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Students' Need Analysis Green Chemistry Focused Active Learning Assisted by a Virtual Laboratory on the Topic of Gas Chromatography

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ABSTRACT

This study aims to analyze the needs of chemistry students for Green Chemistry-focused active learning assisted by a virtual laboratory on the topic of Gas Chromatography within the Separation Chemistry course. A quantitative descriptive method was applied to 45 students from the 2023 cohort of the Chemistry Education Study Program, selected through purposive sampling. Data were collected using an online questionnaire based on four need indicators: the current condition of Separation Chemistry learning, understanding and application of Green Chemistry, the need for a virtual laboratory, and the need for active learning with higher-order thinking skills (HOTS) practice. The results show that 71.1% of students find it difficult to calculate and analyze Gas Chromatography practicum data, and 64.4% have never conducted a direct practicum. Although 95.6% had heard of Green Chemistry, only 82.2% understood its application, and 100% need environmentally oriented learning. Furthermore, 97.8% need a virtual laboratory to support the practicum, 100% already own a device and internet access, 100% need media that support Green Chemistry-based active learning, and 97.8% need HOTS practice. It is concluded that an active-learning medium assisted by a virtual laboratory needs to be developed as a complement to the conventional practicum. In this medium, Green Chemistry Principles 1, 5, 6, 8, and 12 are practiced through simulated planning and decision-making, while their real application still requires hands-on practicum, and students' higher-order thinking skills are trained.

INTRODUCTION

Separation Chemistry is a compulsory course in the Chemistry Education Study Program that covers various methods for separating mixtures, one of which is Gas Chromatography. This topic requires students not only to understand the underlying theory but also to perform quantitative calculations and to analyze and interpret instrumental data such as retention time, peak area, column efficiency, and resolution. Gas chromatography is an instrumental analysis technique widely applied in the food, pharmaceutical, and environmental fields because of its ability to separate and accurately analyze volatile compounds, so that mastering both its concepts and analytical skills is essential for pre-service chemistry teachers (Skoog et al., 2017). Because gas chromatography instrumentation is often costly, fragile, and time-consuming to operate, dedicated efforts to design accessible and low-cost approaches to teaching it, including remote-access and simplified instrumentation, continue to receive attention in the chemical-education literature (Nolvachai et al., 2023).

In practice, learning gas chromatography is frequently hindered by limited laboratory facilities, the hazards associated with the chemicals used, and restricted practicum time, so that not all students obtain the opportunity to perform hands-on practicum. This

condition also causes Separation Chemistry learning to remain dominated by the lecture (teacher-centered) method, which does not sufficiently train students to think critically, analyze data, and solve problems. This limitation of facilities is well documented: commercial gas chromatographs are generally large and expensive, which has prompted efforts to assemble simple, low-cost instruments for teaching (Susilo et al., 2023), and in one documented teaching laboratory with a single gas chromatograph, a limited budget meant that each student could attend only one 3-hour session and had to share the instrument with one to five other students (Largy et al., 2022). In contrast to lecture-dominated instruction, active learning, in which students engage in small-group problem solving, discussion, and team-based projects, has been reported to improve student achievement and retention, and dedicated resources now exist to support its use in analytical chemistry courses (Kovarik et al., 2022).

At the same time, growing environmental concerns have increased the importance of applying Green Chemistry principles in every chemistry laboratory activity. Integrating Green Chemistry into the curriculum is now considered a necessity for preparing students for a sustainable future, and institutions in North America, Europe, and Asia have increasingly embedded green and sustainable chemistry content, classroom resources, and assessment approaches into their chemistry programs (Etzkorn & Ferguson, 2023). At the undergraduate level, redesigned laboratory curricula that incorporate green and sustainable chemistry together with evidence-based instructional approaches, cooperative project work, and case studies have been reported to strengthen students' scientific practices, including defining problems, designing experiments, analyzing data, and proposing solutions (Armstrong et al., 2024; Grieger et al., 2022). Embedding research-like green-chemistry laboratory modules has likewise been found to improve students' perceptions of scientific research, self-efficacy, and understanding of sustainable practice (Liu, 2022), while curriculum-development scholarship continues to stress that greening the chemistry curriculum should begin early and be pursued systematically as a contribution to education for sustainable development (Eilks & Linkwitz, 2025). Applying Green Chemistry principles to Gas Chromatography practicum is therefore highly relevant, given that conventional instrumental-analysis activities may generate solvent and chemical waste that poses environmental risks if not properly managed.

