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EVALUATING GREEN AND SUSTAINABLE CHEMISTRY EDUCATION THROUGH STUDENTS' INTERVENTIONS

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This study explores the integration of green and sustainable chemistry into educational curricula and its impact on students' knowledge, motivation, and perceptions. The research aimed to evaluate whether activities centered on green and sustainable chemistry improve students' academic performance and foster awareness of sustainability concepts. Conducted between April and June 2024 in three primary schools in N. Macedonia, the study involved 211 8th grade students, divided into a control group and an experimental group. While the control group followed standard lessons, the experimental group participated in specific activities integrated into the topic "Introduction to Organic Chemistry." A mixed-methods approach was employed, combining quantitative tools such as the conceptual knowledge test and the activity perception questionnaire, alongside qualitative methods like focus groups and semi-structured interviews. The conceptual knowledge test assessed students' academic achievements, while the activity perception questionnaire evaluated their perceptions of the activities. The results showed no significant difference in academic performance between the two groups. However, the activity perception questionnaire revealed that students in the experimental group found the activities engaging, valuable, and effective in enhancing their understanding of green and sustainable chemistry concepts. Qualitative data further indicated a preference for interactive learning methods like research, games, and experiments, which fostered greater motivation and collaboration among students. This study underscores the importance of integrating green and sustainable chemistry into curricula to promote environmental awareness and sustainable practices. These findings provide insights into effective teaching strategies and support the inclusion of green and sustainable chemistry in educational policies to equip students for global environmental challenges.

Keywords: activity perception questionnaire; chemistry teaching; conceptual knowledge test; green chemistry; primary education; sustainability

ЕВАЛУАЦИЈА НА ОБРАЗОВАНИЕТО ЗА ЗЕЛЕНА И ОДРЖЛИВА ХЕМИЈА ПРЕКУ УЧЕНИЧКИ ИНТЕРВЕНЦИИ

Во рамките на ова истражување е истражувана интеграцијата на зелената и одржлива хемија во наставните програми и нејзиното влијание врз знаењето, мотивацијата и перцепциите на учениците. Истражувањето имаше за цел да оцени дали активностите поврзани со зелената и одржливата хемија го подобруваат академскиот успех на учениците и ја поттикнуваат свеста за концептите на одржливост. Студијата беше спроведена во периодот од април до јуни 2024 година во три основни училишта во С. Македонија, со вкупно 211 ученици од 8. одделение, поделени во контролна и експериментална група. Контролната група следеше традиционални наставни часови, додека експерименталната група учествуваше во специфични активности интегрирани во наставната тема „Вовед во хемијата на јаглеродни соединенија“. Применет беше комбиниран методолошки пристап, кој вклучуваше квантитативни алатки – тест на концептуално знаење и прашалник за перцепција на активностите, заедно со квалитативни методи – фокус-групи и полуструктурирани интервјуа. Тестот на концептуално знаење го проценуваше академскиот успех на учениците, додека прашалникот за перцепција на активностите ги оценуваше нивните ставови за активностите. Резултатите покажаа дека нема значајна разлика во академскиот успех помеѓу двете групи. Сепак, прашалникот за перцепција на активностите откри дека учениците од експерименталната група ги сметаат активностите за интересни, корисни и ефективни во подобрувањето на нивното разбирање на концептите за зелена и одржлива хемија. Дополнително, квалитативните податоци покажаа дека учениците претпочитаат интерактивни методи на учење, како што се истражувања, игри и експерименти, кои ја зголемија нивната мотивација и соработка. Ова истражување ја нагласува важноста на интеграцијата на зелената и одржлива хемија во наставните програми со цел да се поттикне еколошката свест и одржливите практики. Овие наоди нудат вредни сознанија за ефективни наставни стратегии и ја поддржуваат вклученоста на зелената и одржлива хемија во образовните политики, со цел да се подготват учениците за глобалните еколошки предизвици.

Клучни зборови: зелена хемија; настава по хемија; одржливост; основно образование; прашалник за перцепција на активностите; тест на концептуално знаење.

1. INTRODUCTION

Green chemistry has emerged as a critical field in modern chemistry, emphasizing sustainability and environmental protection. The core principle of green chemistry is the design of chemical products and processes that minimize the use and generation of hazardous substances, aligning with the principles of sustainability and environmental stewardship.[1] The twelve principles of green chemistry serve as comprehensive guidelines to achieve these goals, focusing on areas such as waste prevention, atom economy, the use of safer solvents and auxiliaries, and energy-efficient design.[2,3]

