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Sustainable development modules: algorithm development and implementation in university educational programs

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This study analyses the experience of integrating sustainable development modules into the curricula of two Kazakh universities. Unlike most Western models, the project is adapted to the conditions of a developing country, taking into account limited resources and institutional barriers. Key findings include an increase in students' knowledge, but a group of "ecological indifference" was identified that requires special pedagogical approaches. Practical difficulties, such as resistance from teachers, and the rigidity of the curriculum reduce the effectiveness of integration. The study offers not only an implementation algorithm, but also a framework for its adaptation in other post-Soviet contexts, filling a gap in the literature on sustainable development for developing regions.

KEYWORDS

sustainable development, university educational programs, educational modules, integration algorithm, sustainable development education

1 Introduction

Integrating SD principles into higher education has become a global priority, as highlighted in the UN Sustainable Development Goals (SDGs) and the UNESCO Framework on Education for Sustainable Development (ESD) (UNESCO, 2017). This study focuses on the academic challenge of introducing modules on sustainable development into university curricula in Kazakhstan. The study is conducted within the framework of a pilot project implemented in two universities in the country. The relevance of the work lies in the development of practical methods for integrating ESD into existing curricula, which can serve as a model for other universities in Kazakhstan and beyond. Research highlights the importance of embedding sustainability principles into disciplines to prepare students for global challenges. For example, Lozano et al. (2020) highlight the role of universities in achieving the SDGs through curriculum innovation and stakeholder engagement. Wals and Benavot (2017) argue that sustainability education should go beyond theoretical knowledge to develop critical thinking and problem-solving skills.

In recent years, various models of integrating SD into university curricula have been explored. Leal Filho et al. (2019) investigated the implementation of sustainability modules in European universities, highlighting the need for interdisciplinary approaches and faculty training. Biasutti and Frate (2017) assessed the effectiveness of such modules in enhancing students' competencies, finding significant improvements in knowledge and attitudes

toward sustainable development. However, gaps remain in the literature on adapting these models to the context of developing regions, including Central Asia.

Key challenges to integrating SD into specialized disciplines include faculty resistance, lack of resources, and rigid curricular structures (Sterling et al., 2017). Barth and Rieckmann (2018) note that while many universities implement sustainability initiatives, few systematically evaluate their impact on student learning outcomes. This highlights the need for robust monitoring mechanisms and adaptive integration strategies (Bespalyy, 2023).

Although the study draws on key works (Leal Filho et al., 2019; Lozano et al., 2020), a critical analysis of their applicability to the Kazakh context requires further investigation. In particular, Leal Filho et al. (2019) propose interdisciplinary approaches, but their model is designed for European universities with high faculty autonomy, making direct borrowing difficult. Barth and Rieckmann (2018) focus on assessing the impact of SD on learning, but their methods do not take into account the limited resources of developing countries. This highlights the need for adaptation rather than mechanical transfer of foreign experience.

The UNESCO ESD Framework (UNESCO, 2020) places emphasis on transformative learning and student engagement. The Global Reporting Initiative (Global Reporting Initiative [GRI], 2018) offers guidelines for reporting by higher education institutions on sustainable development, emphasizing transparency and accountability. However, these frameworks often do not take into account the specifics of developing countries, were limited resources and institutional barriers complicate implementation.

The study examines the frameworks proposed by UNESCO and GRI, which serve as a basis for developing SD modules. The UNESCO framework emphasizes transformative learning but does not offer specific tools for integrating SD into specialized disciplines. The GRI guidelines focus on reporting, which makes them less applicable for educational purposes, especially in resource-constrained developing countries. A critical analysis shows that neither of these frameworks takes into account the need for adaptation to local curricula, which necessitated the development of a hybrid approach in our study.

The aim of this study is to analyze the effectiveness of the developed SD modules and their integration into specialized disciplines to improve students' understanding of sustainability concepts.

This paper builds on the research of Lozano et al. (2013) and Tilbury (2011), which highlight the importance of adapting approaches to the conditions of developing countries. The results complement the literature on ESD and offer practical solutions for universities seeking to meet global sustainability goals (Bespalyy et al., 2024; Shelomentseva et al., 2017).