The advancement of information technology has opened opportunities to use virtual laboratories as an alternative to, or complement of, hands-on practicum. A virtual laboratory allows students to simulate chemical-analysis procedures anytime and anywhere without the risk of sugir enabling repeatable experiments, providing timely feedback, and making sub-microscopic phenomena visible (Hu-au, 2024). Recent systematic reviews of interactive science laboratories confirm that well-designed virtual and remote laboratories can support conceptual understanding and procedural skills across chemistry and other science disciplines (Ali et al., 2022), and virtual-laboratory-based prelaboratory activities have been reported to improve students' engagement with and comprehension of subsequent hands-on procedures, including titration-based

analyses (Fu et al., 2024). Integrating virtual laboratories with conventional school and university teaching has also been associated with measurable gains in students' knowledge scores and learning motivation (Berdi et al., 2025). Moreover, well-designed virtual-laboratory activities have been found to support the development of higher-order thinking skills such as analysis and evaluation among learners, beyond simple procedural training (Abdulrahman & Alshaikh, 2022).

Green Chemistry is guided by twelve principles (Török & Dransfield, 2017), and several of them can be matched directly to the stages of a Gas Chromatography practicum. At the sample-preparation stage, waste prevention (Principle 1), safer solvents and auxiliaries (Principle 5), and reduction of derivatives (Principle 8) can be applied by using micro-scale sample volumes, replacing hazardous extraction solvents such as hexane or dichloromethane with safer alternatives such as ethanol or ethyl acetate, and avoiding derivatization steps that are not strictly required. At the instrument-operation stage, energy efficiency (Principle 6) can be applied by optimizing the oven temperature program and the run time, and inherently safer chemistry for accident prevention (Principle 12) by handling flammable solvents, pressurized carrier-gas cylinders, and the heated injector safely. In a conventional laboratory, these principles can only be implemented with real equipment, materials, and procedures, and their consequences (the amount of solvent used, waste produced, and energy consumed) are not always visible to students. A virtual laboratory does not generate real waste or expose students to real hazards; instead, it can make these principles tangible by allowing students to select and compare solvents, sample volumes, and instrument settings in a simulation that displays the resulting hazard, waste, energy use, and chromatogram quality. In this way, Green Chemistry decisions can be practiced and evaluated before the procedure is carried out in the real laboratory, so that the virtual laboratory functions as a complement to, rather than a replacement for, the conventional laboratory.

Preliminary observation indicates that most Chemistry Education students already possess a personal device (laptop/smartphone) and internet access, yet the use of virtual laboratories and the integration of Green Chemistry principles into Gas Chromatography learning remain suboptimal. A systematic needs analysis is therefore required to precisely determine students' needs regarding Green Chemistry-focused active learning assisted by a virtual laboratory on the topic of Gas Chromatography, as a basis for developing a learning medium that matches students' current conditions and needs.

The purpose of this study is to analyze the needs of Chemistry Education students for Green Chemistry-focused active learning assisted by a virtual laboratory on the topic of Gas Chromatography, examined through four indicators: the current condition of Separation Chemistry learning, understanding of and need for Green Chemistry application, the need for a virtual laboratory, and the need for active learning together with higher-order thinking skills.