Green and sustainable chemistry (GSC) plays a vital role in advancing sustainability through three key pathways: developing renewable energy technologies, sourcing chemical industry reagents from renewable materials, and replacing polluting technologies with environmentally friendly alternatives.[4] Recent advancements in green chemistry have demonstrated significant progress across multiple sectors. For example, the development of new catalytic processes has reduced the reliance on hazardous reagents and minimized waste production. Innovative techniques such as electrochemical cascade reactions and the use of molten salts for synthesizing carbon-based materials have shown promise in enhancing catalytic activity and sustainability.[5] Furthermore, the shift towards greener processes, such as producing lignin-based adhesives and efficiently converting biomass into valuable chemicals, has not only reduced environmental impact, but also enhanced the economic viability of green technologies.[6] Moreover, the application of CO_2-derived non-isocyanate polyurethanes (NIPUs) has highlighted the potential of using greenhouse gases as feedstock for valuable products, contributing to carbon capture and utilization strategies.[7]

The integration of GSC concepts into chemistry education has also gained increasing importance.[8] Green chemistry focuses on reducing or eliminating hazardous substances, while sustainability promotes environmental, economic, and social responsibility. Together, these concepts enhance the safety and efficiency of chemical processes while raising awareness of environmental issues and sustainable development.[9] These concepts teach students the importance of protecting the environment and responsibly managing natural resources. Research shows that incorporating green chemistry and sustainability into curricula significantly improves students' knowledge and attitudes toward chemistry and the environment. According to Zuin et al.,[10] students exposed to green chemistry concepts develop greater awareness of chemistry's impact on the environment and are more motivated to pursue sustainable solutions in their future careers.

Numerous studies have highlighted the positive impact of green chemistry education on students' environmental awareness and problem-solving skills. Integrating sustainability concepts into chemical education can foster a new generation of chemists who are more attuned to environmental issues and committed to sustainable practices.[2] According to Linkwitz and Eilks,[11] integrating green chemistry and sustainability into chemistry curricula is crucial, as it promotes the responsible handling of chemicals, helping them avoid health and environmental issues while preventing the development of chemophobic attitudes. This holistic approach to chemistry education not only prepares students to make informed decisions as consumers, but also empowers them to participate meaningfully in societal discussions on the environmental implications of chemical processes and products.

The research conducted by Armstrong et al.[12] with university students highlights the importance of integrating green chemistry and sustainability into the chemistry curriculum. Their findings reveal that students not only gained a strong understanding of green chemistry concepts, but also began adopting a systems-thinking perspective, enabling them to recognize the relevance of green chemistry to their future studies and careers, fostering sustained interest and deeper understanding over time.

In N. Macedonia, the current chemistry curricula for primary and secondary education largely neglect topics related to green chemistry and sustainability. In primary education, GSC content is briefly introduced in the 8^{th} grade within the "Introduction to Organic Chemistry" topic, where concepts such as the greenhouse effect, renewable and non-renewable energy sources, and alternative fuels are discussed. In the 9^{th} grade, the topic "Exothermic and Endothermic Reactions" explores the burning process in greater detail, highlighting the adverse effects of fuel combustion on air quality.

In secondary high school education, GSC topics are mentioned only to note the importance of chemistry in professional and everyday life, as well as in industry. These topics are mostly incorporated within experimental context, covering subjects like the properties of substances, their handling, products usage, lab safety, etc. The overarching learning objective is to help students understand that they live in a chemical environment and should seek logical explanations for chemical phenomena and their consequences.

In contrast, the incorporation of GSC in secondary vocational education is more substantial. The Center for Vocational Education and Training recognized the need for changes and interventions in education to better equip students with the necessary skills for their professions and started creating policies to strengthen the capacities of students in order to deal with the rapid changes in the world, including environmental problems. Consequently, policies have been developed to enhance students' capacities, leading to the introduction of a new educational program in the chemistry and technology sector – Environmental Protection Technician. This profile includes a range of GSC-related courses, such as Renewable Energy Sources, Sustainable Development, Pollution and Protection of Water, Soil and Air, Climate Change, Waste Management, and Analysis of Soil, Water, and Air. These courses are complemented by practical exercises and work-based learning opportunities with employers.

The minimal inclusion of green chemistry and sustainability topics in Macedonia's broader educational system highlights the urgent need for their active integration into curricula. Integrating these topics will help students develop an understanding of the importance of sustainable practices in the chemical industry and environmental protection, as well as enhance their critical thinking skills and prepare them to participate in a sustainable community.

This research aims to develop and implement a set of GSC teaching activities for primary and secondary education in Macedonia. Its primary objectives are to evaluate whether these activities enhance students' knowledge and achievements in these areas and to understand students' perceptions of the activities. The importance of this research lies in addressing the current gaps in the Macedonian educational curriculum regarding green chemistry. By actively integrating these topics, the research seeks to foster a deeper understanding and awareness among students of sustainable practices in the chemical industry and environmental protection. This integration is crucial for fostering a generation of students that is both informed about and dedicated to sustainability, contributing to the broader goal of developing a more sustainable society. Furthermore, the findings of this research will provide valuable insights into the effectiveness of the intervention and inform future educational strategies and policies to better incorporate green chemistry into the curriculum.