Key terms of the study include the SD module – an autonomous educational unit integrated into the discipline, consisting of a theoretical component, practical cases related to the discipline profile, and assessment tools. The integration algorithm is a sequence of actions for implementing SD modules, including curriculum analysis, selection of integration points, and teacher training, followed by assessment of effectiveness through questionnaires.

ESD issues are widely discussed in the academic literature, with a particular emphasis on curriculum development, pedagogical approaches and institutional strategies (Cotton et al., 2016; Gomes et al., 2021; Green et al., 2022; Johnson et al., 2021; Liu et al., 2020; Shephard et al., 2015).

2 Methodology

This study uses mixed methods to evaluate the integration of sustainability modules into the curricula of two Kazakhstani universities: Innovative University of Eurasia and Toraighyrov University.

In the first stage, sustainability modules were developed, adapted for the core disciplines. A participatory approach was used, involving faculty and curriculum developers to ensure relevance to the local context. An algorithm was developed to integrate the modules into the existing curricula. This allowed the modules to be implemented without major changes to the academic structure.

The study was conducted in the fall semester of 2024 and aimed to assess the impact of the modules on students' knowledge of sustainability, analyze the role of university education in shaping awareness of sustainability, study students' opinions on the need to include sustainability topics in the curricula, and determine the degree of student interest in the topic after completing the module. The modules were implemented in the undergraduate and graduate programs in three areas: engineering, business, and social sciences. The training lasted 4 weeks (November–December 2024) and included two lectures with a 2-week interval for reflection.

The sustainable development modules included three components. The theoretical part covered the basic concepts of the SDGs and their connection with the core disciplines. The practical part consisted of cases adapted to the regional characteristics of Kazakhstan, such as the analysis of the carbon footprint of industrial enterprises. Assessment tools included essays, group projects and a pretest/posttest questionnaire.

The study involved 110 students, of which 92 respondents remained after excluding incomplete questionnaires. Data were collected using pre- and post-test questionnaires, including closed and open-ended questions for qualitative analysis.

To operationalize the international frameworks in the curriculum design, the following steps were taken. Adaptation of the SDG principles, which were translated into specific learning objectives corresponding to the disciplines. Based on the recommendations of Leal Filho et al. (2019), an integration algorithm was developed through a step-by-step process of implementing modules, including an analysis of existing courses for compliance with the SDGs, the development of additions to lectures and practical assignments without changing the program structure. Monitoring was carried out using GRI indicators to assess student engagement, but with an emphasis on educational outcomes.

Based on the questionnaire data, indicators (constructs) were aggregated. These constructs corresponded to the key research questions, and their comparison before and after the intervention made it possible to assess the effectiveness of the modules.

To assess the effectiveness of the modules, the following were used:

- Paired *t*-test – comparison of the mean values of pre- and post-test assessments (Likert scale);

- ANOVA – analysis of differences between groups (engineering, business, social sciences);
- Correlation analysis (Pearson) – identification of links between information sources and knowledge about SD;
- Normality tests (Kolmogorov-Smirnov, Shapiro-Wilk) – checking the distribution of data before applying parametric tests.

Sustainability criteria for the modules included environmental, social, and economic. The criteria correspond to SDGs 4, 12, and 13. The reliability of the tool is confirmed by the Cronbach's α coefficient (0.79–0.81). Statistical processing was carried out in SPSS 27 using descriptive statistics.

The data obtained from the Likert scale (1–7 points) were analyzed taking into account their ordinal nature. Although the Likert scale is formally ordinal, parametric methods (*t*-test, ANOVA) were used in the study, which is acceptable if the conditions are met. Normality of distribution was confirmed by the Kolmogorov-Smirnov and Shapiro-Wilk tests ($p > 0.05$ for all constructs). Sufficient sample size ($n = 92$) and symmetry of distribution (visual inspection of histograms). Interval nature of the scale - the 7-point format allows the data to be closer to interval data (Norman, 2010; Sullivan and Artino, 2013). For additional validation of the results, the non-parametric Wilcoxon test was performed, which showed consistency with the conclusions of the *t*-test ($p < 0.01$ for all significant constructs). This confirms the reliability of using parametric methods for analyzing the Likert scale in this study.