RESEARCH METHOD

This study used a quantitative descriptive method. According to (Rachman et al., 2024), quantitative research is grounded in the positivist paradigm and is used to study a particular population or sample, with quantitative data analysis employed to test hypotheses or describe existing field conditions. This study focused on analyzing students' needs for Green Chemistry-focused active learning assisted by a virtual laboratory on the topic of Gas Chromatography within the Separation Chemistry course. Because Green Chemistry principles are ultimately implemented through real equipment, materials, and procedures in a conventional laboratory, the virtual laboratory in this study is positioned not as a replacement for the conventional laboratory but as a complementary pre-laboratory medium, in which students plan and simulate practicum procedures designed according to the selected Green Chemistry principles before performing them in the real laboratory.

The subjects of this study were 45 students from the 2023 cohort of the Chemistry Education Study Program, distributed across several classes, who had taken the Separation Chemistry course. The sampling technique used was purposive sampling, that is, a technique for determining the sample based on particular considerations in order to obtain representative data (Rachman et al., 2024).

The instrument used in this study was a needs questionnaire distributed online through an electronic form. The questionnaire was developed based on four need indicators: (1) the condition of and difficulties in Separation Chemistry learning on the Gas Chromatography topic; (2) understanding of and need for Green Chemistry application; (3) the need for a virtual laboratory to support practicum; and (4) the need for active learning together with higher-order thinking skills. Each indicator consisted of several dichotomous statements with "Yes" and "No" response options, complemented by three open-ended questions exploring learning difficulties, the characteristics of the learning approach expected by students, and the virtual-laboratory features students require.

Questionnaire data were analyzed using the percentage formula shown in Equation (1) (Rachman et al., 2024):

$$P = F / N \times 100\% \quad (1)$$

where P is the percentage of student responses, F is the frequency of student responses, and N is the number of students (respondents). In addition to the quantitative data, qualitative data from the open-ended questions were analyzed descriptively to reinforce and clarify the results of the needs analysis obtained from the quantitative data.

RESULTS AND DISCUSSION

Data were collected through an online questionnaire completed by 45 students of the Chemistry Education Study Program. The results of the needs analysis were grouped into four indicators: the condition of Separation Chemistry learning, understanding of and need for Green Chemistry, the need for a virtual laboratory, and the need for active learning together with higher-order thinking skills.

Condition of Separation Chemistry Learning

The questionnaire results for the learning-condition indicator are presented in Table 1. As shown in Table 1, 48.9% of students find it difficult to understand the concept and working principle of gas chromatography, and the same percentage (48.9%) report that learning has so far been dominated by the lecture method. As many as 64.4% of students have not had the opportunity to conduct a direct gas chromatography practicum, even though 66.7% state that laboratory equipment and chemicals are already fully available. This indicates that the limitation lies not solely in facilities, but also in the opportunity and time allocated for practicum, a constraint frequently noted in analytical-chemistry teaching where costly and time-consuming instrumentation, such as gas chromatographs, must be shared among many students within limited laboratory sessions (Nolvachai et al., 2023).

Table 1. Results for the Condition of Separation Chemistry Learning Indicator

No.	Statement	Response	%
1	I find it difficult to understand the concept and working principle of gas chromatography.	Yes	48.9
		No	51.1
2	Separation Chemistry learning has so far been dominated by the lecture (teacher-centered) method.	Yes	48.9
		No	51.1
3	I have not had the opportunity to conduct a direct gas chromatography practicum in the laboratory.	Yes	64.4
		No	35.6
4	Laboratory equipment and chemicals are fully available for the Separation Chemistry practicum.	Yes	66.7
		No	33.3
5	I find it difficult to calculate and analyze the data from the gas chromatography practicum.	Yes	71.1
		No	28.9
6	The chemistry learning I have experienced trains me to think critically and solve problems, not just memorize.	Yes	91.1
		No	8.9

Other data show that 71.1% of students find it difficult to calculate and analyze data from the gas chromatography practicum, while 91.1% state that the chemistry learning they have experienced already trains critical thinking and problem-solving rather than mere memorization. This finding is consistent with the open-ended responses, which indicate that students' main difficulties lie in interpreting chromatograms (e.g., overlapping peaks, tailing, and calculating percent recovery), applying formulas such as the theoretical plate number (N), resolution (Rs), and HETP that are easily confused, and visualizing the separation process at the molecular level.