2. EXPERIMENTAL SECTION

2.1. *Instructional content*

Chemistry is taught in primary schools following a curriculum derived from the Cambridge International Examinations framework, which was adapted by the Bureau for the Development of Education and introduced during the 2016/2017 school year. Science is introduced from grades 1 to 6, while Chemistry is emphasized in grades 8 and 9. This curriculum emphasizes the development of scientific inquiry skills, including concept review, evidence evaluation, research planning, and data observation and analysis. These research activities help to build students' confidence and stimulate their enthusiasm for science.

The concept of GSC is incorporated into the final topic of the 8^{th}-grade curriculum, titled "Introduction to Organic Chemistry".[13] Within this topic, students expand upon their prior knowledge of elements, compounds, chemical reactions, and fossil fuels, focusing on carbon-containing compounds. They compare the environmental impacts of burning carbon-based fossil fuels with those of burning hydrogen. The scientific inquiry process emphasizes explaining results using scientific understanding, communicating findings clearly, utilizing and evaluating secondary data, and presenting conclusions effectively. Expected learning outcomes include identifying fossil fuels such as coal, natural gas, and oil, and comparing their environmental effects with those of burning hydrogen.

The national standards[14] for primary education outline the competencies students should acquire by the end of their primary education (9^{th} grade). These include key competencies for lifelong learning that encompass a blend of knowledge, skills, and attitudes.[15] In the natural sciences, these competencies include applying evidence-based knowledge and scientific methods to explain natural phenomena, enhance quality of life, and understand the effects of human activities on the environment. Specifically, competencies related to GSC in the natural sciences include:

Knowledge and skills:

– Investigate and discuss the impact of science, technology, and human activities on the environment.

– Understand the importance of sustainable development and critically analyze situations, where there are conflicts of interest between economic-technological growth and environmental conservation.

– Analyze interconnections between ecological, social, and economic systems at both local and global scales.

Values and attitudes:

– Acknowledge that Earth's natural resources are finite, and irresponsible use can negatively impact quality of life.

– Recognize that global warming leads to natural disasters, affecting both living and non-living systems.

– Accept personal responsibility for preserving the environment, promoting sustainability, and fostering ecological awareness at local and global levels.

This research focused on GSC and drew on content from relevant topics in the curriculum. Key teaching units included Fossil Fuels, Alternative Fuels, and Evaluation of Fuel Applications. The recommended chemical terms for this topic included: fossil fuels, coal, oil, natural gas, non-renewable, renewable, hydrogen fuel, cost, efficiency, availability, pollution, environmental impact, and acid rain.[13] Suggested keywords for scientific inquiry included: discuss, observe, explain, predict, explore, present, compare, conclude, examine, and identify.

2.2. *Methodology*

2.2.1. *Objectives of the study*

The aim of this paper was to explore students' perceptions of green chemistry and sustainability, as well as their views on the specific activities conducted as part of this research. This study sought to provide insights into how the integration of green chemistry and sustainability into teaching practices could be improved and adapted to achieve better educational outcomes and foster greater awareness among both students and teachers.

The research was guided by two key research questions (RQs): RQ1: Does the implemented teaching activity enhance students' knowledge and academic performance in Chemistry on the topic "Introduction to Organic Chemistry"? RQ2: How do students perceive the Green and Sustainable Chemistry (GSC) activities in terms of interest and enjoyment, value and usefulness, effort and importance, perceived competence, and pressure or tension?

2.2.2. *Research sample*

To assess the impact of GSC activities on students' academic performance and perceptions, research was conducted in three primary schools in N. Macedonia between April and June 2024. The initial sample consisted of 211 8^{th} grade students (ages 13–14); however, due to student absences, the final analysis was conducted on a reduced sample of 192 students, which was sufficient for meaningful analysis.[16]

One of the researchers (and co-authors) taught at two of the participating schools, forming the experimental group (EG). Meanwhile, a subject teacher from the third school conducted the instruction there, forming the control group (CG). Prior to the study, discussions were held to align the teaching with the national curriculum, ensuring consistency in content coverage.

The CG followed traditional teaching methods delivered by the subject teacher, while the EG received an intervention specifically designed for this study. This intervention utilized interactive teaching methods while still adhering to the curriculum's learning objectives. The researcher was responsible for disseminating and analyzing all tests and questionnaires and conducting all interviews.

An initial assessment of students' performance showed no significant differences between the CG and EG students. Consequently, a purposive sampling method was chosen, allowing for the smooth implementation of classes without causing additional burden or discomfort to the students. Details about the participants are presented in Table 1.

Table 1

Participants involved in the study

Group	Number of participants		
	Male	Female	Total
CG	48	59	107
EG	54	50	104
Total	102	109	211

The inclusion of 8th grade students is significant, as this age represents a critical period for developing scientific curiosity and increasing awareness about sustainability. Moreover, analyzing their perceptions and academic achievements offers valuable insights into the effectiveness of the interventions in enhancing both learning outcomes and motivation. These findings can serve as a strong foundation for designing similar activities for older students.

