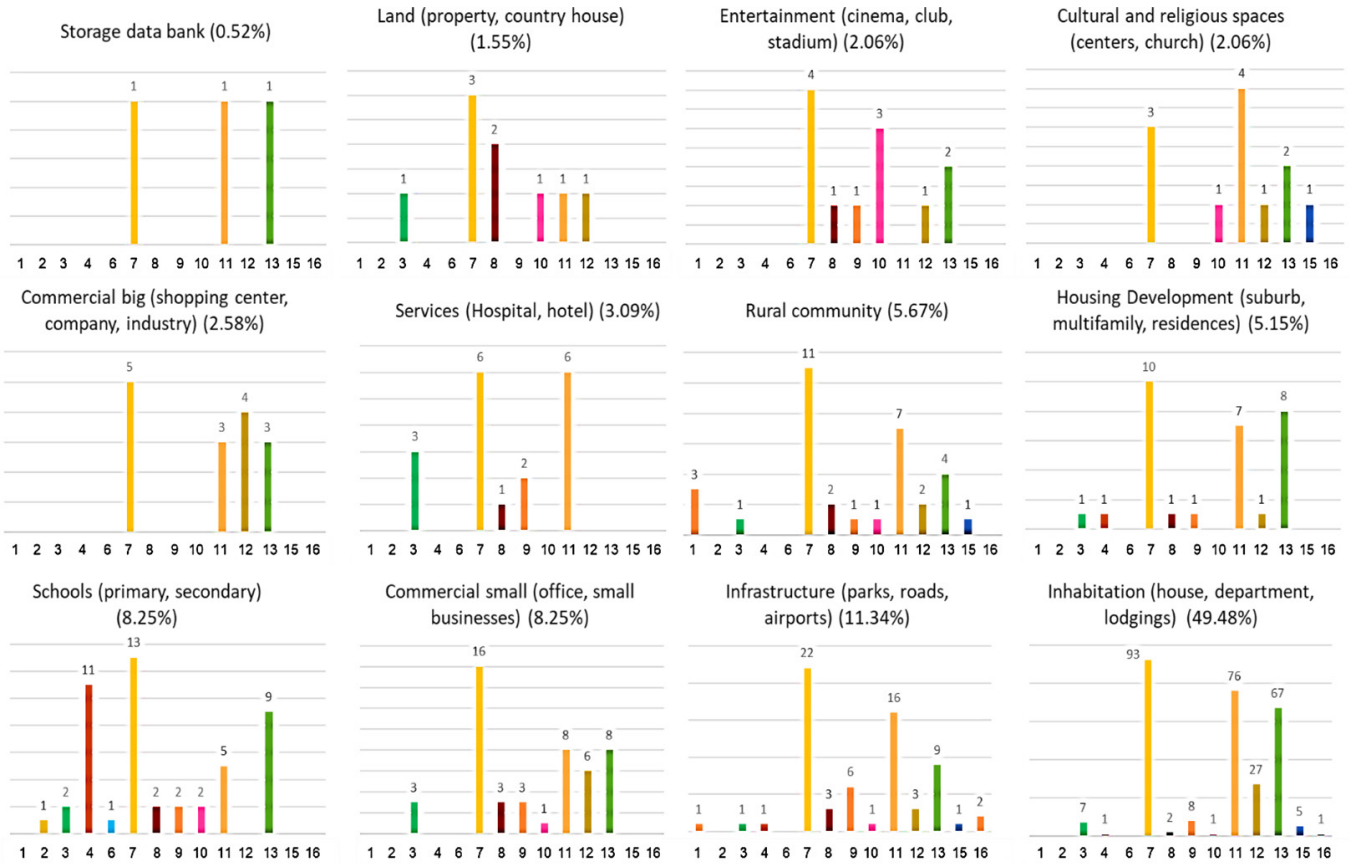

Fig. 3. Distribution of the types of buildings (real estate) selected by the students for the "Energy Harvesting" activity in the B&S course (n = 194), showing the frequency of the selected SDGs. SDGs #5 (Gender Equality and Women's Empowerment), #14 (Life Below Water), and #17 (Partnerships for the Goals) were not selected by any student