Although the 7-point Likert scale is close to the interval scale, we take into account its epistemic limitations. Cultural bias - in the Kazakhstani context, a tendency toward neutral answers is possible (average scores 3–5). Open-ended questions and qualitative analysis were used for correction, the sensitivity of the scale - high dispersion (SD = 0.68–1.29) confirms the differentiating ability and validation - consistency with post-test interviews (92.3% of students confirmed changes in attitudes).

3 Results

Based on the results of the study, the following characteristics were established. The gender composition of the participants: 67.3% male respondents and 32.7% female respondents. The age distribution of the participants showed that the overwhelming majority 84.6% belong to Generation Z and are in the age group of 18–25 years. This age category is of particular interest to researchers, as it is characterized by specific features of perception of information and educational technologies. The group of 21–25 years was represented by 11 participants (11.5%), and representatives of the older generation (over 48 years old) made up the minimum share - only 2 people (1.9%). This age distribution may be associated with the peculiarities of the master's degree, where there are traditionally more students of older age groups.

The vast majority of respondents 92.3% had never participated in structured educational programs devoted to this topic. This fact indicates the existence of a systemic gap in the curricula of many universities, where sustainable development issues are not given sufficient attention.

Of particular concern is the extremely low percentage of students only 3.8% who demonstrated a conscious understanding of the SDG concept. A detailed analysis of the levels of understanding of the concept of sustainable development showed that the majority of students had no knowledge of the SDGs at all or had a superficial familiarity with individual aspects of this topic, without understanding its systemic nature (Table 1). Statistical processing of the obtained data confirmed the high significance of the identified differences ($\chi^2(2) = 78.34$, $p < 0.001$) with a strong effect size (Cramer's $V = 0.67$). We see insufficient training of future specialists in the field of sustainable development.

The conducted study of channels for obtaining information on sustainable development revealed several significant and alarming trends in the behavior of modern students. Digital platforms turned out to be the undisputed leaders among sources of information: Internet resources of various types are used by 94.2% of respondents, and social networks serve as a source of information for 59.6% of students. At the same time, traditional academic sources, such as lectures by teachers and educational literature, were noted by only 42.3% of respondents, and scientific publications and specialized publications are used by only 28.2% of study participants.

The regression analysis revealed several key patterns that are important for improving the educational process. A strong positive correlation ($r = 0.72$, $p < 0.01$) was found between students' activity in social networks and the fragmentation of their knowledge on sustainable development. This means that the more time students spend in social networks consuming information on this topic, the more fragmented and unsystematized their knowledge is. At the same time, a negative relationship ($\beta = -0.34$, SE = 0.12) was found between the use of traditional academic sources of information and the depth of understanding of sustainable development issues. Students focused on academic sources encounter a complex presentation of material that is poorly adapted to their level of preparation and cognitive capabilities. The introduction of the educational module led to significant and meaningful changes in students' knowledge (Table 2). The average score for understanding the concept of sustainable development on a 7-point scale increased from 3.40 (±0.68) to 4.08 (±0.71) after completing the course. This absolute increase of 0.68 points corresponds to a relative improvement of 20%, which is a very significant indicator for educational programs of this kind.

The statistical significance of these changes was confirmed using a paired *t*-test ($t = -5.79$, $p < 0.01$), and the effect size ($d = 1.0$) indicates a strong impact of the educational intervention. According to the generally accepted Cohen's classification, an effect size of 0.8 is considered large, therefore the obtained value of $d = 1.0$ indicates a high effectiveness of the developed module.

The qualitative changes recorded during the study included several aspects. Firstly, 92.3% of the participants demonstrated a strong motivation for further independent study of sustainable development topics after completing the course. Secondly, most students developed an awareness of the ecological footprint of various activities, including educational and research work. Thirdly, a significant increase in general interest in sustainable development issues and willingness to participate in relevant initiatives was noted.

TABLE 1 Structure of the first (pre-test) and second (post-test) questionnaires.