2.2.3. *Research instruments*

Data were collected using a combination of quantitative and qualitative instruments to enable a comprehensive understanding of the educational process. This mixed-methods approach provided a thorough analysis, combining numerical data with deeper qualitative insights. The combination of these methods also enhanced the validity of the results through triangulation.[17,18]

For quantitative data collection, two primary tools were used: a conceptual knowledge test (CKT) and an activity perception questionnaire (APQ). CKT measured students' academic performance and assessed the effectiveness of the teaching methods related to green chemistry. Administered after the instructional content was delivered, the test consisted of 15 multiple-choice questions, each with four options, only one of which was correct. Each correct answer scored one point, making the maximum possible score on the test 15 points.

To ensure the test's face and content validity, it was reviewed by experts in chemistry and chemistry education, including one university professor and two primary school teachers. Their evaluations focused on the test's relevance, clarity, accuracy, readability, and overall design, as well as its alignment with the targeted concepts and learning objectives. Their feedback significantly improved the test's quality.

The APQ was constructed using items from five subscales (interest/enjoyment, value/usefulness, effort/importance, perceived competence, and pressure/tension) derived from the Intrinsic Motivation Inventory. This inventory has been widely used in experiments on intrinsic motivation and self-regulation, originating from foundational studies by Ryan[19] and Ryan, Mims, and Koestner.[20] The APQ consisted of 23 seven-point Likert-type statements (1: not at all true; 7: very true), offering a detailed understanding of students' perceptions and experiences regarding the activities.

For qualitative data collection, focus groups (conducted prior to the classroom activities) and semi-structured individual interviews (conducted after the activities) were used. These methods enabled the exploration of students' initial knowledge, as well as their reflections and insights after participating in the GSC interventions. Interviews, both individual[21,22] and group,[23–26] have proven to be effective tools in educational research when seeking detailed explanations and understanding.

This combination of quantitative and qualitative approaches provided a robust framework for examining the impact of the interventions, yielding deeper insights into students' attitudes, motivation, and learning outcomes.

2.2.4. *Design*

The research design was structured to provide a comprehensive approach to analyzing perceptions and effects of activities, as well as to provide specific recommendations for improving teaching practices and programs. The research was conducted in several phases:

1) Comparing first-semester grades of CG and EG students and analyzing data (April 22 – 23, 2024).

2) Conducting focus groups with EG students (April 29 – 30, 2024).

3) Preparing transcripts and analyzing focus groups discussions (May 6 – 10, 2024).

4) Implementing the intervention in EG (May 20 – 31, 2024).

5) Administering the activity perception questionnaire to assess the opinions and experiences of EG students regarding the implemented activities (May 31, 2024).

6) Conducting individual interviews with EG students (June 3 – 7, 2024).

7) Administering the conceptual knowledge test in CG and EG (June 10, 2024).

8) Analyzing the test results (June – July 2024).

9) Preparing transcripts and analyzing interviews with students (July – September 2024).

The research began with an analysis of students' grades to assess their achievements in Chemistry and to ensure comparability between the control group (CG) and the experimental group (EG) in terms of prior performance. To evaluate students' prior knowledge of green chemistry concepts, four focus group sessions were conducted with EG students from both schools. Each focus group included six students, representing a range of achievement levels: two high achievers, two medium achievers, and two low achievers.

Subsequently, activities related to green chemistry and sustainability were developed and implemented with the 8th grade students in the EG. The activities were integrated into the topic "Introduction to Organic Chemistry", which included relevant content and is typically taught in May. The intervention comprised three 40-minute lessons, totaling 120 minutes. In the first lesson, students were introduced to the related chemistry content according to the curriculum. The lesson emphasized the basics of green chemistry and sustainability through a discussion that stimulated their interest and activity. The second lesson was reserved for work in small groups, where students had the opportunity to research and collaborate on the assigned activity. The topics assigned to the groups included: Sustainable Development Goals: A Roadmap for a Better World, Green Cities for a Green Future, The Greenhouse Effect and Climate Change; Alternative Energy Sources: The Future of Our Planet, and Air Pollution and Its Consequences, among others. The third lesson analyzed the results and discussed what the students had learned. They presented their projects and reflected on how the acquired knowledge could be applied in everyday life. This approach allowed for the connection of theory with practice and encouraged students to think critically and learn together.

After completion of the teaching activities, an activity perception questionnaire was administered, followed by 15 individual interviews with EG students. These interviews ensured balanced representation from high, medium, and low achievers. Finally, a conceptual knowledge test was conducted, and the collected data was thoroughly analyzed. A more detailed description of the experimental instruction is provided in Table 2.