Understanding of and Need for Green Chemistry

The questionnaire results for the understanding and need for Green Chemistry indicator are presented in Table 2. All students (100%) stated that they need Separation Chemistry learning with more varied activities that actively involve students. As many as 95.6% of students had heard of the term Green Chemistry, but only 82.2% reported understanding its principles and application in the laboratory. This gap between awareness of the term and understanding of its application suggests that Green Chemistry content needs to be integrated more explicitly into Separation Chemistry learning, consistent with calls in the literature to move green-chemistry education from theoretical exposure toward the applied practices, systems thinking, and safety and sustainability skills that students are expected to internalize (Grieger & Hill, 2022). Because a virtual laboratory involves no real equipment or chemicals, principles concerning physical waste reduction, solvent use, and process safety are not enacted in it directly as they are in a conventional laboratory; instead, they are practiced as planning and decision-making. In this study, the Green Chemistry principles considered applicable are Principle 1 (waste prevention), Principle 5 (safer solvents and auxiliaries), Principle 6 (design for energy efficiency), Principle 8 (reduction of derivatives), and Principle 12 (inherently safer chemistry for accident prevention). Students can apply them by selecting and justifying solvents, sample volumes, derivatization steps, and instrument conditions in the simulation, and by evaluating the simulated hazard, waste, and energy outcomes. The actual reduction of waste and hazard is then realized when students carry these decisions over to the conventional laboratory practicum.

Table 2. Results for the Understanding of and Need for Green Chemistry Indicator

No.	Statement	Response	%
1	I need Separation Chemistry (especially Gas Chromatography) learning with more varied activities that actively involve students.	Yes	100
2	I have previously heard of or studied the term Green Chemistry.	Yes	95.6
		No	4.4
3	I understand the principles of Green Chemistry and their application in laboratory activities.	Yes	82.2
		No	17.8
4	My lecturer has related Separation Chemistry material to environmental issues or Green Chemistry principles.	Yes	88.9
		No	11.1
5	I am aware that conventional chemistry practicum can produce chemical waste that impacts the environment.	Yes	95.6
		No	4.4
6	I am interested in learning how to minimize the use of hazardous chemicals and waste through a Green Chemistry approach.	Yes	100
7	I need Separation Chemistry learning that is environmentally oriented (Green Chemistry).	Yes	100

As many as 88.9% of students stated that their lecturer has related Separation Chemistry material to environmental issues or Green Chemistry principles, and 95.6% recognize that conventional chemistry practicum can produce chemical waste that impacts the environment. All students (100%) reported being interested in learning how to minimize the use of hazardous chemicals and waste through a Green Chemistry approach, and 100% need Separation Chemistry learning that is environmentally oriented. However, this interest is a stated need that can only be fulfilled through learning experiences involving real action, such as actually selecting solvents, minimizing waste, and handling chemicals safely in a hands-on practicum, and not through virtual experiences alone. These results align with the broader movement to integrate green and sustainable chemistry into undergraduate curricula through project-based experiments, case studies, and systems-thinking activities that build students' safety and sustainability skills ls (Armstrong et al., 2024; Grieger & Hill, 2022), and support the view that embedding research-like sustainability-oriented laboratory modules can strengthen students' self-efficacy and appreciation of scientific practice (Liu, 2022).