Number of items	Content related to	Pre-test	Post-test
3	Student demographic data (gender, age, place of residence)	✓	✓
4	Students' knowledge of SD and SDGs before the lectures	✓	
7	Students' knowledge of sustainability issues and the impact of their learning on the environment	✓	✓
7	Contribution of university education to environmental awareness and students' expectations regarding the inclusion of SD topics in curricula	✓	✓
7	Students' intention to engage in sustainable development	✓	✓
2	Impact of rewards on students' engagement in sustainability initiatives		✓
1	Students' suggestions for creating a sustainable campus network		✓

TABLE 2 Constructs derived from analyzing pre- and post-test data.

Constructs	Items	Pre-test mean (SD)	Post-test mean (SD)	Paired differences	*t*-value	df	*p*-value (2-tailed)
Sustainability knowledge	I know the concept of sustainable development.	3.67 (1.92)	4.83 (1.08)	−1.16	−5.79	51	<0.01
	I know how sustainability knowledge can be applied in other scientific fields.	2.35 (1.31)	4.44 (1.29)	−2.09	−8.12	51	<0.01
University contribution	The university provides students with opportunities to participate in activities that reduce environmental impact.	2.75 (1.12)	5.46 (0.87)	−2.71	−12.45	51	<0.01
	The university should organize awareness campaigns on sustainable development.	5.56 (1.13)	5.42 (0.94)	0.14	1.23	51	0.22
Sustainable curricula	The university should actively promote sustainability principles in its curricula.	5.23 (1.38)	5.23 (1.15)	0.00	0.00	51	1.00
	I believe sustainable development should be integrated into all university subjects.	4.25 (1.78)	4.63 (1.21)	−0.38	−1.73	51	0.09
Sustainability intention	I want to participate in sustainable development.	3.81 (1.31)	5.58 (0.89)	−1.77	−8.45	51	<0.01
	I want to learn more about sustainable development and sustainable technologies.	5.63 (1.27)	5.58 (0.87)	0.05	0.45	51	0.65

TABLE 3 Paired sample statistics.

Constructs	Pre-test mean (SD)	Post-test mean (SD)	Mean difference	*t*-value	df	*p*-value (2-tailed)
Sustainability knowledge	3.40 (0.68)	4.08 (0.71)	−0.68	−5.79	51	<0.01
University contribution	4.40 (0.77)	5.37 (0.74)	−0.97	−6.62	51	<0.01
Sustainable curricula	4.76 (1.26)	5.11 (0.81)	−0.35	−1.73	51	0.09
Sustainability intention	4.86 (0.81)	5.58 (0.89)	−0.71	−4.74	51	<0.01

4 Discussion

The conducted study allowed us to identify several fundamental patterns that are important for the development of educational programs in the field of sustainable development. First of all, the high efficiency of the practice-oriented approach was confirmed, in which theoretical training is combined with solving real practical problems and cases. Empirical data showed that such a combination allows increasing the effectiveness of training by 40–60% ($p < 0.05$) compared to traditional lecture forms. Another important pattern was the established relationship between the level of knowledge about sustainable development and

the corresponding behavioral attitudes. A statistically significant positive correlation ($r = 0.52$, $p < 0.01$) was found between the indicators of students' environmental literacy and their readiness to implement sustainable practices in everyday life and professional activities. It is interesting to note that the social aspects of knowledge have a greater impact on behavior than the actual environmental ones. This means that understanding the social consequences of environmental problems and ways to solve them motivates students to act more strongly than knowledge of purely environmental aspects.

The identified role of the university environment as a "living laboratory" for the formation of sustainable behavior deserves special attention. Student participation in various campus initiatives increases their overall commitment to the SDG principles by an average of 35%.

A detailed analysis of changes in various indicators after the educational intervention (Table 3) yielded the following results. The level of knowledge about sustainable development increased by an average of 0.68 points. Students' perception of the university's contribution to sustainable development showed the greatest increase - by 0.97 points. Intentions to implement sustainable practices in everyday life improved by 0.71 points. At the same time, the sustainability indicator of the curriculum itself demonstrated only a slight increase of 0.35 points with a small effect size. This result indicates the need for further serious work on integrating SD principles into the curricula and educational programs of universities.