Although each proposal is unique, most students agree on the sustainable development goals included in these proposals. Most students (n = 187) selected goal #7, "Affordable and clean energy." The second place was obtained by Goal #11, "Sustainable Cities and Communities" (n = 134), and the third place was Goal #13, "Climate Actions" (n = 113). Those who proposed homes or commercial buildings also ranked SDG #12, "Responsible production and consumption," in fourth place. On the other hand, SDG #1, "No poverty," tends to be featured in proposals for utilizing resources in rural areas that currently lack electricity. SDG #4, "Quality education," is closely related to educational initiatives. The selection of the least frequently occurring SDGs (#2, "Zero Hunger," #6, "Clean Water and Sanitation," and #16, "Peace, Justice, and Strong Institutions") depended not on the type of place selected in the proposal but on a broader and deeper analysis that the student conducted for his proposal.

Table 2 shows the results of the chi-test association between the sets of two variables, looking for a significant association below a significant level of 5%.

Table 2. Results of the chi-square test for association between variables pairs of the B&S courses

Variable 1	Variable 2	p-Value	Association
Career Avenue	Scores	–	Undetermined
Career Avenue	Technology	0.779	No association
Gender	Scores	0.124	No association
Academic level	Scores	0.093	No association
Group	Scores	0.197	No association
Technology	Scores	0.605	No association
Technology	Group	0.001	Association
Technology	SDG1	–	Undetermined
Technology	SDG2	–	Undetermined
Technology	SDG3	–	Undetermined
Scores	SDG1	–	Undetermined
Scores	SDG2	–	Undetermined
Scores	SDG3	–	Undetermined

Some association tests were inconclusive because the expected counts for the contingency tables were less than 1. Hence, the test is invalid [46], [54]. Most associations were insignificant, except for the detected association between technology and group. The six groups predominantly selected the option "solar." Under this panorama, it can be said that the variables of gender, academic level, group, and technology, do not influence scores. This reflects the independence of the scores and the absence of bias. It is challenging to establish from the current results whether there is a correlation between the technologies used and the types of SDGs chosen by students as their top three preferences and if the selected SDGs are related to the scores achieved.

After conducting content analysis, student observation, and collecting feedback on the impact of including SDGs in the B&S course, the results were analyzed. As a result of observations, it was noted that students showed a high level of interest and engagement in the topic. The students' opinions indicated that they were highly engaged in understanding and applying the SDGs, suggesting that the activity motivated them to learn. Only 81 optional survey answers were received. A total of 37 codes are displayed as a word cloud in Figure 4.

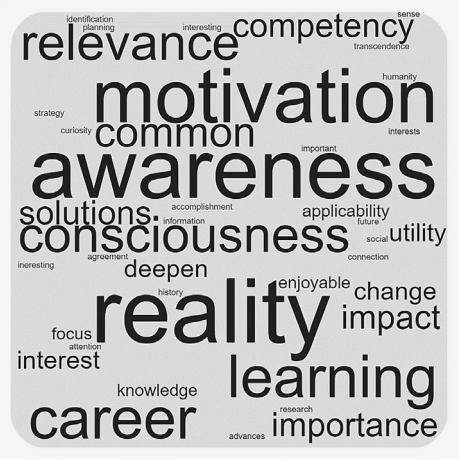

Fig. 4. Word cloud of inductive codes assigned to the students' answers to the optional survey about their opinion of the SDGs implementation in the B&S course (The size of the letter represents the number of repeated codes)

These codes were grouped into more general inductive categories, as shown in Table 3. This table shows the practical implications of including the SDGs in a B&S course (or any course).

Table 3. Inductive categories from the qualitative content analysis of the feedback survey regarding the inclusion of SDGs in the B&S course