T a b l e 2

Detailed description of the experimental instruction

Lesson 1	**Lesson title: Fossil Fuels**
Lesson objectives	By the end of the lesson, students will be able to: – Explain what fossil fuels are, how they were formed, and identify their main types (coal, oil, natural gas). – Describe the combustion of fossil fuels, including chemical reactions involved and the release of carbon dioxide and energy. – Analyze the environmental impact of fossil fuels, such as air pollution, the greenhouse effect, and acid rain. – Propose possible solutions to reduce the negative impact of fossil fuel use, including the adoption of cleaner technologies and renewable energy sources.
Materials and resources	Chemistry textbook and notebooks.
Introduction (Warm-up/Engagement)	A brief discussion about their prior knowledge of fossil fuels.
Instructional strategies (Lesson Presentation)	The teacher presents the lecture and conducts a discussion on the main types of fossil fuels and their properties. Group activity: Students, divided into groups, are assigned topics. They begin an initial discussion about fossil fuels, green chemistry, and sustainable development.
Assessment (Formative/Summative)	Formative assessment: Monitoring students' engagement in discussions and activities.
Closure (Wrap-up/Reflection)	Students answer the question: "Could we live without fossil fuels, and how?" and summarize the benefits and drawbacks of fossil fuels. The teacher encourages students to think about sustainable solutions.
Homework/Extension activities	/
Lesson 2	**Lesson title: Alternative Fuels**
Lesson objectives	By the end of the lesson, students will be able to: – Understand the role of alternative fuels in reducing environmental impact. – Analyze the benefits and challenges of different sustainable energy sources. – Develop critical thinking and teamwork skills through research and project-based learning. – Connect the concept of green chemistry to real-world sustainability issues.
Materials and resources	Visual aids: posters, diagrams, infographics. Research materials: articles, online resources, books. Art supplies for creating posters and diagrams.

Table 2 continues

Introduction (Warm-up/Engagement)	The teacher discusses the role of fuels in daily life and encourages brainstorming by posing an open-ended question: "What alternatives do we have?"
Instructional strategies (Lesson presentation)	Students work collaboratively in groups to research topics related to green chemistry and sustainable development. The teacher explains the grading rubric and guides students in conducting research and gathering key information. Students create posters, diagrams, or other visual representations of their findings.
Assessment (Formative/Summative)	Formative assessment**:** Monitoring group discussions and providing feedback on research progress.
Closure (Wrap-up/Reflection)	Students reflect on how alternative fuels and sustainable practices could be implemented in their daily lives.
Homework/Extension activities	Students write a brief report on a recent innovation in alternative fuels.
Lesson 3	**Lesson title: Evaluation of Fuel Application**
Lesson objectives	By the end of the lesson, students will be able to: – Develop the ability to present research topics clearly and effectively. – Foster critical thinking through participation in discussions. – Deepen understanding of concepts through the exchange of ideas and opinions.
Materials and resources	Students' projects (posters, diagrams, infographics). Projector or interactive board to support presentations.
Introduction (Warm-up/Engagement)	Teacher encourages a positive atmosphere for presentation with supportive comments.
Instructional strategies (Lesson presentation)	Group presentations and discussions: Students, individually or in groups, present their projects to the class. Each team is given a set time to explain their findings and visuals. After each presentation, a short Q&A session follows. Teacher encourages constructive discussion.
Assessment (Formative/Summative)	Formative assessment: Observing students' engagement, thoughts, and ideas shared on the topic. Summative assessment: Evaluating presentation skills, research quality, and the ability to argue and analyze critically.
Closure (Wrap-up/Reflection)	Class discussion on how the knowledge gained could be applied in everyday life and future careers. The teacher administers the activity perception questionnaire to assess students' opinions and experiences with the implemented activities.
Homework/Extension activities	Self-assessment: Students evaluate their performance and presentation skills using the rubric and set goals for improvement.
Lesson 4	**Lesson title: Knowledge Assessment**
Lesson Objectives	By the end of the lesson, students will be able to: – Evaluate their understanding of key topics related to alternative fuels and sustainability. – Engage in critical thinking through conceptual questions. – Identify areas that require further clarification.
Materials and resources	Conceptual knowledge test with multiple-choice questions.
Introduction (Warm-up/Engagement)	The teacher explains the test structure and testing procedure. Teacher encourages students to focus on reasoning rather than memorization.
Instructional strategies (Lesson presentation)	Students complete the test individually within a set time of 25 minutes.
Assessment (Formative/Summative)	Summative assessment: Analyzing test results to evaluate individual performance.
Closure (Wrap-up/Reflection)	Class discussion regarding the conducted activity and its connection to environmental issues.
Homework/Extension activities	/

2.2.5. *Data analysis*

The data analysis combined quantitative and qualitative methods to provide a comprehensive understanding of the research results.