Need for a Virtual Laboratory

The questionnaire results for the virtual-laboratory-need indicator are presented in Table 3. As many as 97.8% of students stated that they need a virtual laboratory to support learning and practicum on Gas Chromatography, and all students (100%) already own a device (laptop/smartphone) and personal internet access that can be used to access one. This indicates that, in terms of supporting-facility readiness, students are prepared to make use of a virtual laboratory in the learning process. It should be noted that the need for a virtual laboratory expressed here concerns supporting learning and the Gas Chromatography practicum, such as understanding procedures, simulating the practicum, and analyzing data. It does not mean that Green Chemistry principles are themselves applied through the virtual laboratory, because their actual application, such as reducing real waste and using safer solvents, requires real equipment and materials in the conventional laboratory. The virtual laboratory is therefore needed as a complement that prepares students for a Green Chemistry-oriented hands-on practicum, not as a substitute for it.

Table 3. Results for the Need for a Virtual Laboratory Indicator

No.	Statement	Response	%
1	I need a virtual laboratory to support learning and the Gas Chromatography practicum.	Yes No	97.8 2.2
2	I have a device (laptop/smartphone) and personal internet access that can be used to access a virtual laboratory.	Yes	100
3	Practicum using a virtual laboratory can help me understand chemical analysis procedures without the risk of hazardous chemicals.	Yes No	95.6 4.4
4	A virtual laboratory can be an alternative when practicum materials/tools are limited.	Yes	100
5	I need virtual laboratory media to support the Gas Chromatography practicum.	Yes	100
6	I find it easier to understand the stages of an experiment when it is simulated first through a virtual laboratory before the real practicum.	Yes No	93.3 6.7

As many as 95.6% of students stated that practicum using a virtual laboratory can help them understand chemical-analysis procedures without the risk of hazardous chemicals, and all students (100%) agreed that a virtual laboratory can serve as an alternative when practicum materials or tools are limited and that they need virtual-laboratory media to support Gas Chromatography practicum. As many as 93.3% of students also reported that they find it easier to understand the stages of an experiment when it is simulated beforehand through a virtual laboratory prior to the actual practicum. This finding is supported by the qualitative data, in which students expressed the hope that a virtual laboratory would provide interactive simulations of instruments such as gas chromatographs and HPLC with adjustable parameters, real-time chromatograms/data, automatic calculations, immediate feedback, and indicators reflecting the application of Green Chemistry principles, such as the assessment of environmentally friendly solvent choices. This is in line with the view that physical and virtual laboratories play complementary roles, with virtual laboratories offering particular value in providing flexible, repeatable, and accessible experimental experiences that complement hands-on practicum (Jeffery et al., 2022), and with recent evidence that well-designed virtual and prelaboratory activities can strengthen conceptual understanding and readiness for hands-on procedures (Ali et al., 2022; Berdi et al., 2025).

Need for Active Learning and Higher-Order Thinking Skills

The questionnaire results for the need for active learning and higher-order thinking skills (HOTS) indicator are presented in Table 4. All students (100%) need learning that

provides opportunities to discuss, investigate, analyze data, and present results, and reported that active learning makes it easier for them to remember and understand Separation Chemistry material. All students (100%) also stated that they need media that support Green Chemistry-based active learning.

Table 4. Results for the Need for Active Learning and Higher-Order Thinking Skills Indicator

No.	Statement	Response	%
1	I need learning that provides opportunities to discuss, investigate, analyze data, and present results.	Yes	100
2	Active learning makes it easier for me to remember and understand Separation Chemistry material.	Yes	100
3	I need media that supports Green Chemistry-based active learning.	Yes	100
4	I want to be involved in activities that require me to design, test, and evaluate a chemical analysis procedure independently.	Yes No	93.3 6.7
5	I prefer to learn by being actively involved (discussing, experimenting, presenting) rather than only listening to the lecturer's explanation.	Yes No	95.6 4.4
6	I find it difficult to analyze and interpret data from separation chemistry analysis.	Yes No	84.4 15.6
7	The Separation Chemistry questions I have worked on so far demand more memorization than analysis and reasoning.	Yes No	53.3 46.7
8	I find it difficult to determine solutions to problems that arise in chemical analysis activities.	Yes No	88.9 11.1
9	I need practice items or activities that train higher-order thinking skills (analyzing, evaluating, creating) in Separation Chemistry learning.	Yes No	97.8 2.2
10	I feel it is important to develop critical thinking and problem-solving skills through chemistry learning.	Yes No	97.8 2.2