Main Category	Second Order Category	n	Examples of Student's Statements	Transformative Implications
Learning engagement	Motivation	19	"It has made me reflect on their importance and impact in other areas." "It has motivated me to know specific topics that catch my attention."	Including the SDGs in the B&S project motivates students to learn more about topics they may not have been aware of before. It increases their interest, attention, and curiosity, making learning more enjoyable.
	Commitment	5	"I want to dedicate my professional life to supporting the fulfillment of the SDGs in some way." "In the future, I want to make a positive impact."	Including the theme of the SDGs in a B&S course allows students to connect their goals and careers, generating a commitment to achieve them in their future jobs.
Learning significance	Pertinence	20	"Focusing the SDGs on a subject is useful and necessary to understand how they should be reflected in some work." "The interactions with the course materials have given me more knowledge on applying these objectives in different areas."	Students learn relevant content to focus on the knowledge acquired in their careers.
	Recognition	23	"It made me more aware that we must actively work to achieve ODSs." "It helped me give a more transcendental sense to the topics seen in class and helped me to learn more to achieve the objectives in the future."	Students recognize the importance of the SDGs and the actions to achieve them, generating an awareness of current problems and that they must work to solve them so that learning becomes transcendent.
	Actuality	21	"Not many people know the ODSs, so I think including them and relating them to today's environmental and social problems is very important." "It gave me a baseline to want to improve my processes in the company I work for the common good with a clear objective."	The learning obtained considers real and current problems. Allowing students to generate solutions and impact strategies to these problems makes learning more sense.
Learning competencies	Culture	7	"It lets us know more about our reality and encourages us to seek solutions based on our values and knowledge." "ODSs are not being fulfilled as planned. This motivates me to study and learn to find accessible solutions that can make a change."	The introduction of the SDGs in subjects such as B&S allows the practice of competence that involves skills, attitudes, and values in addition to knowledge, which can generate lasting change.
	Self-efficacy	15	"I want to know what steps the UN is taking to meet those goals." "I have come to know ODSs more thoroughly, understand them, and begin to relate them to ideas and topics that I did not know before."	By being motivated to learn, students develop skills to learn more independently. They can develop skills such as analyzing information, researching, or planning to learn more about the knowledge gained in the class and its application.
	Moral assimilation	8	"Now, I know that my learning is also focused on the human part." "It motivated me to do something that benefits others and myself."	Students recognize their role as actors of change in society. It allows them to understand how to apply their career knowledge and act for the common good.

Note: N = number of codes grouped in each category.

Some students had already been introduced to the SDGs in previous classes during their academic career or in high school. The greatest impact was on those students who were first-time or in careers where they had not seen all the SDGs, such

as in music or medicine: “It has been very relevant, especially for the career I have, since there is no course that specifically helps you understand the importance of these objectives applied to health.”

In the students’ feedback, negative outcomes were found (n = 16). For example, some students mentioned that including SDGs in the course was redundant. These answers were neutral or negative: “They have not had any impact on the things I learn,” and “I think sometimes they make certain topics repeat within various subjects, which can be tedious.” Ultimately, we received more positive responses. However, this type of response motivates us to enhance the approach through which the SDGs are integrated, making it engaging for individuals, irrespective of their prior exposure to the subject in other courses. Moreover, engage them by emphasizing their importance and reiterating that, as future professionals, they must take action to achieve the objectives.

4 DISCUSSION

The results observed in this study are consistent with other research on selecting SDGs for university assignments. In McLean et al. [55], students utilized systems and design thinking, focusing on SDG13 (climate action) along with a second SDG of their choice, to develop a deliverable “product” for a specific audience. This work was carried out over five years in a medical program. The authors concluded that engagement with planetary health enhances competencies, attitudes, and values. In their feedback, students reported personal and professional development in terms of their awareness of the environment as a determinant of health and their responsibility to “take action” on climate change [55]. Including the SDGs in the curriculum provided a more favorable approach to integrating sustainability into the business school [56]. In other words, the SDGs have been included in biomimicry activities, with a part of the student’s score dependent on whether the project aligns with any SDGs. However, the implication has not been studied [57]. On the other hand, the positive results may have been attributed to the B&S course itself. In other studies, it has been found that the biomimicry class stimulates curiosity and motivation, making learning an active and enjoyable experience. On the other hand, research has shown that students often make unnecessary connections and struggle to involve all participants [58].

In addressing the research question, how does incorporating the SDGs enrich the B&S course? The “Harvesting Energy” project was beneficial in achieving the cognitive, socio-emotional, and behavioral objectives of the SDGs [12]. The study highlights the relevance and importance of equipping students with the skills and knowledge necessary to tackle global challenges. This study emphasizes the need for ongoing assessment of the influence of SDG integration on student engagement and learning outcomes to guarantee that the curriculum aligns with its objectives. Because broader sustainability practices within biomimicry remain largely unaddressed, biomimicry educators are leading the way towards a more nature-inspired and biologically more nature-inspired. All biomimicry educators and facilitators should commit to always including an explicit sustainability approach within their pedagogy [59].