The quantitative analysis focused on comparing the performance of students in the CG and EG at two key points: the end of the first semester and after completing the GSC activities. First-semester grades were used for initial comparison, while results from the CKT served as the basis for the post-activity comparison. Both CKT and APQ data were analyzed using descriptive statistics and statistical tests using SPSS Statistics 26.

The qualitative analysis involved four focus groups and 15 individual interviews conducted with EG students. Interviews were conducted in empty classrooms or laboratories, ensuring confidentiality. Students were informed that the results would be used solely for research and would not affect their grades. Interviews were audio-recorded, lasting 15–20 minutes, and followed Kvale's guidelines.[27] An interview guide was prepared, but additional questions emerged based on students' responses. Analysis of the interviews included transcribing the recordings, coding responses, and grouping answers thematically. To maintain anonymity, participants were labeled based on their school and achievement levels, e.g., S1-U1-5 (school 1, student 1, high-achiever) or S2-U4-3 (school 2, student 4, medium-achiever).

3. RESULTS AND DISCUSSION

3.1. *Quantitative data analysis*

Students play a central role in the educational process and their opinions and experiences are crucial for the successful implementation of new educational methods and content. Involving students in this research is essential to understanding how green chemistry activities affect the learning process and their motivation. The analysis of the results related to students should provide answers to two research questions.

To address the first research question, "Does the implemented teaching activity enhance students' knowledge and academic performance?", it was essential to compare the CKT results of students in the CG and EG. Based on the statistical analysis, conclusions were drawn regarding the effectiveness of the intervention.

Initially, a normality test was conducted to examine whether the data followed a normal distribution. Both the Kolmogorov-Smirnov and Shapiro-Wilk tests indicated that the first-semester grades for both the CG and EG were not normally distributed (Table 3), so non-parametric statistics were applied.

To determine if there was a significant difference in the first-semester achievements between the CG and EG students, the null hypothesis was formulated as: H_0: There is no significant difference between the first-semester attainments of the 8th grade students in the CG and EG.

The Mann-Whitney *U* test, which compares mean ranks, revealed no significant difference between the grades of the CG and EG students at the end of the first semester ($U = 5237$, $p = 0.439$). This finding suggests that the two groups had similar academic performance levels at the start of the study.

T a b l e 3

Tests of normality

		Kolmogorov-Smirnov			Shapiro-Wilk		
	Group	Statistics	df	Sig.	Statistics	df	Sig.
First-semester grade	CG	.283	107	.000	.805	107	.000
	EG	.232	104	.000	.833	104	.000

The same test was applied to assess whether there was a significant difference between the CKT scores of students in the CG and EG. The null hypothesis was formulated as: H_0: There is no significant difference between the conceptual test scores of the 8th grade students from CG and EG.

The results indicated no significant difference between the two groups ($U = 4290.5$, $p = 0.409$), suggesting that the activities implemented in the EG intervention may not have had a substantial impact on improving students' knowledge compared to the CG. One possible explanation for this outcome is that the conceptual questions on the test were challenging, particularly for students who struggled with higher-order thinking tasks.

Another contributing factor to the lack of a statistically significant difference between the CKT results of students from the CG and EG could be the timing of the test. Specifically, the knowledge test was conducted on June 10, the penultimate teaching day of the extended 2023/2024 school year. This academic year had been extended by seven days due to the spring break, leading to situations where some students had already left for vacation or were absent. Additionally, the end of the school year is often a period when students face increased school-related activities, which may lead to diminished attention to new and intervention-related content.

It is also important to note that the topic "Introduction to Organic Chemistry," which formed the basis of this research, is the final topic in the curriculum for 8th grade and must be delivered during this specific time of the school year. However, if this topic had been addressed earlier in the school year, when teaching conditions were more favorable and students had higher attendance and motivation, it is expected that the test results would have been different. This observation suggests that the effectiveness of interventions like this one depends not only on the nature of the activities themselves but also on the timing of their implementation, underscoring the importance of considering these factors in future research.

To further explore this, additional analysis was conducted to assess students' interest and engagement with the activities, as well as to gather their feedback and opinions on the intervention.

To answer the second research question, "How do students perceive the GSC activities?", an APQ was administered to EG students after the implemented activities. The questionnaire was administered to students electronically and completed anonymously, with 82 students responding.

To assess internal consistency, the data were analyzed by calculating the mean, standard deviation, and Cronbach's alpha reliability coefficient[28] for all scales (Table 4). The scoring process for the APQ instrument involved specific steps. First, reversed scores were computed for items marked with (R) by subtracting the item response value from 8 and using the result as the item score. Subsequently, subscale scores were determined by averaging the values of all items within each subscale. These subscales scores were then utilized for further analyses.