As many as 93.3% of students want to be involved in activities that require them to design, test, and evaluate a chemical-analysis procedure independently, and 95.6% prefer to learn by being actively involved rather than only listening to the lecturer's explanation. On the other hand, 84.4% of students still find it difficult to analyze and interpret data from separation-chemistry analysis, 53.3% consider that the questions they have worked on so far demand more memorization than analysis and reasoning, and 88.9% find it difficult to determine solutions to problems arising in chemical-analysis activities. As many as 97.8% of students need practice items or activities that train higher-order thinking skills (analyzing, evaluating, creating), and the same percentage (97.8%) feel it

is important to develop critical thinking and problem-solving skills through chemistry learning. These findings reinforce the well-established evidence that active learning consistently improves student performance in science, technology, engineering, and mathematics courses compared with passive, lecture-centered instruction (Xu et al., 2026), including in analytical chemistry courses, where it also promotes problem solving and critical thinking (Kovarik et al., 2022), and are consistent with reports that well-designed virtual and interactive laboratory activities can specifically foster higher-order thinking skills such as analysis and evaluation(Abdulrahman & Alshaikh, 2022).

Based on the open-ended responses, students expect Separation Chemistry learning based on Green Chemistry and a virtual laboratory to be interactive, simple, and easily accessible via laptop or smartphone, equipped with clear step-by-step guidance, animations/visualizations of the separation process at the molecular level, gradual calculation exercises with feedback, real-world case studies (such as the isolation of compounds from natural materials or industrial waste), and evaluative quizzes at the end of each simulation. Overall, the results of the needs analysis across the four indicators show that students require the development of an active-learning medium focused on Green Chemistry and assisted by a virtual laboratory on the topic of Gas Chromatography, as an effort to overcome the limitations of conventional practicum while training students' higher-order thinking skills.

CONCLUSION

Based on the results of this study, it can be concluded that Chemistry Education students need Green Chemistry-focused active learning assisted by a virtual laboratory on the topic of Gas Chromatography. This is supported by the finding that 71.1% of students find it difficult to calculate and analyze Gas Chromatography practicum data and 64.4% have not had the opportunity for direct practicum, while 100% of students need environmentally oriented Separation Chemistry learning even though only 82.2% currently understand the application of Green Chemistry principles. Regarding facility readiness, 97.8% of students need a virtual laboratory to support the practicum and 100% already own a device and personal internet access to use one. In addition, 100% of students need media that support Green Chemistry-based active learning, and 97.8% need practice in higher-order thinking skills. Green Chemistry-focused active learning assisted by a virtual laboratory is expected to provide an interactive simulation of the Gas Chromatography practicum in which Green Chemistry Principles 1, 5, 6, 8, and 12 are practiced through planning and decision-making, and to facilitate discussion, investigation, and independent data analysis, so that students can learn anytime and anywhere. Because the actual application of these principles, such as reducing real waste and using safer solvents, requires real equipment and materials, the virtual laboratory should be used as a complement to, not a substitute for, the conventional laboratory, and students' interest in Green Chemistry should be followed by hands-on practicum that involves real action. Therefore, implementing this learning approach is considered a relevant solution to address the limited practicum opportunities and the difficulties in

data analysis, to strengthen students' understanding of Green Chemistry principles before they apply them in the real laboratory, and to train their higher-order thinking skills in Separation Chemistry.

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