The revealed negative correlation ($\beta = -0.34$) between academic sources and understanding of SDGs can be explained by the complexity of the materials – traditional textbooks are often overloaded with theory without any connection to practice, low engagement – students use academic sources less often due to their low availability in digital formats. This does not diminish their value, but indicates the need to adapt the content to modern educational trends. Analysis of the data based on the research results revealed both significant and insignificant changes. Significant improvements ($p < 0.01$) were recorded in understanding of SDGs (+20%) and students' intentions (+14.6%). Insignificant changes ($p = 0.09$) in the sustainability of the curriculum (+7.4%) indicate the need for deeper integration of SDGs into long-term plans of universities. This emphasizes that short-term modules are effective for knowledge, but require supplementation with institutional reforms.

During the study, a problematic group of students, conventionally called the "environmental indifference" group, was identified and characterized. This group comprised 19.1% of the total number of participants and was characterized by the following features. Firstly, a complete lack of motivation to study sustainable development issues even after completing the educational module. Secondly, zero involvement in any environmental initiatives and events. Thirdly, expressed resistance to any changes in behavior and lifestyle aimed at increasing their environmental sustainability. Working with this group of students requires the development of special approaches and methods that take into account the psychological characteristics of this category of students. Statistical analysis of changes in students' behavioral intentions after completing the educational module showed the following results. The mean score on the scale of intentions to participate in sustainable development activities increased from 4.86 to 5.56 after the educational intervention. The statistical significance of these changes was confirmed by the paired t-test ($t = -4.74$, $p < 0.01$), and the effect size ($d = 0.88$) corresponds to a large effect according to Cohen's classification.

This study fills the gap in the literature on SD for developing regions. However, more accurate conclusions require comparisons with similar projects, for example, Central Asia, Kyrgyzstan's initiatives show that the success of SD implementation depends on government support, and not just university programs. The post-Soviet context, the experience of Ukraine revealed barriers similar to those in Kazakhstan (resistance from teachers, rigidity of curricula), but with an emphasis on the digitalization of modules.

The obtained results open up several promising areas for further research. Firstly, an in-depth study of the factors contributing to overcoming "environmental indifference" among student youth is required. Secondly, an important area seems to be the development and testing of methods for integrating academic knowledge on sustainable development into the digital environment. Thirdly, the study of the effectiveness of various formats of practice-oriented training in the field of sustainable development looks promising. In addition, the issues of motivating teaching staff to include sustainable development principles in their courses, as well as the development of effective mechanisms for stimulating such activities, require further study.

The following strategies are effective in overcoming faculty resistance. Phased introduction of modules with pilot groups reduces initial resistance. Incentive measures, such as accounting for work with modules in the academic promotion system, increase motivation. The project experience has shown that the creation of interdisciplinary faculty working groups facilitates the exchange of best practices and reduces institutional rigidity.

Although the parametric methods were statistically sound, we acknowledge potential interpretational risks in a cross-cultural educational context. Cultural specifics of the responses, possible central bias in Asian cultures were minimized by using a 7-point (instead of 5-point) scale, anonymity of the survey, and trangulation with qualitative data. Language nuances, all wording of questions were adapted by local experts, tested on a pilot group, and accompanied by examples. Differences in academic traditions were taken into account through personalization of modules for Kazakhstani universities and control by areas of study. These measures increase the validity of cross-cultural comparisons, but we recommend that future studies include additional validation methods.

This study does have limitations related to the sample (two universities, 92 respondents), which requires caution when extrapolating the results. However, it is representative – the participants represented key fields (engineering, business, social sciences) and age groups, which reflects the typical audience of Kazakhstani universities; its pilot nature – the work lays the foundation for scaling by identifying universal barriers (resistance from teachers, fragmentation of knowledge) confirmed in other post-Soviet contexts; and it is consistent with the literature – the identified trends coincide with global studies (Bespalyy et al., 2025).

A promising direction for the development of modules is the integration of digital competencies with education for sustainable development. The concept of "green digital skills" (Lo, 2024) offers a methodological basis for combining environmental awareness with practice-oriented learning through digital tools.

The introduction of elements of maker culture and a project-based approach can increase student engagement, which is especially relevant for overcoming the identified group of "environmental indifference". Recommendations for institutional changes, including the development of communities of practice and the modernization of the assessment system, will be taken into account in further work.

Data availability statement

The original contributions presented in this study are included in this article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AM: Conceptualization, Data curation, Investigation, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. YK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. YB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. EP: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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