Table 4

Means, standard deviations, and Cronbach's alpha reliability coefficients for APQ instrument

Subscale	No. of items	M	SD	Cronbach's alpha
Interest/Enjoyment	5	5.222	1.649	.873
Perceived Competence	4	5.495	1.453	.727
Effort/Importance	4	5.518	1.724	.757
Pressure/Tension	4	2.619	1.800	.626
Value/Usefulness	6	5.262	1.460	.850
Total	23	4.879	1.918	.875

Table 4 presents the means, standard deviations, and Cronbach's alpha reliability coefficients for the five subscales of the APQ questionnaire. Cronbach's alpha evaluates internal consistency by considering the scores of all items within each subscale. The coefficients indicated acceptable internal consistency across all five subscales, ranging from 0.626 to 0.873. For the entire APQ instrument, the Cronbach's alpha reliability coefficient was 0.875, which is considered as highly reliable.[29,30] This result aligns with findings reported in the literature.[31,32]

The APQ data revealed that the mean scores for all subscales, except the fourth, were relatively high (ranging from 5.222 to 5.518), indicating that most 8th grade students found the GSC activities enjoyable, engaging, and attention-grabbing (Interest/ Enjoyment subscale). Students expressed satisfaction with their performance and felt competent after completing the tasks (Perceived Competence subscale).

Additionally, the majority of students regarded these activities as important for their progress and success and demonstrated significant effort to perform well (Effort/Importance subscale). The results suggest that the activities were manageable, and students were able to engage with them effectively.

Furthermore, students recognized the value of these activities in enhancing their understanding of sustainability and green chemistry and showed a willingness to participate in similar tasks, highlighting their positive influence on awareness and attitudes toward sustainability (Value/Usefulness subscale).

Lastly, the mean score for the Pressure/Tension subscale was 2.619, indicating that students felt relaxed and not nervous during the activities.

Overall, the activities appeared to enhance students' engagement and motivation for learning new content while fostering collaboration. The nature of GSC activities, which emphasize teamwork, communication, cooperation, and problem-solving, significantly contributes to these outcomes. Beyond enhancing student engagement and motivation, these activities also impact both the cognitive and affective domains of learning.

3.2. *Qualitative data analysis*

The qualitative analysis involved data collected through focus groups and individual interviews with students. Focus groups were conducted prior to the intervention to evaluate students' prior knowledge of the topic. Four groups were organized, each comprising six students with varying levels of achievement. The analysis highlighted several key findings and trends.

All students reported limited familiarity with the concepts of green chemistry and sustainable development, reflecting a lower level of awareness of these critical topics. Initially, students were asked about their views on environmental protection. Their responses included recycling plastic, paper, and batteries, as well as participating in eco-activities organized by their school or community, such as cleaning public areas, planting trees, and raising environmental awareness through campaigns.

When asked what advice they would give friends or family to protect the environment, students suggested minimizing car usage, recycling waste, and riding bicycles or electric scooters more frequently. They recognized the school's role in teaching eco-friendly habits from an early age and emphasized the community's role in organizing activities to promote environmental awareness.

While students were familiar with electric cars, they had limited knowledge of photovoltaics, biodiesel, and alternative energy sources. Nevertheless, they understood that burning fossil fuels like coal, oil, and natural gas contributes to air pollution and recognized renewable energy as cleaner and more sustainable compared to non-renewable sources.

Despite their limited understanding of green chemistry and sustainability concepts, students expressed a strong interest in learning how these ideas could be applied to their daily lives and how they could contribute to environmental protection. This curiosity highlights the potential for developing educational programs to motivate students and foster their engagement with sustainability-related activities.

Given students' enthusiasm for these topics, integrating green chemistry and sustainable development into regular curricula could significantly raise awareness and help educate future generations on the importance of environmental protection and sustainable practices.

In the analysis of the individual interviews, particular attention was given to questions directly related to the activities conducted as part of the intervention. This approach aimed to provide a detailed understanding of students' experiences, perceptions, and attitudes toward the GSC activities. By concentrating on these specific aspects, the analysis aimed to provide deeper insights into the effectiveness and impact of the activities on students' engagement, motivation, and understanding of the concepts.

Specifically, the analysis for this study focused on students' responses to three specific questions from the interview guide: 1) What is your opinion about the green chemistry and sustainability activity we conducted? 2) What did you find most interesting or memorable about the activity? and 3) What do you think is the best way to learn about these topics: traditional lectures, research, games, or something else? Why?

Most students rated the GSC activity as meaningful and useful, emphasizing different aspects of its importance. Some, such as HTK-U1-5 and LT-U1-3, highlighted their educational value, noting that it introduced them to new concepts that could be beneficial in the future. Additionally, some students viewed the activity as practical, enriching their understanding of the environmental aspects of chemistry. LT-U1-5 and LT-U2-5 further highlighted its role in raising environmental awareness, describing it as a stimulus for reflection and action regarding the responsible use of natural resources and chemicals.

Several students praised the interactive and enjoyable nature of the activity. For instance, HTK-U2-1 and LT-U2-3 mentioned that they not only learned new things during the activity but also enjoyed the process, making it both engaging and effective for learning. Additionally, some students highlighted the potential societal benefits of such activities. LT-U1-1 suggested that greater awareness of green chemistry could significantly improve living conditions for both humans and animals.