4.1 Implications of this work

This work explores the implementation of a framework that integrates the activities of the B&S class with sustainable development objectives. This framework

presents a challenge or problem for students to work on, aiming to develop their skills and raise awareness about sustainability. It fosters skills like systemic thinking among students from the first to the sixth semester across various disciplines (refer to Table 3 for evidence).

Complex systems thinking is one of the key competencies for sustainability. It refers to recognizing and understanding relationships, analyzing complex systems, considering how they fit into different domains and scales, and addressing uncertainty [12]. Furthermore, critical thinking, self-awareness, and integrated problem-solving skills are crucial for achieving sustainable development goals [12].

It is proposed that the framework presented in the bibliographic review of this work can be applied to other interdisciplinary courses. Students can learn about the SDGs by integrating them with the knowledge they have acquired. Consequently, they can apply this knowledge to their professional work. The objective of this strategy is to develop transversal competencies rather than view the concept as static. Implementing strategies to accomplish the SDGs is crucial for the future.

4.2 Limitations of the study and suggestions for future research

Integrating SDGs into higher education curricula is becoming increasingly important, as students play a critical role in achieving these goals. However, several challenges and trends must be addressed to effectively integrate the SDGs into higher education curricula.

Many educators, stakeholders [60], and students are unaware of the SDGs and their relevance to higher education. Educators may lack an understanding of the importance of the SDGs in their field, and students may not see the relevance of the SDGs to their coursework. Integrating the SDGs across disciplines and curricula can help students better understand the interconnectedness of environmental, social, and economic issues. This can be accomplished by:

1. Encouraging collaboration among stakeholders, such as faculty members, students, and community members, can help ensure the integration of the SDGs across higher education curricula.
2. Adopting innovative pedagogical approaches, such as experiential learning, problem-based learning, and service learning, can help integrate the SDGs.
3. Developing appropriate assessment methods to measure the impact of integrating the SDGs into higher education curricula.

On the other hand, few or no students selected SDG #2 (Zero Hunger), #5 (Gender Equality), #6 (Clean Water and Sanitation), #14 (Life Below Water), #16 (Peace, Justice, and Strong Institutions), and #17 (Partnerships to Achieve the Goals). It is suggested to develop new projects, both within this subject and others, to enable students to propose projects that are in line with these objectives. In this regard, other pedagogical approaches that utilize information and communications technologies [61] and methodologies, such as blended learning [62], could be utilized.

5 CONCLUSION

This study on the impact of SDG inclusion on student engagement and learning outcomes in an engineering course (B&S) can significantly contribute to the existing

literature on sustainability education and SDG integration. The study provides empirical evidence on the impact of SDG integration on student engagement and learning outcomes in higher education. The results indicate that the selected SDGs were closely related to the students' proposals. However, they have a lower level of consideration for other SDGs. There was no association between the student scores obtained and the variables avenue, gender, academic level, group, and technology. For now, there is no evidence of an association between the choice of SDGs in the study and the scores assigned to the students. Only a significant association existed between groups and technology, and all groups preferred solar technology.

The adopted student-centered approach, focusing on the impact of SDG inclusion on student engagement and learning outcomes, provided insights into how to design and implement SDG-related activities and assignments that effectively engage students and promote their learning in other engineering courses.

A positive aspect of the article is the coverage of the pedagogical aspects of implementing SDG in the course. This assessment can guide the design and implementation of pedagogical strategies that effectively engage students and promote their learning about the SDGs. Overall, this work presents a framework that delves into the process of integrating the SDGs into a B&S course. It focuses on assessing the influence on student engagement and learning outcomes and offers implications and recommendations for future sustainability education initiatives.

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8 AUTHORS

Patricia Vázquez-Villegas, Tecnologico de Monterrey, Institute for the Future of Education, Monterrey, Mexico.

Elsy Geny Molina-Solis, Tecnologico de Monterrey, School of Engineering and Sciences, Monterrey, Mexico.

Luis Alberto Mejía-Manzano, Tecnologico de Monterrey, Institute for the Future of Education, Monterrey, Mexico.

Javier Romo-Molina, Tecnologico de Monterrey, School of Engineering and Sciences, Monterrey, Mexico.

Jorge Membrillo-Hernández, Tecnologico de Monterrey, Institute for the Future of Education, Monterrey, Mexico; Tecnologico de Monterrey, School of Engineering and Sciences, Monterrey, Mexico (E-mail: jmembrillo@tec.mx).