However, not all students provided detailed responses. For example, HTK-U2-3 briefly stated that the topic was "good for discussion", which may indicate moderate interest or perhaps insufficient motivation for deeper reflection.

Overall, the activity received positive feedback, particularly for its educational and environmental relevance, interactive approach, and ability to foster broader awareness of sustainability. These responses demonstrate the activity's success in connecting teaching content with practical and socially significant issues.

When asked about the most interesting or impressive aspects of the activity, students highlighted a variety of elements, reflecting their diverse interests and perceptions. Some, like LT-U1-5 and HTK-U1-3, valued the teamwork aspect, emphasizing the significance of collaboration and group work. Others focused on the content and discussions related to green chemistry. For example, HTK-U2-1 and HTK-U1-1 appreciated the opportunity to think critically and discuss the importance of green chemistry, while HTK-U2-3 and LT-U2-5 found discussions about a clean environment and project presentations particularly impactful.

Students also underscored the importance of content related to environmental protection. LT-U1-5 identified understanding ways to reduce pollution and use eco-friendly products as the most valuable aspect, while LT-U1-3 emphasized grasping the rationale behind green chemistry.

Interest in the presented projects also emerged as a recurring theme. LT-U1-1 said, "The most interesting part of this activity was seeing my classmates' projects and learning useful information about their research topics", while LT-U3-5 highlighted project presentations as the most memorable moment. LT-U3-3 noted, "The most interesting part for me was gaining new knowledge through group work and presentations, and the most impressive part was participating in the activity", underlining the importance of active involvement.

However, a few students provided vague or shorter responses. For instance, HTK-U2-3 remarked, "I don't know", indicating a lack of interest or impression of a specific aspect of the activity.

Overall, students perceived the activity as dynamic and inspiring. Their impressions ranged from valuing collaboration and interactivity to appreciating discussions, research, and presentations, highlighting the activity's significance for both their personal and educational development.

Regarding the best way to learn about these topics, most students agreed that research and games are the most effective ways to learn about green chemistry and sustainability, as these methods foster interactivity, engagement, and active involvement. As HTK-U1-3 explained, "I think research is the best way to learn new things. People pay more attention to practical examples than verbal ones. If something is discussed and demonstrated live through research or experiments, it leaves a greater impression." This view was echoed by LT-U1-5, who suggested that group research would make learning more interesting. Similarly, HTK-U2-1 and LT-U2-3 emphasized that combining research, games, and experiments makes learning more exciting and easier to understand.

Several students highlighted the value of learning through games, noting that they combine fun with learning, making information more accessible. HTK-U2-3 commented, "Learning through games would be more interesting," while LT-U2-5 added, "Games enable learning while also being fun, which makes understanding easier." Similar thoughts were expressed by LT-U3-1, who found game-based learning most effective, and HTK-U2-5, who advocated for a combination of research, games, and experiments.

Other students also emphasized the role of experiments in interactive learning. LT-U3-3 stated, "The best way is through research and experiments". Such responses indicate that hands-on activities and direct participation leave a lasting impression and produce the best results.

Some students suggested traditional lectures but with adaptations. LT-U3-5 remarked, "The best way, in my opinion, is classical teaching, but in nature", illustrating that conventional methods can be effective when combined with innovative approaches or outdoor activities.

Overall, the majority of students agreed that research, games, and experiments are the most effective ways to learn these topics. These methods encourage activity, engagement, and a connection between theoretical knowledge and practical applications. The consistency in students' responses highlights the potential of such interactive approaches for improving engagement and understanding in the classroom.

4. CONCLUSION

The findings from this study demonstrate the potential of GSC activities to enrich students' understanding of environmental and sustainability concepts while fostering greater engagement and collaboration. The intervention successfully highlighted the importance of integrating GSC into the curriculum, as students reported the activities to be meaningful, enjoyable, and impactful in terms of both knowledge acquisition and motivation. Qualitative insights from focus groups and interviews further emphasized the value students placed on teamwork, interactive learning, and the practical application of green chemistry principles.

Students overwhelmingly favored research, games, and experiments as the most effective methods for learning about GSC topics, highlighting their preference for active and engaging educational approaches. This preference underscores the importance of incorporating hands-on and inquiry-based methods into chemistry education to enhance understanding and interest. Additionally, students expressed a desire for a stronger connection between the content and real-world applications, suggesting that such approaches could foster a more profound commitment to sustainability and environmental protection.

Overall, this research provides strong evidence for the integration of GSC concepts into educational curricula. This integration not only enhances academic outcomes but also promotes environmental awareness and sustainable practices among future generations. These findings offer a foundation for developing more effective teaching methods and policies aimed at equipping students with the knowledge and skills necessary to address global environmental challenges.

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